

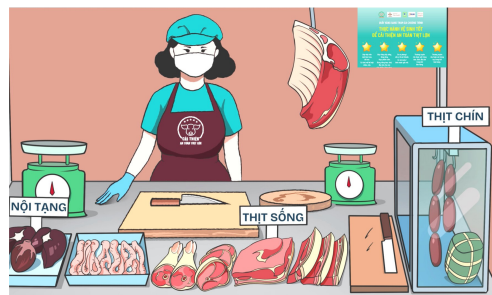
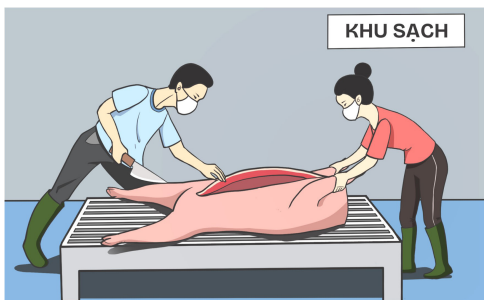


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Improving food safety in Vietnam's traditional pork supply chain

Evaluation of interventions in slaughterhouses and
markets through a One Health approach

TRANG LE THI HUYEN



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Trang Le Thi Huyen

Faculty of Veterinary Medicine and Animal Science

Department of Animal Biosciences

Uppsala



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Cover: Pig being slaughtered on a grid and sold at a traditional market. Adapted from the animation in *How to keep pork safe at slaughterhouses and traditional market stalls in Vietnam* by Sinh Dang-Xuan and Trang Le (2025), licensed under CC BY 4.0.

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© 2026 Trang Le Thi Huyen, <https://orcid.org/0000-0001-8978-040X>

Swedish University of Agricultural Sciences, Department of Animal Biosciences, Uppsala, Sweden

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Improving food safety in Vietnam's traditional pork supply chain

Abstract

Foodborne diseases linked with pork consumption remain a major public health concern in low- and middle- income countries, where traditional supply chains dominate, food safety controls are limited, and interventions are under-explored. This thesis tested and evaluated food safety interventions in pig slaughterhouses and traditional markets, using a One Health approach that integrates microbiological, behavioural, economic, and socio-cultural perspectives. Two intervention studies were conducted across five provinces in the north, central, and south of Vietnam. At 16 slaughterhouses, a controlled trial evaluated a technique-based (low-cost equipment and hygiene training) and an incentive-based (performance-based inspection with financial rewards) intervention. At 68 traditional markets, a randomised controlled trial assessed interventions including vendor training, inspection and public disclosure, equipment provision, and a consumer awareness campaign. A total of 192 samples from slaughterhouses (pig carcasses and workers' hand swabs) and 814 samples from markets (cut pork and cutting board swabs) were analysed for total bacterial count, *Salmonella*, coliforms, and *Escherichia coli*, alongside pre- and post- intervention observations and interviews (486 participants each round). Baseline findings demonstrated high microbiological contamination and poor hygiene practices at both slaughterhouses and markets. Interventions improved knowledge, hygiene practices, equipment availability, and additionally at the market level, increased vendor revenues. Microbiological reductions were observed for certain indicators at slaughterhouses but remained consistently high at markets, indicating the influence of interacting factors, including hygienic practice, infrastructure, environmental conditions, and socio-economic dynamics along the supply chain. Consumer awareness and risk perception exhibited a limited response to the consumer campaign, and purchasing behaviour remained unchanged. This thesis contributes to the evidence based on intervention effectiveness under real-world conditions, suggesting that future strategies should emphasise consumers as active drivers of demand for safe food, combined with coordinated structural and regulatory improvements across the supply chain.

Keywords: pork safety, intervention, enabling environment, capacity building, incentive, inspection, LMIC

Förbättrad livsmedelssäkerhet längs den traditionella värdekedja för fläskkött i Vietnam

Abstract

Livsmedelsburna sjukdomar kopplade till konsumtion av fläskkött är ett betydande folkhälsoproblem i låg- och medelinkomstländer. I dessa länder dominerar traditionella försörjningskedjor, livsmedelskontroll är begränsad och kunskaper om åtgärder för att förbättra livsmedelssäkerhet är otillräckliga. Denna avhandling har utvärderat åtgärder för att förbättra livsmedelssäkerhet vid grisslakterier och på traditionella marknader. Studierna i avhandlingen har haft ett One Health-perspektiv som omfattar mikrobiologi, beteende, ekonomi och sociokulturella aspekter. Två interventionsstudier genomfördes i fem provinser i norra, centrala och södra Vietnam. Vid 16 slakterier utvärderades teknik- och incitamentsbaserade åtgärder. Dessutom genomfördes en randomiserad studie på 68 marknader där åtgärderna bestod av utbildning av försäljare, inspektion och offentlig återkoppling, utrustning samt en informationskampanj riktad till konsumenter. Totalt analyserades 192 prover från slakterier och 814 prover från marknader med avseende på total bakteriehalt, *Salmonella*, koliforma bakterier och *Escherichia coli*. Detta kompletterades med observationer och intervjuer före och efter åtgärderna (486 deltagare vid varje tillfälle). Resultat visade hög mikrobiologisk kontamination och bristande hygienrutiner vid både slakterier och marknader. Åtgärderna ledde till ökade kunskaper, bättre hygienrutiner och på marknaderna ökade intäkter. Det visades även att vissa mikrobiologiska indikatorer minskade vid slakterierna, medan nivåerna på marknaderna förblev höga. Detta tyder på att det finns flera samverkande faktorer som påverkar livsmedelssäkerhet längs hela värdekedjan, såsom hygienrutiner, infrastruktur, miljöförhållanden och socioekonomiska förutsättningar. Konsumenters medvetenhet, riskuppfattning och köpbeteende påverkades i begränsad utsträckning av informationskampanjen. Avhandlingen bidrar med kunskap om hur åtgärder för att förbättra livsmedelssäkerhet fungerar i praktiken och att framtida strategier bör stärka konsumenternas roll, i kombination med samordnade förbättringar av struktur och regelverk längs hela värdekedjan.

Keywords: fläskkött, åtgärder, kapacitetsutveckling, incitament, livsmedelskontroll, låg- och medelinkomstländer

Dedication

To my daughter,
for our bedtime conversations about uncertainty and the choices we face in
life. May knowledge and wisdom be the master keys that unlock the doors
ahead.

To my parents,
for loving me in ways seldom spoken but always trusting and saying yes to
every important path I have chosen.

*“Knowing is not enough, we must apply.
Willing is not enough, we must do.”*
– Johann Wolfgang von Goethe

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List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

- I. **Trang Le Thi Huyen**, Vivian Hoffmann, Kate Ambler, Mike Murphy, Sinh Dang-Xuan, Johanna F Lindahl, Elisabeth Rajala, Steven Lâm, Sofia Boqvist, Fred Unger, Hung Nguyen-Viet (2026). Pork safety across Vietnam's traditional markets: Microbial contamination and vendor knowledge, attitudes, and practices. *Preventive Veterinary Medicine*, vol 247 106757 <https://doi.org/10.1016/j.prevetmed.2025.106757>
- II. **Trang Le Thi Huyen**, Delia Grace, Hung Nguyen-Viet, Steven Lâm, Fred Unger, Huyen Nguyen-Xuan, Yen Luu-Thi-Hai, Kien Tran-Viet-Dung, Johanna F Lindahl, Elisabeth Rajala, Sinh Dang-Xuan, Sofia Boqvist. Evaluating interventions to improve hygienic practices and reduce microbial contamination in small- and medium- scale pig slaughterhouses in Vietnam (*submitted*)
- III. **Trang Le Thi Huyen**, Mike Murphy, Sinh Dang-Xuan, Kate Ambler, Vivian Hoffmann, Fred Unger, Huong Pham-Thi, Duy Nguyen-Quang, Hung Nguyen-Viet. Public health and business impacts of a voluntary food safety inspection and disclosure program among pork vendors in Vietnam (*manuscript*)

Paper I is reproduced with the permission of published open access.

The contribution of Trang Le Thi Huyen to the papers included in this thesis was as follows:

- I. Conceptualisation; Methodology (including study design and development of data collection tools); Ethical approval; Data curation; Investigation (field coordination and sampling); Project administration; Supervision (fieldwork and laboratory testing); Formal analysis; Visualisation; Writing – original draft; Writing – review & editing; Submission and journal correspondence.
- II. Conceptualisation; Methodology (including study design and development of data collection tools and training materials); Ethical approval; Data curation; Investigation (field coordination and sampling); Project administration; Supervision (fieldwork and laboratory testing); Formal analysis; Visualisation; Writing – original draft; Writing – review & editing; Submission and journal correspondence.
- III. Conceptualisation; Methodology (including study design and development of data collection tools and training materials); Ethical approval; Data curation; Investigation (field coordination and sampling); Project administration; Supervision (fieldwork and laboratory testing); Formal analysis; Visualisation; Writing – review & editing.

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Abbreviations

ASF	Animal-source food
DALYs	Disability-adjusted life years
FAO	Food and Agriculture Organization of the United Nations
FBD	Food-borne diseases
HACCP	Hazard Analysis and Critical Control Points
ILRI	International Livestock Research Institute
LMIC	Low- and middle- income countries
RCT	Randomised Controlled Trial
SEA	South-East Asia
TBC	Total Bacteria Count
WHO	World Health Organization

AI declaration

Generative artificial intelligence (AI) tool was used during the preparation of this thesis. Specifically, ChatGPT (OpenAI) was used to assist with improving clarity, grammar, and phrasing in English, and supporting the translations from Vietnamese to English and English to Swedish. All AI-assisted text was critically reviewed, edited, and validated by the author to ensure accuracy, appropriateness, and consistency with the intended meaning.

All research design, data collection, statistical analyses, interpretation of findings, and the overall intellectual content of the thesis were conducted and verified by the author.

1. Introduction

1.1. Burden of food-borne diseases

Food-borne diseases (FBD) are illnesses that result from the consumption of food contaminated with pathogenic microorganisms, parasites, or chemical hazards. They represent a major global public health burden, comparable to that of malaria, HIV/AIDS, and tuberculosis (WHO 2015). In 2010, 31 foodborne hazards were estimated to cause 33 million disability-adjusted life years (DALYs) worldwide, with children under five comprising 40% of the total (Havelaar et al. 2015). Notably, animal-source food (ASF) contributed 35% of the estimated total impact of FBD (Li et al. 2019).

In low- and middle-income countries (LMIC), FBD were responsible for approximately 600 million illnesses and 420,000 deaths (Havelaar et al. 2015) as well as an estimated economic loss of US\$110 billion (Jaffee et al. 2019). Beyond these direct impacts, FBD also inflicted potential effects regarding malnutrition, gender inequality, and the emergence of infectious diseases (Grace 2023). Africa and South-East Asia (SEA) regions were ranked as suffering from the highest burden of FBD (Havelaar et al. 2015). However, assessing FBD in these countries is challenging due to limited research and weak reporting systems. The few studies that do exist, primarily from SEA, have often relied on self-reported attribution of diarrhoeal illness to food consumption and indicate relatively high levels of FBD (Grace 2017).

1.2. Foodborne diseases in Vietnam

In Vietnam, FBD continue to represent a significant yet under-recognised public health issue (World Bank 2017). Although outbreaks of FBD are frequently reported, there is no comprehensive and reliable national dataset, and available statistics are often inconsistent, outdated, or lack transparency in reporting sources. Between 2011 and 2016, there were 1,007 reported foodborne outbreaks nationwide, affecting 30,395 people and causing 164 deaths. The main causes were microorganisms (40.2%), followed by natural toxins (27.9%), and chemicals (4.3%), whilst in 268 cases (26.6%) the cause remained unidentified (MOH 2017). The total annual costs associated with hospitalisation for foodborne diarrhoea cases range between US\$ 5.8-6.4

million (Hoang et al. 2015). Another report claimed that the burden from productivity loss due to FBD is approximately USD 0.8 billion annually (Jaffee et al. 2019). However, the true burden is likely underestimated due to substantial underreporting, particularly regarding sporadic and mild cases where individuals often do not seek medical attention.

The structure of Vietnam's food system contributes to this challenge. Traditional wet markets remain the dominant retail channel for fresh foods, whilst cold chain infrastructure is limited, especially in peri-urban and rural areas (Gligor et al. 2018). Additionally, food production and distribution are largely based on smallholder and informal systems, complicating traceability and regulatory oversight. As a result, food safety in Vietnam constitutes a systemic issue across the entire food supply chain, as opposed to an isolated problem of individual practices. Within this context, risks associated with foodborne hazards, particularly microbial contamination, become a critical concern.

1.3. Animal-source foods and microbial hazards

ASF are particularly important in the context of FBD due to their high susceptibility to contamination. They provide rich nutrient environments that support microbial growth, are frequently exposed to contamination during slaughter and processing, and often require strict temperature control to prevent bacterial multiplication (Heredia and García 2018a; Sofos 2008). Among the three main types of foodborne hazards, microbial pathogens account for the majority of the global FBD burden (Todd 2014). In pork production systems, microbial contamination typically originates from the animals' intestinal contents and may be introduced during slaughter and processing through faecal contamination (Tholen et al. 2024; Dang-Xuan et al. 2019). Carcasses can also become contaminated through contact with slaughterhouse environments, including contaminated equipment, workers' hands, processing surfaces, and water used during slaughter, particularly when hygiene practices and sanitation controls are inadequate (Saenkankam et al. 2025; Dang-Xuan et al. 2019). Unlike chemical hazards, microbial hazards can multiply and spread along the food supply chain, an issue exacerbated by poor hygiene and inadequate temperature control (Dang-Xuan et al. 2019). Microbial contamination is therefore a commonly used

indicator for assessing hygiene conditions and food safety risks in meat production.

To assess overall microbial load and hygienic conditions during slaughter and meat handling, total bacteria count (TBC) is widely used, whilst total coliforms and pathogenic strains of *Escherichia coli* (*E. coli*) are common indicators of faecal contamination and poor sanitation, reflecting cross-contamination from intestinal contents, water, equipment, or handlers (Desta Sisay 2015; Hemalata and Virupakshaiah 2016; Abebe et al. 2020; Heredia and García 2018b). Furthermore, *Salmonella* spp. is a key foodborne pathogen and a major cause of pork-associated foodborne illness (WHO 2015; FAO 2020; Havelaar et al. 2015). These indicators are both essential and practical for monitoring hygiene conditions and evaluating the impact of food safety interventions across pork supply chains.

1.4. Risks from traditional pork supply chain in Vietnam

Among ASF, pork occupies a central position within the Vietnamese diet, with per-capita intake increasing from approximately 30 kg in 2021 to about 39 kg in 2025, accounting for nearly 60% of total meat consumption (VNA 2026; World Bank 2017; Nguyen-Viet, Dang-Xuan, et al. 2019). Most consumed pork is distributed through traditional value chains which involve multiple intermediaries (World Bank 2017; Nguyen Thi Thuy et al. 2020; Nguyen-Minh et al. 2023). These supply chains generally consist of multiple stages, including smallholder farming, slaughtering, transportation, and retailing through traditional wet markets before the pork reaching consumers (Dang-Xuan et al. 2016). They are largely informal and fragmented, with limited standardisation of hygiene practices. At each stage, conditions exist that facilitate microbial contamination and its persistence along the chain, but slaughter and retail stages are the most critical points for microbiological cross-contamination (Duggan et al. 2010; Yokozawa et al. 2016; Ngo et al. 2021).

At the slaughterhouse level, pigs are often processed in small- to medium-scale facilities that typically slaughter fewer than 10 to around 100 pigs per day (Dang-Xuan et al. 2017; Ting et al. 2023). In 2023, Vietnam had 456 licensed centralised slaughterhouses, whilst more than 22,000 small-scale facilities continued to operate without veterinary hygiene or food safety certification (Directive 02/CT-TTg 2023). Many of these facilities rely on

basic equipment, slaughter animals directly on the floor, lack separation between clean and dirty areas, and conduct limited sanitation between slaughter operations. These conditions create significant opportunities for faecal contamination and cross-contamination between carcasses (Ting et al. 2023).

After slaughter, pork is transported to traditional markets primarily by motorbike without cold storage. Meat is often stored in plastic containers or temporarily covered during transport, thereby increasing the risk of microbial growth. These practices are partly driven by consumer preference for freshly slaughtered “warm meat” rather than chilled pork (Maruyama and Trung 2009; Lapar and Toan 2010). Traditional markets usually consist of small, independently operated stalls located within residential neighbourhoods, where fresh meat is frequently displayed without refrigeration (Gligor et al. 2018). Under such conditions, pork can be exposed to insects, dust, and shared utensils, further increasing the risk of cross-contamination and facilitating pathogen persistence (Nga et al. 2015; USDA 2020; Dang-Xuan et al. 2016).

Studies performed throughout the past two decades have consistently documented that microbiological contamination along the pork supply chain may persist or even increase as products move from farm to consumer. *Salmonella* prevalence has been reported at 30 – 40% at farm and slaughter level, rising to 40-90% at traditional retail (Takeshi et al. 2009, Thai et al. 2012, Dang-Xuan et al. 2019, Nhung et al. 2018, Ngo et al., 2021; Vu et al., 2021). The evidence suggested that more than half of the *Salmonella* contamination in pork originated during slaughter (Yokozawa et al. 2016), with further amplification occurring at the market level (Nguyen-Viet et al. 2022; Wallace et al. 2022). Indeed, it has been estimated that approximately 17% of the population experiences foodborne illness annually due to *Salmonella* infection associated with pork consumption (Dang-Xuan et al. 2017).

These findings indicate that contamination is not effectively controlled along the supply chain and highlight slaughterhouses and wet markets as critical intervention points for reducing foodborne risks.

1.5. Food safety management in Vietnam

Efforts to improve food safety in Vietnam have been implemented through various policies and regulatory frameworks. The promulgation of the Food Safety Law in 2010 marked an important shift toward risk-based, farm-to-fork management and clarified responsibilities across three ministries: the Ministry of Health, the Ministry of Agriculture and Forestry, and the Ministry of Industry and Trade (The National Assembly 2010; Sarter et al. 2015). The law is currently under revision to address emerging challenges in food safety governance. Despite this progress, there is still a significant gap between legislation and implementation (Tran et al. 2024). The risk-based approach prioritises inspection and testing activities according to the level of food safety risk. However, in practice, the current system continues to be predominantly reactive, meaning that interventions are often only triggered after food incidents or poisoning outbreaks occur (World Bank 2017). Moreover, underreporting is common, as only large outbreaks tend to be captured, whilst small outbreaks and sporadic cases are often missed. Food safety monitoring programmes exist, yet surveillance data are not systematically compiled or analysed at the national level (Dinh et al. 2024). Although approximately 5,000 food safety inspectors operate nationwide, an integrated and comprehensive monitoring system is still lacking, and information on outbreak response capacity remains limited (World Bank 2017). The transition toward risk-based management is further constrained by fragmented and non-integrated data systems across ministries, continued reliance on manual processes, and uneven enforcement capacity across administrative levels (World Bank 2017). Additionally, the division of regulatory authority by commodity across ministries complicates oversight in complex settings such as traditional markets, where diverse food products are handled simultaneously (Pham and Dinh 2020).

Whilst modern supply chains and export sectors are relatively well controlled, food safety oversight in traditional markets and small-scale operations persists as a particular challenge (World Bank 2017). Vietnamese regulations also establish hygiene requirements for slaughterhouses. For example, slaughter operations are required to follow veterinary hygiene standards, including conducting slaughter on raised platforms rather than directly on the floor to reduce contamination risks (MARD 2010). In practice, compliance with these hygiene requirements is limited in many traditional slaughter facilities due to infrastructural constraints and a lack of

enforcement capacity. Strict penalties, such as the closure of non-compliant facilities, may also disrupt local pork supply chains and threaten the livelihoods of small operators, thereby generating additional challenges for regulatory implementation (World Bank 2017; Nguyen-Viet et al. 2017). Consequently, although regulatory standards exist, implementation remains uneven. Thus, food safety management remains largely reactive and focused on end-product inspection, with limited effectiveness in preventing contamination at critical points along the supply chain, particularly at slaughterhouses and wet markets.

1.6. Vietnamese consumer perceptions of food safety

Food safety was found to be a major increasing concern among Vietnamese consumers. However, consumer perceptions and behaviours do not always align with actual food safety risks. Despite the importance of microbial hazards, studies in Vietnam show that consumers tend to perceive chemical risks as a greater concern than microbial contamination (Nguyen-Viet et al. 2017; Ha et al. 2019a). Previous studies indicate that consumer knowledge of foodborne pathogens and their transmission pathways remain limited (Samapundo et al. 2016; A. T. L. Nguyen et al. 2018; Le et al. 2022). This misalignment may restrict the effectiveness of interventions targeting microbial contamination and affect consumers' ability to pay for safer food (Hoffmann et al. 2019).

Nevertheless, there is evidence that consumers in Vietnam are willing to pay a premium for safer food products, ranging from 20 to 102% above the current market price for certified pork (Vuong et al. 2024; H. T. Nguyen et al. 2019; Ngo, Dang-Xuan, Målqvist, Pham-Duc, et al. 2023). However, this willingness to pay is highly dependent on consumers having trust in food safety systems, which can be undermined by food safety incidents and a lack of transparent information (Yan 2012).

These findings highlight a critical gap between consumer concern and their ability to act on it. Thus, improving access to trustworthy and understandable food safety information may enable consumers to make safer choices. In turn, informed consumer demand has the potential to influence vendor practices, creating a pathway for incentive-based approaches to improve food safety in traditional markets.

1.7. Food safety interventions and their gaps

In response to persistent food safety challenges, various interventions have been implemented in several LMIC to improve hygiene practices along food supply chains. These include training programmes, infrastructure improvements, and the provision of hygiene technologies (Kwoba et al. 2023). However, many studies rely on before-and-after designs without appropriate control groups, making it difficult to attribute observed changes directly to the interventions (Grace 2023). In addition, most interventions have focused on improving knowledge and providing equipment, whilst paying less attention to creating enabling environments and incentives that are necessary for sustained behaviour change. A hygiene intervention in the abattoir and meat market in Nigeria initially improved food safety, but these gains were not sustained when institutional support weakened and coordination between stakeholders deteriorated (Grace et al. 2019).

In Vietnam, similar challenges have been observed. Formal approaches such as Hazard Analysis and Critical Control Points (HACCP) have been largely confined to export-oriented systems, with limited applicability to the informal sector (Pham and Dinh 2020). Large-scale programmes such as the Livestock Competitiveness and Food Safety Project (LIFSAP) have demonstrated that improvements in infrastructure, training, and hygiene practices can enhance food safety outcomes. However, evidence suggests that these improvements remain partial, with microbiological compliance at the market level still lacking, and their sustainability beyond the project period uncertain without continued institutional support and incentives (L. T. Nguyen et al. 2020; Lam et al. 2025). A recent low-cost, behaviour-based intervention has shown the potential to reduce contamination at slaughterhouse and market levels (Ngo, Dang-Xuan, Målqvist, Nguyen-Thanh, et al. 2023), but evidence of their long-term effectiveness and scalability remains limited, as the study was conducted under specific pilot conditions.

Furthermore, in many informal markets, food safety practices are not easily visible to consumers, and safer products do not necessarily receive higher market rewards. This reduces the incentive for vendors to adopt improved practices. Addressing this gap requires approaches that not only improve hygiene but also create conditions in which safer practices are recognised and rewarded within the market (Hoffmann et al. 2019).

Scaling up food safety interventions requires greater attention to the broader context in which they are implemented. This includes social and cultural practices, local market organisation, gender roles in food handling and trading, and the capacity of local institutions to support and sustain change (Kwoba et al. 2023; Grace 2023). Without considering these factors, interventions are unlikely to achieve a lasting impact.

2. Aim of the thesis

The overall aim of this thesis was to generate evidence on the effectiveness of food safety interventions in traditional pig slaughterhouses and retail markets in Vietnam to reduce microbiological contamination and associated food-borne disease risks using a One Health approach.

The specific objectives were to:

- Determine microbiological contamination and food safety practices in traditional pig slaughterhouses and markets in Vietnam.
- Assess the effectiveness of food safety interventions at pig slaughterhouses in terms of improved practices and reduced microbiological contamination.
- Evaluate the effectiveness of food safety interventions at traditional markets in terms of change in behaviour, microbiological contamination, and business.
- Examine the impact of food safety interventions on consumer demand for safer food.

3. Materials and methods

3.1. Study design

The thesis consists of two intervention studies, with the results presented across three papers. In both studies, baseline and endline data were collected to assess intervention effects. Qualitative analyses were conducted to inform intervention design and are not presented in the three papers, only in the thesis.

One intervention was based at markets, with baseline results presented in Paper I and intervention effects reported in Paper III. The intervention at slaughterhouses, including both baseline and post-intervention results, is presented in Paper II. Table 1 summarises the main characteristics of each study.

3.2. Study sites

The project was conducted in five provinces across Vietnam, covering northern (Thai Nguyen, Hanoi), central (Thua Thien Hue), and southern (Can Tho, Dong Nai) regions (Figure 1), although not all provinces were included in each study (Table 1). These regions differ in climatic conditions, the scale and organisation of pig supply chain structures, operations, and associated cultural practices. Further details are provided in Paper I.

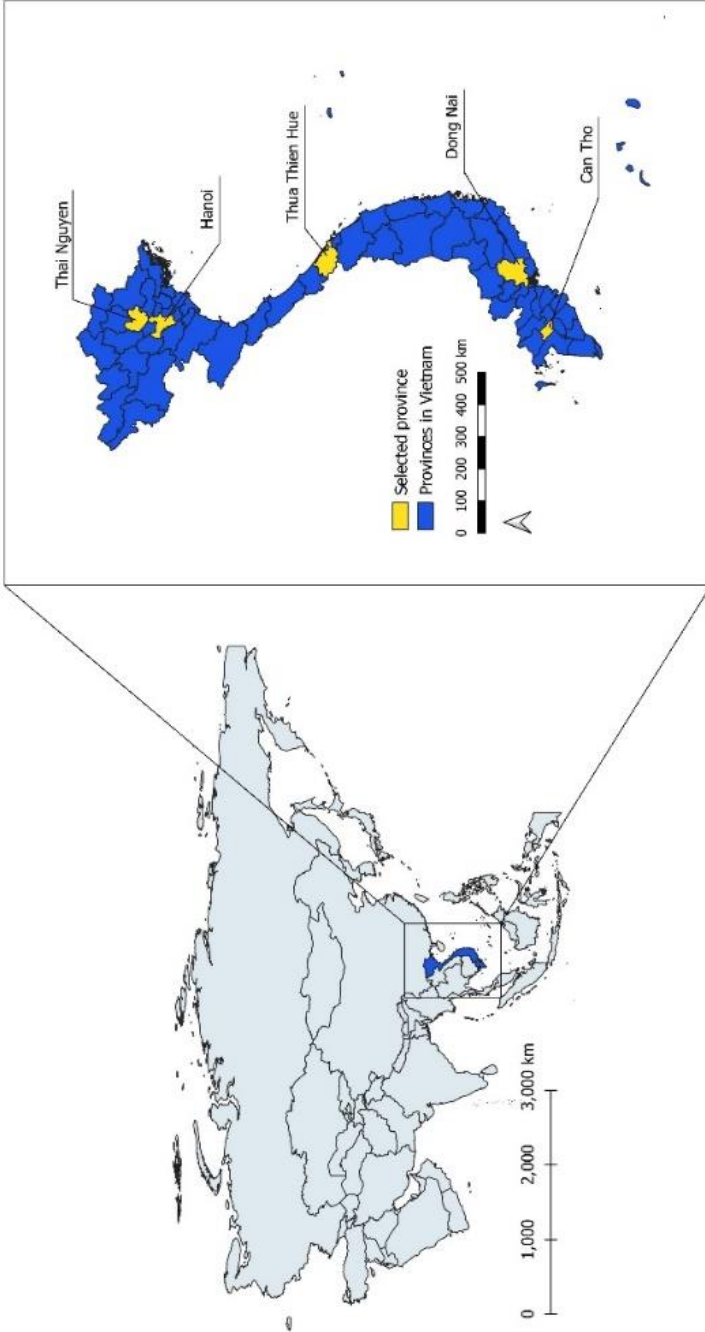


Figure 1. Map of the Asia continent with Vietnam marked in blue (left) and a map of Vietnam (2023) with five selected provinces marked in yellow (right)

Table 1. Summary of applied methods and materials in two intervention studies at pig slaughterhouses and traditional markets

	Study 1 Intervention at pig slaughterhouses	Study 2 Intervention at traditional markets	
Study design	Non-RCT (Paper II)	Mixed methods	
		Qualitative (presented in thesis only)	Quantitative: RCT (Papers I and III)
Study period	Jul – Dec 2024	Dec 2022 – Dec 2023	Dec 2022 – Jun 2024
Study sites (province)	Hanoi, Thai Nguyen, Thua Thien Hue, Can Tho	Hanoi, Thai Nguyen, Thua Thien Hue, Can Tho, Dong Nai	
Study population	Pig SH owners and workers	AH officers, PH officers, market managers, SH workers vendors, and consumers	Pork vendors and consumers
Data collection	Observational checklists, pig carcass swabs and worker hand swabs	In-depth interviews	Observations, vendors surveys, cut pork and cutting board swabs, and consumer surveys
Lab analysis	TBC, <i>Salmonella</i> spp., coliforms, <i>E. coli</i>	Not applicable	TBC and <i>Salmonella</i> spp.
Data analysis	Descriptive statistics, Chi- square, Fisher’s exact tests, paired t- test, ANOVA with Tukey’s HSD, linear regression, GLMMs	Thematic analysis	Descriptive statistics, Chi- square, Fisher’s exact tests, Wilcoxon rank- sum, Kruskal- Wallis test, linear regression

RCT: Randomised Controlled Trial. AH: Animal Health. PH: Public Health. SH: Slaughterhouse. ANOVA: Analysis of Variance. GLMMs: Generalised Linear Mixed-effect Models. TBC: Total Bacteria Count.

3.3. Sample size

In Papers I and III, the sample size was calculated to detect a minimum 15% absolute reduction in *Salmonella* prevalence using a two-proportion comparison. Assuming an intra-cluster correlation coefficient (ICC) of 0.2, a 95% confidence level, and 80% power, the number of required vendors for each group was 139. The study was set up to have 170 vendors per group at the endline, with 5 vendors per market (corresponding to 34 interventions and 34 control markets). For the intervention markets, to account for potential loss of follow-up, the number of selected vendors was doubled to 10 per market. As a result, the total target sample size was 510 vendors (170 in control and 340 in intervention markets). In practice, due to limited vendor availability and refusals, 494 pork vendors were recruited at the baseline and 486 were retained at the endline. These vendors are hereafter referred as “study vendors”. Additionally, 15 consumers per market were interviewed at each time point.

For the qualitative piece in the same study above, snowball sampling was used to target key actors involved in pork safety at the market. Interviews continued until data saturation was reached, defined as the point when no new relevant information emerged. In total, 34 participants were interviewed.

In Paper II, sample size was calculated using a two-mean comparison based on data from a previous project (ILRI 2017). The ICC, confidence level, and power were set as in Papers I and III, and the cluster size was fixed at six carcass samples per slaughterhouse. An expected reduction of 0.7 log₁₀ CFU/cm² in TBC on pig carcasses was considered biologically significance. The calculation indicated that 16 slaughterhouses (8 treatment, 8 control) were required to detect the main effect of the intervention.

3.4. Intervention descriptions

Intervention packages were developed based on evidence from previous projects in Vietnam (SafePork project) and Cambodia (Safe Food Fair Food project) (ILRI 2021, 2017). At both traditional slaughterhouses and markets, interventions were designed using the Enabling, Capacitating, Motivating (ECM) framework to promote sustainable improvements in food safety practices (Nguyen-Viet and Hoffmann 2021):

- Enabling: an enabling environment (e.g., non-punitive co-regulation, support by local authorities)

- Capacity: provide repeated training and low-cost equipment
- Motivating: incentives for behaviour change (scoring system based on practices, awards for successful participation, etc.).

The three core components with examples of implementation activities are summarised in Table 2 and illustrated in Figures 2 and 3.

Paper II evaluated two interventions implemented at slaughterhouses. The ‘Technique’ intervention combined stakeholder engagement, infrastructure upgrades, and hygiene training. These activities focused on strengthening slaughterhouse management, improving awareness of food safety risks, and providing practical guidance on hygienic slaughtering procedures. The ‘Incentive’ intervention introduced a performance-based inspection programme to motivate workers to adopt safer practices. During the intervention period, slaughterhouse workers were periodically assessed on hygiene performance, and financial rewards were provided to those meeting predefined performance scores. The inspection programme was conducted twice in each selected slaughterhouse before endline sampling. There was no follow-up inspection after the study.

In Paper III, all pork vendors were invited to attend food safety training which was delivered after baseline data collection. Study vendors in intervention markets were subsequently exposed to two components. First, market-level intervention included all study vendors who attended food safety training. Vendors were opted into a voluntary inspection and disclosure programme (inspection programme), with repeated unannounced inspections to reinforce compliance. Second, study vendors were randomised through a public lottery to receive a hygiene equipment package designed to facilitate safer practices after the training (individual-level intervention). Among the study vendors in intervention markets, 85% (277/324) attended the training and 75% (242/324) enrolled in the inspection programme. Consumers in intervention markets were informed about the inspection system through an awareness campaign that included distribution of promotional materials whilst shopping.



Figure 2: Intervention package at pig slaughterhouses with arrows pointing to describing components in Table 3



Figure 3: Intervention package at pork stall in market with arrows pointing to describing components in Table 3

Table 2. Interventions following Enabling - Capacity – Motivating (ECM) approach at traditional pig slaughterhouses and markets

ECM	Slaughterhouses	Markets
Enabling	Support from local authority through inclusion of logo into slaughterhouse’s signage (2a)	Support from local authority through their inclusion in study design and data collection progress
Capacity	Training in hygiene practice for slaughterhouse workers and provision of low-cost equipment: posters (2b) and stainless-steel grid (2c) to avoid slaughtering on floor	Training in hygiene practice for pork vendors and provision of low-cost equipment, e.g. cutting boards (3a), water container with spigot and soap/disinfectant (3b), easy-to-clean surface to cover wooden table (3c)
Motivating	Inspection programme with prizes, scores disclosed publicly on signs (2d)	Inspection programme, scores disclosed publicly on signs (3d)

The labels 2a–2d and 3a–3d indicate specific intervention components illustrated in Figures 2 and 3, respectively.

3.5. Participants recruitment and randomisation

In Papers I and III, eligible markets contained more than eight pork vendors, operated daily, had access to fresh water (required for handwashing), and were located within a two-hour drive of a local laboratory that performed microbial analyses. From 68 eligible markets, study markets were randomly assigned to intervention or control status with equal probability, stratified by province. Within each selected market, study vendors were randomly sampled from a census list of eligible pork vendors. Up to 10 vendors were selected in intervention markets and up to 5 in control markets. If a selected vendor refused to participate, replacements were drawn from a randomly ordered back-up list. All participants were required to be at least 18 years of age and provide informed consent. Consumers were recruited during market operating hours by trained enumerators stationed near the pork section. Enumerators approached consumers as they exited the area and invited them to participate in the survey.

In Paper II, eligible slaughterhouses were required to meet the following criteria: (i) slaughtered 6–30 pigs per day; (ii) were under the management of the Sub-Department of Animal Health; and (iii) the owner agreed to participate and comply with study procedures. Sixteen slaughterhouses were selected. Randomisation was implemented for the ‘Technique’ intervention. The ‘Incentive’ intervention was conducted in all slaughterhouses in two

purposively selected provinces to facilitate logistical arrangements and monitoring.

3.6. Data collection and outcome measures

In Papers I and III, each study vendor underwent data collection, as illustrated in Figure 4. Discreet observations were first conducted to assess routine hygiene practices during selling for 10 minutes. A structured vendor questionnaire on food safety knowledge, attitudes, practices, market conditions, and business characteristics was captured, whilst cut pork and cutting-board swabs were collected in parallel. Lastly, a 30-minute direct observation recorded the frequency of hygiene behaviours using standardised criteria. Consumer surveys were conducted separately to collect information on purchasing decisions, vendor selection, and perceived food safety risks.

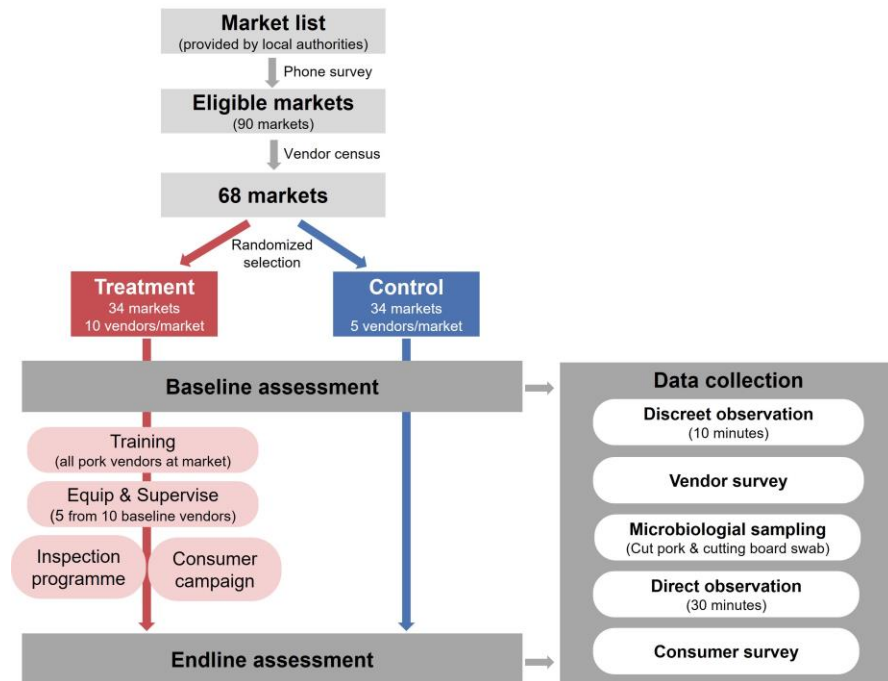


Figure 4. Design of intervention and data collection at traditional markets

In Paper II, 96 carcass swabs, 64 worker hand swabs, along with 96 structured observations was collected at both baseline and endline. Hand and carcass swabs were analysed for TBC, total coliforms, and *E. coli*, whilst carcass samples were additionally tested for *Salmonella* spp. At baseline and endline, hygiene practices were assessed throughout the slaughtering process (approximately 4 – 5 hours) using a standardised observation checklist (Appendix 1) covering operational characteristics and 16 hygiene-related practices. After reliability testing using Cronbach’s alpha, eight indicators were retained to construct the final practice score used in the analysis. For the inspection programme, participants were observed by a research team for at least 30 minutes and evaluated on 9 hygiene indicators, earning 1 point for each correct practice. Those who scored at least 7 points received a cash reward of 200,000 VND (~USD 7.6), with results posted on a public board at the facility. Figure 5 presents the study design and data collection.

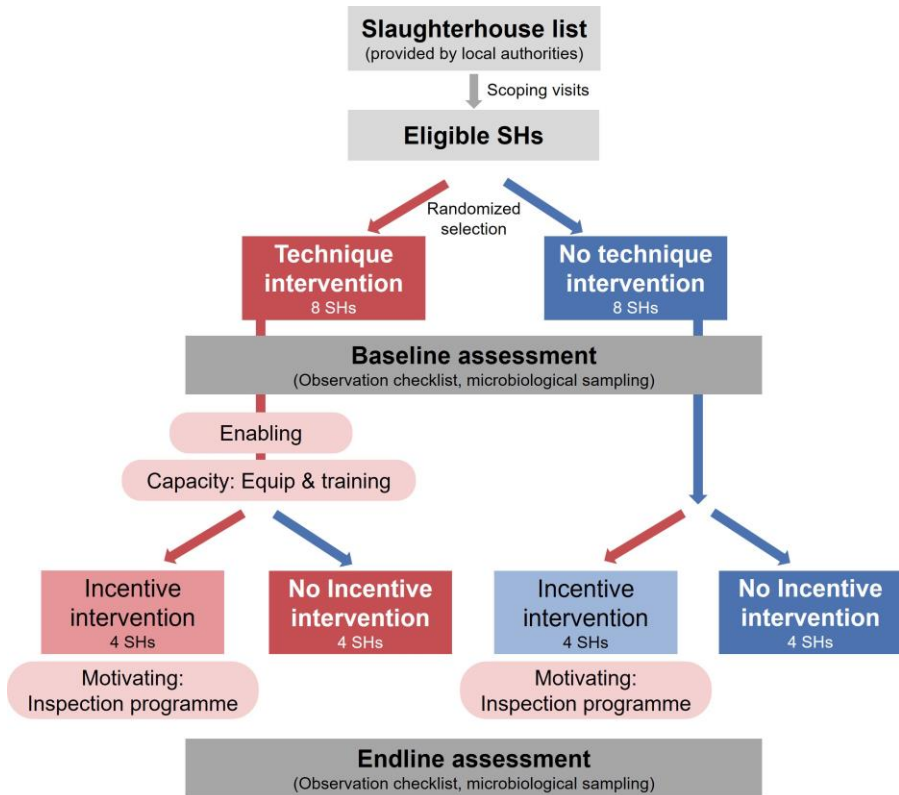


Figure 5. Design of intervention and data collection at slaughterhouses (SHs)

The main outcomes for each paper, along with their operational definitions and measurement scales, are summarised in Table 3.

Table 3. Definition and measurement of study outcomes in the three papers

Outcome	Measurement
Papers I and III	
<i>Salmonella</i> on cut pork	Binary on prevalence, continuous in modelling
TBC on cut pork	\log_{10} CFU/g
TBC on cutting boards	\log_{10} CFU/cm ²
Vendor knowledge	Total points for five questions. Binary (correct/incorrect) or the proportion of correctly selected options relative to the total number of pre-defined correct options was given for each question. Points ranged from 0 to 5
Vendor perception	Count of factors that vendors believed motivated consumers to choose a particular vendor in the market such as a clean stall, a clean vendor, and/or safe food
Vendor hardware score	Total points for possessing necessary equipment, ranged from 0 to 4
Vendor action score	Total points for five actions, each correct action received 1 point, points ranged from 0 to 5
Vendor inspection score	Five-point scale combining features of the action and hardware scores. Scores for vendors who participated in the inspection programme were posted on their signage at stalls
Vendor monthly profits	Based on today's revenue minus pork costs, multiplied by number of days per week selling pork based on previous week and multiplied by the number of weeks per month, minus monthly costs
Consumer risk perception	Consumers' response to vendor selection due to cleanliness, food safety, or high inspection score and their perceptions about food safety risks
Paper II	
TBC on pig carcass	\log_{10} CFU/cm ²
<i>Salmonella</i> on pig carcass	Binary
Coliforms and <i>E. coli</i> on pig carcasses	\log_{10} CFU/cm ²
Coliforms and <i>E. coli</i> on hands	\log_{10} CFU/hand
Worker practice score	Total points for eight actions, each correct practice received 1 point, points ranged from 0 to 8

Qualitative data in study 2 were collected through semi-structured interviews (around 60 minutes each) with slaughterhouse workers, pork vendors, consumers, market managers, and animal and public health staff in selected traditional markets. Interview guides were developed to explore perceptions of safe pork, food safety practices, barriers to hygiene compliance, regulatory awareness, and gender roles.

3.7. Laboratory analysis

Detection of *Salmonella* spp. followed ISO 6579-1:2017. TBC was determined according to ISO 4833-2:2013, whereas total coliforms and *E. coli* were analysed using TCVN 13875:2023. All samples were analysed in the respective provincial laboratories using standardised protocols. The research team conducted regular checks and confirmations with the laboratories throughout the analysis period to ensure quality control.

3.8. Data management and statistical analysis

The initial study designs for the two studies were pre-registered on AsPredicted (ID: 183149) and AEA RCT Registry (ID: AEARCTR-0012244). Survey data in Papers I and III were collected electronically using Open Data Kit (ODK) and analysed using RStudio (R Core Team 2021) and Stata (StataCorp, College Station, TX, USA). In Paper II, observational data were collected using paper-based forms, double-entered into Excel, subjected to two rounds of random verification checks to ensure accuracy, and analysed using RStudio. Descriptive statistics were calculated in all papers, including percentages for categorical data and means, standard deviations, ranges, min - max for quantitative data. In Papers II and III, intervention effects were analysed under an intention-to-treat principle, based on original assignment. Statistical significance was set at a p-value ≤ 0.05 .

Additionally, Paper I used linear and generalised linear mixed-effects models to identify risk factors for TBC and *Salmonella* prevalence. Following that, in Paper III, post-intervention outcomes were analysed using linear regression models (linear probability model for *Salmonella*). Baseline values of the outcome variable were included to improve precision, selected using post-double-selection LASSO (Belloni et al. 2014). Province was

included as a fixed effect. Standard errors were clustered at the market level to account for intra-market correlation. For microbiological outcomes, sampling time and ambient temperature were additionally controlled. Outcomes in this paper are presented in three comparison levels (Table 4). Additional analyses to compare regional and environment effects to TBC level were added using linear regression.

Table 4. Treatment comparisons for market- and individual- level interventions

Term	Definition	Comparison
Market-level intervention	Effect of being in a treatment market through the market-level activities (e.g. training and inspection programme)	Vendors in treatment markets vs. vendors in control markets
Individual-level intervention	Additional effect of receiving equipment within treatment market	Vendors assigned to receive equipment vs. vendors who were not in treatment markets
Combined effect	Effect of receiving both level-interventions relative to control	Vendors assigned to receive equipment vs. vendors in control markets

For Paper II, microbiological outcomes and practice scores were first compared across intervention groups using ANOVA, chi-square, or Fisher’s exact tests, and paired t-tests as appropriate. The effectiveness of ‘Technique’ and ‘Incentive’ interventions was assumed to influence microbial contamination of carcasses indirectly through workers’ practices. Mixed-effects models were used to examine associations of microbial contamination and hygiene practices with the explanatory variables. Confounding factors (temperature and slaughterhouse operation) and survey round were included in both univariable and multivariable analyses, whilst intervening factor (bacterial contamination in workers’ hands) was excluded from all analyses. Slaughterhouse and provincial were set as random factors.

The qualitative interviews were analysed using thematic analysis to identify and interpret recurring patterns in the data. All interviews were conducted in Vietnamese, audio-recorded with consent, and transcribed for analysis. The transcripts were initially reviewed twice to allow familiarisation with the data and to identify relevant quotations. Keywords were subsequently identified and the data were coded using the software MAXQDA version 24.8.0 (*VERBI Software 2024*). These codes were organised into preliminary themes and then reviewed and refined to ensure

that they accurately represented the data. The final themes included local perceptions of safe pork, normal food handling practices, structural and institutional barriers to food safety, and gendered roles within the pork supply chain. At this stage, the qualitative data presented in this thesis were analysed by the first author. The analysis will be further reviewed and refined by the research team to provide a more in-depth analysis in a future manuscript.

3.9. Ethical considerations

The Institutional Review Board of Hanoi University of Public Health approved all aspects of the project (Decision number: 458/2022/YTCC-HD3).

Voluntary participation and anonymity

Written (for Papers I and III) or verbal informed consent (Paper II) was obtained from each participant prior to enrolment. All participants received clear information regarding the study objectives, procedures, types of data collected (including observation and microbiological sampling), and were informed that they could withdraw from the study at any time without facing any consequences. All collected information was handled confidentially. Individual identifiers were removed during data management, and the results are presented in an aggregated form to prevent identification of specific individuals, slaughterhouses, or vendors.

Compensation

Meat samples were purchased at the regular market price. Vendors were compensated USD 3 in cash for their time spent with the survey team, consistent with practices for similar studies in the country.

Potential risks and risk mitigation

The study was assessed as involving minimal risk. Identified risks were primarily social or reputational rather than physical, and appropriate mitigation strategies were implemented throughout fieldwork.

First, participation in the vendor inspection programme could potentially affect vendors' reputation or income if results were perceived negatively. In some cases, stars stuck on to the signage used to publicly display inspection results were stolen by other vendors who questioned the fairness of the assessments. To mitigate reputational risks and reduce conflict, results were

communicated carefully and transparently in the presence of the market manager. The assessment criteria and procedures were openly explained to ensure procedural clarity and fairness.

Second, tensions arose in instances where vendors selected to receive equipment through the lottery did not attend the required training sessions. In accordance with the predefined protocol, no redraw was conducted, and equipment packages were not distributed to those vendors. The research team explained the rationale to both vendors and market managers to ensure transparency and minimise perceptions of unfairness.

Lastly, there was a minor risk of discomfort during the hygiene practice observations, as participants may feel scrutinised. This was addressed during the informed consent process, where the full study procedures were clearly explained. Participants were informed that data would be treated confidentially and not disclosed at the individual level. During fieldwork, observers maintained a neutral and non-judgmental presence to minimise potential discomfort.

4. Results and discussion

4.1. Baseline situation in traditional pork supply chains

4.1.1 Contamination and practices at traditional markets (Paper I)

Across 64 traditional markets, the overall *Salmonella* prevalence in pork was 64.4%, comparable to reports from China, Thailand, and the Laos–Thailand border (Chen et al. 2021; Patchanee et al. 2016; Meunsene et al. 2021), but higher than findings from Cambodia (Rortana et al. 2021). The high *Salmonella* prevalence observed in this study reflects a consistent increasing trend reported in Vietnam throughout the past two decades, rising from approximately 40% between 2007 and 2015 (Takeshi et al. 2009; Thai et al. 2012) to over 60% during 2018–2021 (Dang-Xuan et al. 2019; Nhung et al. 2018; Ngo et al. 2021; Vu et al. 2021). This upward trend underscores the persistent and possibly worsening burden of *Salmonella* contamination in traditional pork supply chains. Mean TBC was 6.4 log₁₀ CFU/g in pork and 6.9 log₁₀ CFU/cm² on cutting boards, and nearly 70% of pork samples exceeded Vietnam’s permitted TBC limits for fresh meat. Both *Salmonella* prevalence and TBC level were significantly higher in the Southern compared to the Northern provinces¹.

In line with studies from other LMIC (Wallace et al. 2022), vendors demonstrated limited food safety knowledge (mean score 1.4/5), misconceptions about hygiene, and a minimal awareness of cross-contamination or disinfection. Vendors generally perceived the pork that they personally sold to carry a lower risk compared to others. Infrastructure was inadequate, with limited handwashing facilities and an extreme lack of disinfectant use. Observations confirmed that workers’ hands or equipment were rarely cleaned during sales. Knowledge and equipment were positively associated with practice, and trained vendors demonstrated better practices despite similar knowledge scores. Overall, both knowledge gaps and structural limitations contribute to persistent retail-level food safety risks,

¹ Baseline TBC and *Salmonella* results in Thua Thien Hue (a central province) were excluded from all analyses in this paper due to inconsistencies in laboratory procedures compared with other provinces. In Paper III, only endline *Salmonella* results were included.

highlighting the need for integrated education and infrastructure improvements.

4.1.2 Qualitative insights on determinants of market practices

Figure 6 presents a visual synthesis of the thematic relationships identified in the analysis. The findings show that food safety practices in traditional pork markets are shaped by the interaction of regulatory arrangements, local constructions of “safe pork,” structural and operational constraints, and gendered roles. Together, these interconnected factors contribute to a persistent gap between formal standards and day-to-day implementation.

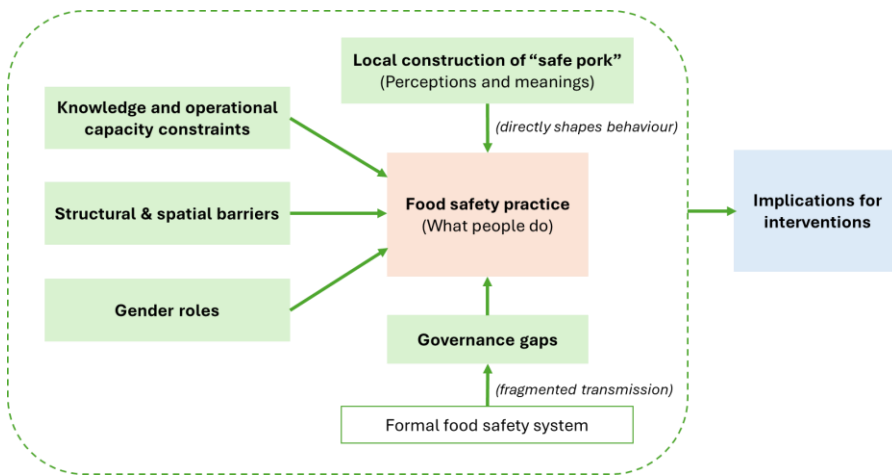


Figure 6. Thematic relationships shaping food safety practices in traditional markets

Local constructions of “safe pork”

Pork was confirmed as the most consumed ASF due to its versatility, taste, and ease of preparation. Food safety was locally defined through freshness, trust, and visibility rather than formal hygiene standards. Consumers preferred buying pork from familiar vendors. Purchasing decisions were primarily guided by sensory cues, with meat colour viewed as the key indicator of freshness and safety, alongside smell, dryness, elasticity, and signs of recent slaughter. These norms are similar to findings from previous studies, indicating a rooted habit culture among the population (Nguyen-Viet, Dang-Xuan, et al. 2019). In addition, there was a general belief that unsafe pork predominantly originates at the farm level (diseased pigs), and pork possesses a low risk because it’s sold within a short duration of 7 – 8

hours after slaughter. This echoes previous findings that consumers often underestimate the risks associated with handling and retail environments, particularly microbial contamination (Cook and Phuc 2019; Le et al. 2022).

Knowledge and operational capacity constraints

Daily food safety practices were further constrained by time pressure, selling volume, and experience-based knowledge. Hygiene was harder to maintain during peak selling hours, especially for high-volume vendors. Training for pork vendors was largely absent, which usually results in poor knowledge and practice (Teym et al. 2025; Al Banna et al. 2021; Kulpiisova et al. 2025; Huynh-Van et al. 2022). Moreover, when training did occur, it was delivered to large groups and perceived as ineffective. Certain vendors and slaughterhouse workers did not see training as necessary, viewing their work as simple manual labour learned through experience. Vendors believed that consumers did not understand food safety signage. Consumers could not observe routine hygiene practices, and inspection systems were distrusted due to inconsistent compliance. Isanovic et al. (2022) explained how this mistrust causes consumer to predominantly rely on familiar vendors as a key mechanism for managing uncertainty rather than formal food safety indicators.

“Vendors are already accustomed to traditional ways of doing business. Besides, frankly, when they do it this way, their awareness of food safety isn't very deep or comprehensive. They attend training sessions enthusiastically and do understand the content, but when it comes to implementation, it is difficult due to time constraints, it takes up too much of their time.” (Vendor, CT08)

Structural & spatial barriers

Markets had inadequate facilities, including poor drainage, dark areas, old stalls, and limited water access, despite the basic hygiene standards set by national regulation (MOIT 2017). Vendors renting stalls were unwilling to invest in infrastructure, viewing this as the responsibility of market authorities. The chaotic market layout had led to many vendors selling outside official stalls, particularly near entrances. These informal stalls fell outside regulatory oversight, rendering food safety and meat origin difficult to control, but attracting customers due to lower prices and convenience. This aligns with the theory that both vendors and consumers adapt to market

environments in ways that prioritise accessibility and economic efficiency over formal market layouts (Wertheim-Heck et al. 2015).

“After Covid, people rented stalls along the area outside markets. They set up stalls on both sides to sell their goods, so they refused to go inside. That's convenient for consumers. They moved outside for convenience. Now, how can we get them to come back in? It's very difficult.” (Animal health staff, CT09)

“The market is so cramped and there are no proper entrances or exits, so people are hesitant to go in and buy it on the street instead.” (Vendor, TN04)

Gender roles

Women dominated retail pork selling and customer interaction, emphasising communication and stall presentation, but had less access to training due to caregiving responsibilities. Men were more likely to receive training and hold managerial roles. These gendered patterns are consistent with earlier findings in the pig supply chain in Vietnam (Nguyen-Thi-Duong et al. 2022) and shape access to knowledge, authority, and responsibility across the supply chain. From these findings, the strategy for training material and training curriculum during the interventions has been carefully designed to include both man and women, considering their different roles and constraints, and promoting a shared responsibility for food safety.

Governance gaps

Food safety oversight was limited by staff shortages, fragmented mandates, weak enforcement, and unclear penalties. Monitoring was inconsistent, inspections infrequent, and test results rarely communicated. Vendors reported that formal requirements (e.g., health checks and health certificates) were not actively enforced. Formal standards existed on paper but were weakly embedded in daily market practice. Regulatory overlap and unclear accountability, issues that have been previously documented (Pham and Dinh 2020; USDA 2020), were evident in this study and enabled the continued circumvention of rules.

“There are many regulations that are not consistent across sectors. For example, vendors offering on-site dining (with tables or seating) fall under the management

of the health sector, while those selling for take-away are managed by the economic sector. This overlap exists in some business types, and the lack of clear classification allows vendors to exploit these gaps to circumvent food safety requirements.” (Human health staff, DN03)

“There are also some regulations that lack specific guidance on how violations should be penalised. For example, health check requirements may stipulate that vendors must not have infectious diseases, but there is no clear guidance on how violations should be sanctioned. Even when penalties are mentioned, the level of punishment is not specified. Without such guidance, it is difficult to impose penalties on violators.” (Human health staff, DN03)

Food safety practices

To meet consumer expectations of freshness, vendors prioritised visual quality. The lack of cold storage together with the high temperatures and humidity in tropical areas (Gligor et al. 2018; Dang-Xuan et al. 2019) causes pork to leak water, therefore vendors have to use cloths or cardboard to absorb the liquid and maintain its colour. Whilst some respondents mentioned potential chemical risks associated with these materials, no clear regulations or evidence were identified, and the practices were widely accepted by consumers, particularly when trust in the vendor was strong.

Hygiene practices were shaped by shared market norms rather than formal standards, with infrequent washing considered acceptable and disinfectant use viewed cautiously due to fears of altering meat colour. Stall-level contamination was viewed as unavoidable, with safety responsibility largely shifted to consumers through washing and cooking at home, reflecting limited concern for microbial risks and a focus on visible cleanliness (Nguyen-Viet, Dang-Xuan, et al. 2019; Ha et al. 2019a). This shift of responsibility highlights the need to strengthen consumer knowledge and awareness of food safety risks, as an increased demand for safer products may incentivise actors along the supply chain to adopt improved practices (FAO and WHO 2003; Isanovic et al. 2022).

“When pork is slaughtered and displayed for sale, it's unavoidable that it will be contaminated with bacteria. Flies and gnats will inevitably land on it. People who buy it will wash it thoroughly before cooking.” (Vendor, TN06)

The high levels of microbial contamination observed in pork at traditional markets likely reflect a combination of poor hygiene practices at the retail level and contamination originating from earlier stages of the supply chain. This raised the question of the extent to which upstream stages, particularly slaughterhouses, contribute to the microbial contamination observed at markets.

4.1.3 Hygiene conditions at pig slaughterhouses (Paper II)

At the slaughterhouses, mean TBC on pig carcasses was 5.4 log₁₀ CFU/cm², approximately one log higher than Ngo et al. (2023) reported, and similar to the levels observed by Nguyen-Viet et al. (2019) in comparable Vietnamese slaughterhouse settings. TBC on workers' hands were statistically higher, with a mean of 7.1 log₁₀ CFU/hand, consistent with findings from Ngo et al. (2023). There were 20.8% and 6.3% of carcass samples with exceeded permissible limits for TBC and *E. coli* according to national fresh meat standards (MOET 2019), respectively. *Salmonella* prevalence was 37.5%, similar to national surveillance data in Vietnam (34.7%) (National Centre for Veterinary Diagnosis No. I 2025). Across samples, TBC, coliforms, and *E. coli* concentrations were significantly higher on workers' hands than on carcasses, underscoring the central role of hand hygiene in carcass contamination pathways (Duggan et al. 2010).

Workers' hygiene practices were generally poor, with a mean score of 2.7±2.0 out of 8. Workers in the South received substantially higher scores (5.5) compared to the Central (1.6) and Northern regions (1.8). Practices of restricting movement between dirty (bleeding/scalding) and clean (evisceration) areas and washing boots and hands with soap or disinfectant before slaughter were not observed in any slaughterhouse. The lack of these practices have been documented in other provinces (Yokozawa et al. 2016). In contrast, simpler or more visible practices, including bleeding pigs on elevated tables and prohibiting smoking or eating during slaughter operations, were reported in around 80% of facilities, similar to findings from Ngo, Dang-Xuan, Målqvist, Nguyen-Thanh, et al. (2023). Of the 16 slaughterhouses, 11 used water from a tank to rinse carcasses and equipment. Such water is often reused and poorly controlled, allowing organic material and microorganisms to accumulate which increases the risk of faecal contamination of carcasses and equipment (Le Bas et al. 2008). Overall, these findings indicate that although some basic procedural norms were adopted,

the absence of key biosecurity and cross-contamination control measures likely contributed to the high levels of bacterial contamination observed, underlining the need for strengthened hygiene control in slaughterhouses.

4.2. Effects of the interventions at slaughterhouses (Paper II)

Hygiene practice scores improved from baseline to endline, accompanied by reductions in TBC, coliforms, and *E. coli*, although effects varied by intervention type. However, *Salmonella* prevalence remained unchanged, likely because score improvements were largely driven by increased water-based washing, which is insufficient for eliminating persistent pathogens on equipment, and critical cross-contaminated practices, such as handling viscera in the same area as carcass splitting, did not improve (Delhalle et al. 2008; Burton et al. 2011; van Hoek et al. 2012). Saenkankam et al. (2025) reported that insufficient hand hygiene during processing can sustain contamination even when other control measures such as HACCP are applied. The ‘Technique’ intervention was associated with more consistent improvements in hygiene practices and reductions in faecal indicator organisms on carcasses and workers’ hands, which is in line with a previous study (Zewude et al. 2025) and suggests that skills-based training can produce relatively stable behavioural change. In contrast, the ‘Incentive’ intervention demonstrated short-term improvements, particularly in TBC, and effects diminished at endline when financial rewards were no longer provided. Improvements were also observed in some non-intervention slaughterhouses, likely reflecting the Hawthorne effect during study activities (Lewis-Beck et al. 2004).

Different microbial outcomes were associated with distinct hygiene practices and were further influenced by infrastructural conditions, slaughterhouse operations, workforce capacity, and environmental factors, at times in opposing directions. Variation in TBC and practice scores was largely attributable to differences at slaughterhouse and provincial levels, whereas *Salmonella* and coliforms contamination predominantly varied at the individual sample level. These patterns highlight the multi-level nature of contamination risks and help to explain why behavioural improvements alone did not consistently translate into reductions in pathogen prevalence.

A limitation in this study was the lack of quality assessment for the water used during slaughter operations. Previous studies have shown that carcasses can become more contaminated after washing when the water itself is microbiologically unsafe (Bello et al. 2011). The absence of water quality monitoring makes it difficult to determine whether washing practices effectively reduce contamination or inadvertently contribute to pathogen spread.

4.3. Impacts of the interventions on pork vendors (Paper III)

4.3.1. Effects on knowledge, perceptions, and practice

The market-level intervention was associated with significant improvements in knowledge regarding viscera handling and causes of contamination, increasing the overall knowledge score by approximately 15% relative to control vendors at the endline. This likely reflects the direct effect of the training and inspection activities delivered at the market level. Previous studies have similarly shown that targeted food safety training can improve vendors' knowledge of hygiene practices and contamination risks, particularly when training focuses on practical handling procedures relevant to daily work (Maung et al. 2017; Lillquist et al. 2005; Nik Husain et al. 2016). The individual-level intervention solely improved knowledge on appropriate display surfaces. Vendors who received equipment were provided with easy-to-clean surfaces that could be used immediately, which likely reinforced awareness of this practice without requiring major behavioural changes.

The combined intervention demonstrated improvements in four of the five knowledge topics, except handwashing. The lack of improvement in handwashing knowledge may reflect structural and behavioural constraints identified in the qualitative findings. Vendors noted limited time during busy selling periods and concern that stopping to their wash hands could delay service and cause customers to move to other stalls. Weak consumer expectations for hand hygiene may also reinforce norms where handwashing during sales is not considered necessary, a barrier which has been reported in other informal food retail settings (Green et al. 2007).

Despite the total knowledge score in the combined effects increasing by approximately 21% compared with control vendors, overall knowledge levels remained limited across all groups at the endline, with most vendors answering only two out of five questions correctly. This suggests that short-term training interventions alone may not be sufficient to substantially improve food safety knowledge in traditional market settings. Sustained behaviour change may require repeated training, supportive infrastructure, and stronger incentives from both regulatory systems and consumer demand.

Whilst adequate food safety knowledge of the food handlers failed to be translated into practice in some cases (Lee et al. 2017; Abdullah Sani and Siow 2014), this intervention was successful in improving food safety perceptions, hardware scores, action scores, and inspection scores in treated vendors. Vendors' perceptions that consumers value food safety when deciding where to purchase pork increased in the market-level intervention. Hardware scores improved in both treatment groups, including among vendors who did not receive equipment, which implies that some vendors acquired equipment independently following the intervention. In contrast, improvements in vendor action scores were predominantly driven by the market-level intervention. The additional effect of providing equipment was smaller and not statistically significant, indicating that changes in practice were primarily associated with the market-level activities rather than the provision of equipment alone. The inspection scores to display in signage, which included elements of both action and hardware scores, improved at all levels and were positively associated with knowledge scores.

4.3.2. Changes in microbiological contamination

Although the intervention improved vendor knowledge, practices, and the availability of food safety equipment, these changes did not translate into reductions in bacterial contamination. Microbiological indicators, including the presence of *Salmonella* in pork samples, remained high following the intervention (Table 5).

Table 5. Microbiological contamination in pork and cutting boards at markets before and after interventions

Indicator		Control		Treatment		Overall	
		BL	EL	BL	EL	BL	EL
<i>Salmonella</i> in cut pork	Number of positive samples (%)	81 (59.1)	124 (74.3)	174 (67.2)	122 (75.8)	255 (64.4)	246 (75.0)
TBC in cut pork (log ₁₀ CFU/g)	mean (sd)	6.2 (1.2)	6.9 (0.7)	6.4 (1.0)	6.8 (0.7)	6.4 (1.1)	6.9 (0.7)
TBC in CB (log ₁₀ CFU/cm ²)	mean (sd)	6.8 (0.9)	6.7 (0.7)	7.0 (0.8)	6.7 (0.8)	6.9 (0.9)	6.7 (0.7)

BL: Baseline. EL: Endline. TBC: Total Bacteria Count. sd: Standard Deviation. CB: Cutting Board.

However, an additional analysis stratified by region indicated that intervention effects on TBC in cut pork were observed in the North. Figure 7 shows that in northern markets the intervention had little effect when baseline contamination was below about 5.5 log₁₀ CFU/g, but produced larger reductions as baseline contamination increased, reaching an approximate 1 log₁₀ CFU/g reduction at the upper end of the baseline range. This suggests that when contamination levels are already relatively low, it becomes difficult for an intervention to further reduce them. This type of pattern is consistent with epidemiological evidence that the absolute benefit of an intervention often increases with a higher baseline risk (Irwig et al. 2008; de Moel-Mandel 2022). In Paper 1, temperature was found to be a strong risk factor for TBC contamination. Whilst baseline samples in the North were collected in winter (9 – 24°C), and endline samples in summer (23 – 34°C), the observed reductions in spite of this seasonal shift therefore support the effectiveness of the intervention in northern markets. In contrast, no clear intervention effect was observed in the South, suggesting that baseline contamination alone does not determine treatment effectiveness. Regional differences in implementation, market practices, or contamination sources along the supply chain may have restricted the impact of the intervention in southern markets.

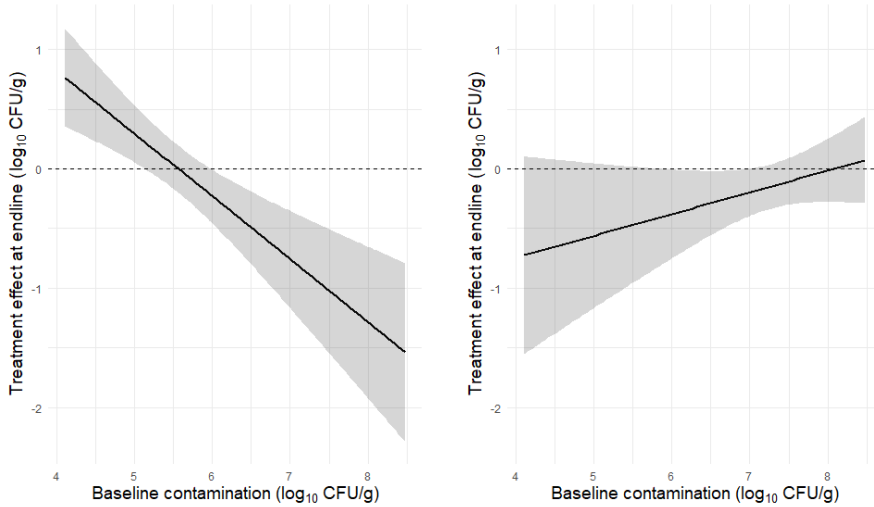


Figure 7. Treatment effects on total bacteria count in cut pork across baseline contamination levels by northern (left) and southern (right) markets.

4.3.3. Impacts to business outcomes

The market-level intervention had a positive impact on vendor revenue, which was predominantly driven by increased sale volumes. Vendors in treatment markets appeared to sell more pork and increased their daily expenditure on stock, whilst pork prices remained static. However, clear changes in cleaning costs, daily net revenue, or monthly profits were not observed. Although the intervention did not lead to a statistically significant increase in monthly profits, the estimates are imprecise and vary considerably across vendors, meaning that positive effects on profits cannot be ruled out. The increase in sales among treated vendors may reflect a shift in market share toward vendors participating in the intervention. Similar effects have been observed when food safety information is disclosed to consumers, leading them to transition toward vendors with better hygiene scorings rather than changes in prices (Jin and Leslie 2003).

4.4. Effects of the interventions on pork consumers (Paper III)

Consumers in treatment markets were more likely to report having received information on safe pork and to perceive lower food safety risks associated

with pork sold at the market than those in control markets. Among consumers whose purchases could be matched with study vendors, those in treatment markets were also more likely to buy from vendors with higher food safety scores. However, the intervention did not affect the quantity or value of purchased pork, nor did it lead consumers to shift purchases across markets or toward alternative protein sources.

Several factors may explain why the scoring system had only a minor influence on consumer behaviour. First, consumers often relied on visible indicators of cleanliness rather than formal scorings, as seen in the findings from the qualitative results. Second, long-standing relationships between vendors and customers reinforced habitual purchasing patterns, reducing incentives to compare vendors based on formal scores. Similar patterns have been reported in previous studies in Vietnam (Ha et al. 2019b; Wertheim-Heck et al. 2014). Third, the effectiveness of scoring systems depends on public trust in the institutions producing them. In contexts where corruption or bribery in food safety inspection is thought to occur, official scorings may lose credibility and have limited influence on consumer behaviour (Van Hoi et al. 2009; UNODC 2023). Moreover, consumers and vendors in traditional markets may be less accustomed to using formal scoring systems or aggregated reviews when making purchasing decisions. Limited understanding of foodborne risks among consumers may also reduce the demand for safer handling practices (Le et al. 2022). In this context, the intervention appears to have influenced perceptions and vendor choice to some extent by making food safety improvements more visible in treatment markets. However, changing deeply embedded purchasing routines and beliefs about food safety will likely require repeated and longer-term engagement. Strengthening communication strategies that increase consumer awareness and demand for safer pork may therefore be necessary to reinforce incentives for vendors.

4.5. One Health perspective

The findings of this thesis highlight the importance of a One Health perspective for addressing food safety risks in small-scale pork supply chains. Persistent contamination with pathogens such as *Salmonella* represents a direct pathway for zoonotic transmission from animals to humans through pork consumption. The interventions examined in this thesis

targeted key stages of the pork supply chain and involved multiple actors, including slaughterhouse workers, market managers, market vendors, consumers, and local authorities responsible for food safety management. By engaging stakeholders at different levels of the supply chain and governance system, the interventions were able to demonstrate the potential for coordinated actions to improve food safety in traditional food systems.

A limitation is that microbiological results from slaughterhouses could not be directly linked to specific markets supplying pork to those locations due to logistical, resource, and time constraints. However, random sampling and a relatively large sample size ensured regional representativeness. The findings suggest a general increase in microbial contamination from slaughterhouses to markets, indicating bacterial growth and cross-contamination along the supply chain. Transportation practices, which the interventions did not address, may represent an important source of contamination, as pork is commonly transported without temperature control or adequate hygiene in traditional supply chains in Vietnam (Dang-Xuan et al. 2016; Ting et al. 2023). In addition, although environmental factors such as temperature and humidity were considered, water quality, which constitutes an important potential source of contamination during carcass washing and handling, was not assessed. These gaps limit the ability to fully identify contamination pathways along the supply chain and should therefore be addressed in future studies.

Moreover, the study demonstrates that intervention outcomes are strongly shaped by structural and socio-economic conditions. In small-scale slaughterhouses, behavioural improvements were often constrained by infrastructural limitations such as water supply, facility layout, and workflow organisation. These findings support previous reviews that highlight the need for stronger regulatory frameworks, enforceable hygiene standards, and institutional oversight in slaughterhouse operations. At the same time, economic pressures, social norms, and market competition influenced the adoption of hygiene practices among vendors and workers, indicating that behavioural interventions may have a greater impact when combined with supportive structural and policy measures (Grace 2015; Hossain et al. 2025).

A key strength of this thesis is the integration of microbiological assessments, behavioural observations, intervention trials, and qualitative analyses across different points of the pork supply chain. Direct observation methods were used to assess hygiene practices, thereby addressing the

limitations of self-reported behaviours that may be affected by social desirability bias (Young et al. 2016). Furthermore, the inclusion of gender considerations in training design and qualitative research helped to capture the different roles that men and women perform during slaughtering, meat handling, and market retail, and targeted the right actors for inclusion in training. By combining quantitative and qualitative approaches, the study provides policy-relevant evidence on how behavioural, environmental, and institutional factors interact to influence food safety outcomes, emphasising the need for integrated One Health strategies to sustainably reduce foodborne risks in informal food systems.

5. Conclusions

This thesis evaluated the effectiveness of interventions in improving pork safety at pig slaughterhouses and traditional markets in Vietnam. A key strength of this thesis is the use of rigorous experimental designs, including a controlled trial at the slaughterhouse level and a randomised controlled trial at the market level. This provides stronger causal evidence on intervention effectiveness than much of the existing literature. This thesis also provides new evidence from Vietnam regarding the implementation of inspection and disclosure-based interventions across both slaughterhouses and markets, including their economic impacts on vendors. The main conclusions that can be drawn from the results presented in this thesis are as follows:

- The level of microbiological contamination (e.g. TBC, *Salmonella*) remained high at both slaughterhouse and market levels, with patterns suggesting potential amplification along the chain. The risks likely originate upstream in the chain and are compounded by structural constraints, including limited cold chain capacity, inadequate water quality, and suboptimal hygiene infrastructure.
- Hygiene practices among actors at both stages were generally inadequate. Food safety practices are embedded in local perceptions, trust-based relationships, and structural constraints, indicating that interventions must go beyond technical training and address socio-cultural norms and market dynamics to achieve sustained behavioural change.
- At slaughterhouses, providing equipment and interactive training rapidly improved workers' hygiene practices. Incentive-based intervention led to temporary improvements but requires continued follow-up to achieve lasting effects. At markets, improved vendors' food safety knowledge and practices was seen to increase the volume of sales in response to this intervention.
- Interventions can change actors' behaviour and perceptions, but this does not translate into reductions in microbiological contamination. Microbial contamination appears to be influenced by multiple factors along the chain, including slaughterhouse and market infrastructure, environmental conditions, and social perspective.

- Consumer awareness and risk perception showed limited responsiveness to the intervention, and purchasing behaviour remained largely driven by habit, price, and existing relationships rather than food safety considerations. More intensive outreach to consumers than a light-touch campaign conducted as part of the intervention is necessary to meaningfully stimulate a demand for safer food.

This thesis built on a pilot study and advanced it by implementing interventions designed for scalability from the outset. The technique intervention was subsequently scaled up, whilst the incentive component provided formative insights into implementation under field conditions. Unlike many pilot interventions conducted under controlled conditions, this research implemented and evaluated interventions across multiple provinces, offering practical evidence on scalability, implementation challenges, and context-dependent effectiveness. By moving beyond highly controlled pilot settings, the thesis highlights the importance of multidisciplinary collaboration and the additional capacities required to translate interventions into real-world food systems at scale.

These findings are particularly timely in the context of ongoing food safety governance reforms in Vietnam. As the revision of the Vietnam Food Safety Law is currently under discussion, the evidence generated by this thesis supports the transition towards more risk-based food safety management approaches, focusing resources on high-risk stages of the supply chain, such as slaughterhouses and traditional markets. The results may also inform emerging institutional initiatives, including the establishment of the Vietnam Center for Food Safety Risk Assessment (under the National Institute for Food Control) and the Food Safety Technical Working Group (under the One Health Partnership framework).

6. Implications for policy, scalability, and future adoption

The findings of this thesis indicate that sustainable improvements in food safety require integrated strategies that combine behavioural interventions with structural upgrades, regulatory enforcement, and control of environmental contamination pathways within a One Health framework.

Whilst training and incentive-based interventions improved hygiene practices, their effects were not sustained without continued reinforcement. This highlights the need to embed follow-up assessments within routine inspection systems and strengthen the capacity of local inspection authorities. Combining regular inspections with public display of hygiene ratings at market stalls could help to maintain improvements by encouraging vendors to continue following good practices. To enhance long-term adoption, future programmes should consider co-investment mechanisms, as full external provision of equipment may limit ownership and sustainability. Strengthening consumer demand for safer food is also critical. In the era of digitalisation and widespread access to information, communication strategies should focus on trusted channels such as local television, official social media platforms, and market-based communication systems, whilst also urging market managers to play a more active role. Integrating food safety with nutrition education, particularly through schools, may further support long-term behavioural change.

At the same time, public investment in infrastructure is essential. Improving access to clean water and sanitation at market stalls and in slaughterhouses should be prioritised in food safety policy, as behavioural improvements alone are unlikely to reduce microbiological contamination. Future interventions should also address contamination pathways between slaughterhouses and markets, including transport conditions, disinfection measures and water quality, which were not fully captured in this study. Although changes in hygiene practices did not immediately translate into reduced microbiological risk, they represent important intermediate outcomes and should be considered alongside microbiological indicators when evaluating intervention success. In resource-constrained settings, cost-effective monitoring systems that combine observational assessments with targeted microbiological testing are needed.

To conclude, effective scale-up requires alignment with local institutional capacity and governance systems. Clear communication of both intermediate and long-term benefits to policymakers is important to support resource allocation and policy adoption. Combining regulatory measures, market-based incentives, and consumer engagement may help to create sustained food safety improvements within traditional pork supply chains.

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Popular science summary

Foodborne diseases cause major health and economic problems around the world, especially in low- and middle-income countries such as Vietnam. Foods from animals account for about 35% of this disease burden. Many consumers are concerned about chemical risks, such as the misuse of additives and preservatives, which may lead to serious long-term health effects such as cancer. However, research in Vietnam shows that the risk from bacterial contamination is much higher and more immediate than people often think. Recent food poisoning outbreaks show that bacteria are responsible for hundreds of cases, with many people requiring hospital care. One study estimated that about 1–2 out of 10 pork consumers in Vietnam may be at risk of *Salmonella* infection each year.

Pork is one of the most consumed foods in Vietnam. Studies throughout the past decade show high levels of bacterial contamination along the pork supply chain. Slaughterhouses and traditional markets are key points where contamination increases due to poor hygiene practices. In slaughterhouses, pigs are often processed directly on the floor, without clean and dirty areas being separated. In markets, vendors frequently use cardboard or cloth to display meat, rarely wash their hands with soap, and often lack clean water and disinfectants. These practices allow bacteria to grow and increase the risk of cross-contamination between clean and contaminated products. These problems are partly due to limited knowledge and practice among people working along the pork supply chain, but they are also accepted because consumers often do not demand high food safety standards. In addition, food safety management faces challenges due to overlapping responsibilities between government agencies and limited resources at the local level.

To address these issues, we carried out interventions to improve the hygiene practices of slaughterhouse workers and market vendors, with the goal of reducing bacterial contamination and protecting consumer health. The interventions focused on three main approaches. First, we worked closely with local authorities and market managers to involve them in the design and implementation of the activities. They also helped to encourage, monitor, and sustain better hygiene practices. Second, we improved knowledge and skills through training and by providing simple, low-cost equipment. The training addressed common misunderstandings, such as the belief that cardboard or cloth is “good for meat,” when in fact it increases

contamination risk. We also provided practical tools such as stainless-steel grids to avoid slaughtering on the ground, easy-to-clean surfaces for displaying meat, trays to separate different types of meat, disinfectants, and handwashing containers with spigots. Third, we encouraged voluntary behaviour change instead of relying on penalties. This was done through visual communication and by publicly recognising good practices, for example by scoring or star scoring systems. This helped vendors to see that better hygiene could attract more customers and increase their income, creating motivation for lasting change.

These simple and low-cost interventions clearly improved knowledge and hygiene practices among slaughterhouse workers and vendors. However, bacterial contamination in pork remained very high, demonstrating that behaviour change alone is not enough to reduce risks to consumers. On average, *Salmonella* was found in about 30% of samples at slaughterhouses and up to 75% at traditional markets. The findings show that food safety does not solely depend on those handling pork, but is influenced by many factors, including infrastructure, environmental conditions, how the supply chain is organised, and consumer habits. To achieve lasting improvements, more comprehensive solutions are needed. These should combine better infrastructure, stronger government management, and increased consumer awareness to create demand and market pressure for safer food.

The thesis also shows that there is no single solution that works for all locations. Interventions must be adapted to local conditions and involve local authorities and other stakeholders. The evidence from this research can help to inform policies and support the scaling up of effective interventions to reduce foodborne disease in Vietnam.

Populärvetenskaplig sammanfattning

Livsmedelsburna sjukdomar orsakar stora hälsoproblem och ekonomiska förluster världen över, särskilt i låg- och medelinkomstländer som Vietnam. Livsmedel från djur utgör ungefär 35 procent av den totala sjukdomsörskadan. Många konsumenter i Vietnam oroar sig för kemiska risker, till exempel felaktig användning av tillsatser och konserveringsmedel, som kan ge allvarliga långsiktiga effekter som cancer. Forskning i Vietnam visar dock att risken att bli sjuk av bakterier i livsmedel är betydligt större än många tror. Utbrott av matförgiftningar orsakade av bakterier kan omfatta hundratals sjukdomsfall, där många behöver sjukhusvård. En studie uppskattar att ungefär en till två av tio personer, per år, som äter griskött i Vietnam riskerar att smittas av *Salmonella* bakterier

I Vietnam är griskött ett av de vanligaste livsmedlen. Studier från det senaste årtiondet visar att förekomsten av bakterier är hög längs hela kedjan från produktion till konsumtion. Slakterier och traditionella marknader är särskilt kritiska punkter, där smittspridningen ofta är hög på grund av bristande hygien. I slakterier hanteras djuren och slaktkroppar oftast direkt på golvet, utan att rena och orena områden hålls åtskilda. På marknader är det vanligt att kött läggs på kartong eller tyg, de som hanterar kött och pengar tvättar sällan händerna med tvål och tillgången till rent vatten och desinfektionsmedel är begränsad. Sådana förhållanden gör att bakterier lätt sprids mellan olika ytor och produkter. Problemen beror delvis på bristande kunskap om livsmedelssäkerhet hos dem som arbetar i kedjan, men också på okunnighet hos konsumenterna. Dessutom försvåras arbetet av att ansvaret för livsmedelssäkerhet delas mellan flera myndigheter och att resurserna på lokal nivå är begränsade.

För att förbättra situationen utvärderade vi olika åtgärder för att minska spridning av bakterier riktade till slakteriarbetare och försäljare på traditionella marknader. Målet var att minska bakterieförekomsten, inklusive sjukdomsorsakande bakterier, och därmed skydda konsumenternas hälsa. Åtgärderna byggde på tre huvudprinciper. För det första samarbetade vi nära med lokala myndigheter och marknadsansvariga, som deltog i planering och genomförande samt bidrog till att följa upp och uppmuntra bättre hygienrutiner. För det andra stärkte vi kunskap och praktiska färdigheter genom utbildning och genom att tillhandahålla enkel och billig utrustning. Utbildningen tog upp vanliga missuppfattningar, till exempel att placera kött

på kartong eller tyg skulle vara "bra för köttet", trots att det i själva verket ökar risken för bakteriespridning. Vi tillhandahöll också upphöjda galler i rostfritt stål för att undvika slakt på marken, lätt rengörbara ytor där kött kan förvaras vid försäljning, olika förvaringskärl för att separera olika typer av kött, desinfektionsmedel samt möjlighet att tvätta händerna. För det tredje uppmuntrade vi till beteendeförändringar i stället för att använda tvingande åtgärder. Det gjordes bland annat genom tydlig information och genom att lyfta fram goda exempel, till exempel genom belöningsystem. Detta visade att bättre hygien i marknadsstånden lockade fler kunder och ökade inkomsterna.

De enkla och kostnadseffektiva åtgärderna förbättrade kunskap och hygienrutiner hos både slakteriarbetare och försäljare. Trots detta var bakterieförekomsten i köttet fortsatt mycket hög. I genomsnitt påvisades *Salmonella* i cirka 30 procent av proverna från slakterier och i upp till 75 procent av proverna från marknader. Resultaten visar att det inte räcker att enbart förändra beteenden. Livsmedelssäkerhet påverkas av många faktorer, såsom infrastruktur, miljöförhållanden, hur livsmedelskedjan är organiserad och konsumenternas vanor. För att uppnå varaktiga förbättringar behövs mer omfattande insatser. Dessa bör omfatta förbättrad infrastruktur, tydligare styrning från myndigheter och ökad medvetenhet hos konsumenter, så att efterfrågan på säker mat ökar.

Denna avhandling visar också att det inte finns någon lösning som fungerar överallt. Åtgärder behöver anpassas till lokala förhållanden och genomföras i samarbete med lokala aktörer. Resultaten från denna forskning kan bidra till att utveckla policyer och stödja en bredare implementering av effektiva åtgärder för att minska livsmedelsburna sjukdomar i Vietnam.

Tóm tắt nghiên cứu

Các bệnh lây truyền từ thực phẩm gây ra thiệt hại lớn về sức khỏe và kinh tế trên toàn cầu, đặc biệt là ở các nước thu nhập trung bình và thấp như Việt Nam. Thực phẩm có nguồn gốc động vật chiếm khoảng 35% gánh nặng bệnh tật này. Người tiêu dùng vẫn lo ngại về các mối nguy hóa học (bao gồm việc lạm dụng các chất phụ gia và chất bảo quản) gây ra ảnh hưởng nghiêm trọng đến sức khỏe như ung thư, nhưng những nghiên cứu trong nước cho thấy nguy cơ đến từ ô nhiễm vi sinh vật có tác động nhanh và lớn hơn nhiều so với nhận thức hiện tại. Các vụ ngộ độc thực phẩm gần đây cho thấy vi khuẩn là nguyên nhân gây ra hàng trăm ca bệnh, khiến nhiều trường hợp phải nhập viện. Một nghiên cứu ước tính có khoảng 1–2 trong 10 người tiêu dùng thịt lợn tại Việt Nam có nguy cơ bị ngộ độc do *Salmonella* mỗi năm.

Tại Việt Nam, thịt lợn là món ăn phổ biến đối với người dân. Các nghiên cứu trong thập kỷ qua cho thấy tỷ lệ ô nhiễm vi sinh cao dọc theo chuỗi thịt lợn, trong đó cơ sở giết mổ và chợ truyền thống là những địa điểm chính nơi nguồn ô nhiễm tăng lên do thực hành vệ sinh không đảm bảo. Tại các cơ sở giết mổ, việc giết mổ chủ yếu được thực hiện trực tiếp trên sàn và không có sự phân tách giữa khu vực sạch và bẩn. Ở chợ, tiêu thương hay sử dụng tấm giấy bìa, vải để bày bán thịt, ít rửa tay bằng xà phòng, thiếu nước sạch và chất khử trùng. Tất cả những thực hành này tạo điều kiện cho vi khuẩn phát triển và dẫn đến nguy cơ lây nhiễm chéo giữa các sản phẩm ô nhiễm và chưa ô nhiễm. Những hạn chế này một phần do kiến thức, nhận thức và thực hành chưa đầy đủ của người lao động trong chuỗi. Những thực hành này được chấp nhận do yêu cầu tiêu chuẩn vệ sinh chưa cao từ phía người tiêu dùng. Bên cạnh đó, công tác quản lý vẫn gặp nhiều khó khăn do sự chồng chéo về phân công nhiệm vụ giữa các bộ ngành dọc theo chuỗi và hạn chế về nguồn lực tại địa phương.

Để cải thiện tình hình, chúng tôi đã triển khai các can thiệp nhằm thay đổi thực hành của người giết mổ và tiêu thương, với mục tiêu giảm ô nhiễm vi sinh và bảo vệ sức khỏe cho người tiêu dùng. Các can thiệp tập trung vào ba nhóm giải pháp chính. Thứ nhất là hợp tác chặt chẽ với chính quyền địa phương và ban quản lý chợ để họ cùng tham gia vào quá trình thiết kế và triển khai can thiệp, đồng thời đóng vai trò thúc đẩy, giám sát và duy trì các thay đổi trong thực hành vệ sinh. Thứ hai là nâng cao năng lực thông qua tập huấn và cung cấp các dụng cụ chi phí thấp nhưng thiết thực. Các buổi tập huấn tập trung vào những hiểu lầm phổ biến tại địa phương, như quan niệm

cho rằng bìa các-tông hay vải là “tốt cho thịt”, trong khi thực hành này làm gia tăng nguy cơ nhiễm vi khuẩn. Một số dụng cụ được cung cấp bao gồm tấm sàn inox để tránh giết mổ trên nền đất tại cơ sở giết mổ, mặt bàn để lau rửa và sát trùng, khay để phân tách riêng thực phẩm, dung dịch sát trùng, bình nước có vòi để dễ rửa tay tại quầy. Thứ ba là khuyến khích thay đổi hành vi một cách tự nguyện thay vì dựa vào xử phạt, thông qua truyền thông trực quan và các hình thức ghi nhận thực hành tốt (ví dụ chấm điểm, gắn sao công khai) giúp người bán thấy rằng thực hành vệ sinh tốt thu hút thêm khách hàng và tăng thu nhập. Cách tiếp cận này giúp tạo động lực tích cực, từ đó duy trì thay đổi hành vi một cách bền vững hơn.

Những can thiệp đơn giản và chi phí thấp đã giúp cải thiện rõ rệt kiến thức và thực hành vệ sinh của người giết mổ và tiểu thương. Tuy nhiên, mức độ ô nhiễm vi sinh trong thịt lợn vẫn còn rất cao, cho thấy thay đổi hành vi thôi là chưa đủ để giảm nguy cơ sức khỏe cho người tiêu dùng. Tỷ lệ *Salmonella* trung bình là 30% tại các cơ sở giết mổ và lên tới 75% tại các chợ truyền thống. Kết quả nghiên cứu nhấn mạnh rằng an toàn thực phẩm không chỉ phụ thuộc vào người giết mổ, tiểu thương, mà còn bị chi phối bởi nhiều yếu tố khác như điều kiện hạ tầng, môi trường, tổ chức chuỗi cung ứng và cả thói quen lựa chọn của người tiêu dùng. Do đó, để cải thiện bền vững, cần có các giải pháp đồng bộ hơn, kết hợp giữa nâng cấp cơ sở vật chất, tăng cường quản lý nhà nước và nâng cao nhận thức của người tiêu dùng để tạo ra nhu cầu và áp lực thị trường đối với thực phẩm an toàn.

Kết quả nghiên cứu cũng cho thấy không có một mô hình can thiệp chung cho tất cả các địa phương. Các giải pháp cần được thiết kế linh hoạt, phù hợp với điều kiện thực tế của từng nơi, đồng thời cần có sự tham gia của chính quyền địa phương và các bên liên quan. Những bằng chứng từ nghiên cứu này có thể làm cơ sở để xây dựng chính sách và mở rộng các mô hình can thiệp hiệu quả nhằm giảm nguy cơ bệnh truyền qua thực phẩm tại Việt Nam.

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Appendix

Appendix I: Checklist to assess hygienic practices at pig slaughterhouse

SH ID: Starting Time:h.....

Date (dd/mm/yyyy):/...../..... Checker's name:

Village:Commune: Province:

A. General information (Ask the owner)

1. How many **pigs** do you slaughter today?.....pigs
2. How many **labors** working in your slaughterhouse **today**? Male / Female

Permanent (Main workers)		Regular (Retailer)		Occasional (workers, not including retailers)		Note
Female	Male	Female	Male	Female	Male	

3. Main water source used for slaughter (washing carcass):
 - a. Tap water
 - b. Well water
 - c. Others (details).....

B. General assessment

No.	Practice	Y	N	No assess (reason)
1	Assessment BEFORE slaughtering			
1	Pig in lairage is clean, no feces (<i>Take picture on observation day</i>)			
2	There is fixed faucet to wash hands, equipment			
3	There is soap/detergent for washing hands and slaughtering tools (e.g. knife)			
4	There is disinfectant to disinfect hands and slaughtering tools (e.g. knife)			
5	There is foot bath with disinfection liquid before entering to SH area			
6	People are not allowed to enter freely without cleaning and disinfection (apply for both workers, guests, owners)			
7	There is easy to drain grid to slaughter pig			

II	Assessment DURING slaughtering			
8	There is specific place for bleeding and/or scalding (dirty area)			
9	There is specific place for evisceration			
10	Evisceration area is separated from bleeding and scalding area (dirty area).			
11	There is specific place to split half the carcasses (<i>NA if it is not the practice at the SH</i>)			
12	Workers do not move freely from bleeding and scalding area (dirty) to evisceration area (clean) during slaughter			
13	If you choose no in question 23 above: The workers clean hands and protective equipment when moving from dirty (e.g. bleeding/evisceration area) to clean area a. Soap b. Water c. Disinfected 0. No			
14	To dehairing, pig was: a. Dipped into hot water tank b. Poured hot water by kettle c. Both			
15	Carcasses are washed by: a. Direct water from pipe b. Water from the tank/container c. Both			

C. Slaughter practice observation table (for each sampled pig – total 6 pigs)

Number of group/households involved in slaughter:

No	Practice/Content	1	2	3	4	5	6
1	Time start observing (pig to be led to slaughter line) (hh:mm)						
2	Slaughtered pig belongs to which group number... (<i>enumerator set group number</i>)						
3	The number of workers take part in slaughter (<i>From the beginning of leading pigs into bleeding until transport out of the slaughterhouse</i>)						
4	Number of workers wear boots						
5	Number of workers clean hands with soap or disinfectant before slaughtering						
6	The number of workers clean boots with soap or disinfectant before slaughtering						
14	Pigs were bleeding on a high table/ floor						
15	Pig is not dirty while bleeding (no fecal on body)						
16	Pig was cleaned with cold water before scalding						
17	Workers who do bleeding and scalding are different from those do subsequent slaughter stages						



Pork safety across Vietnam's traditional markets: Microbial contamination and vendor knowledge, attitudes, and practices

Trang Thi Huyen Le^{a,b,*}, Vivian Hoffmann^{c,g}, Kate Ambler^c, Mike Murphy^c, Sinh Dang-Xuan^b, Johanna F. Lindahl^{d,f}, Elisabeth Rajala^a, Steven Lâm^e, Sofia Boqvist^a, Fred Unger^b, Hung Nguyen-Viet^e

^a Department of Animal Biosciences, Swedish University of Agricultural Sciences, Uppsala, Sweden

^b International Livestock Research Institute, Hanoi, Vietnam

^c International Food Policy Research Institute, Washington, DC, USA

^d Swedish Veterinary Agency, Uppsala, Sweden

^e International Livestock Research Institute, Nairobi, Kenya

^f Department of Medical Biochemistry and Microbiology, Uppsala University, Uppsala, Sweden

^g Carleton University, Ottawa, Canada

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ABSTRACT

Foodborne diseases are a major cause of illness in low- and middle-income countries, and most are due to fresh foods sold in traditional markets. Contamination with foodborne pathogens, especially *Salmonella* spp., continues to be common in these markets. To better understand why this is the case, this study assessed total bacteria count (TBC) and *Salmonella* in pork across Vietnamese traditional markets and evaluated vendors' food safety knowledge, attitudes, and practices, examining their associations with contamination. Data was collected in 68 markets across five provinces, with up to 10 pork vendors per market randomly selected. Microbiological data were collected through cut pork samples and cutting boards swabs ($n = 396$), along with structured questionnaires and observations with vendors ($n = 486$). Cutting board swabs were analyzed for TBC only, while cut pork was tested for both TBC and *Salmonella*. Linear and generalized linear mixed-effects models were constructed to identify risk factors for TBC and *Salmonella* prevalence. The overall *Salmonella* prevalence in cut pork was 64.4% (255/396) and was significantly higher in southern provinces (86.8%) compared to the north (47.5%, $p < 0.01$). TBC was high in pork and cutting boards (6.4 \log_{10} CFU/g and 6.9 \log_{10} CFU/cm², respectively), and only 30% of the pork samples met the Vietnamese standard for TBC in fresh meat. Selling of organs was associated with a higher TBC (coefficient = 0.13, CI: 0.01–0.26, $p = 0.03$) and greater *Salmonella* risk (OR = 2.04, $p = 0.009$). Temperature significantly increased both outcomes ($p < 0.001$), while using easy-to-clean surfaces reduced TBC levels (coefficient = -0.16, CI: -0.30 to -0.01, $p = 0.03$). Vendors demonstrated limited food safety knowledge and mixed attitudes. Observations revealed poor hygienic practices, such as displaying pork on cardboard or cloth or lack of washing with soap and disinfectants, which was influenced by limited access to facilities and equipment. Regional differences suggested contamination levels were influenced by both environmental and market-related factors. These findings highlight the need for holistic interventions targeting an enabling environment, appropriate equipment, and behavioral incentives.

1. Introduction

Foodborne diseases (FBDs) pose a substantial global health and

economic burden. In low- and middle-income countries (LMICs), FBDs were responsible for approximately 600 million illnesses and 420,000 deaths (Havelaar et al., 2015) along with an economic loss estimated at

* Correspondence to: Department of Animal Biosciences, Swedish University of Agricultural Sciences, Almas Allé 8, Uppsala 750 07, Sweden.

E-mail addresses: trang.thi.huyen.le@slu.se, t.le@cgiar.org (T. Thi Huyen Le), V.Hoffmann@cgiar.org (V. Hoffmann), K.Ambler@cgiar.org (K. Ambler), M.Murphy@cgiar.org (M. Murphy), S.Dang@cgiar.org (S. Dang-Xuan), johanna.lindahl@sva.se (J.F. Lindahl), Elisabeth.Rajala@slu.se (E. Rajala), S.Lam@cgiar.org (S. Lâm), sofia.boqvist@slu.se (S. Boqvist), F.Unger@cgiar.org (F. Unger), H.Nguyen@cgiar.org (H. Nguyen-Viet).

¹ International Livestock Research Institute, 298 Kim Ma Street, Ba Dinh District, Hanoi, Vietnam.

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US\$115 billion annually (Jaffee et al., 2019). Beyond these direct impacts, FBDs are associated with malnutrition, gender inequality, and the emergence of infectious diseases (Grace, 2023). Animal-source food (ASF) often carries a wide range of foodborne pathogens, including *Salmonella*, *Campylobacter*, Shiga toxin-producing *Escherichia coli*, and *Listeria monocytogenes*, and the consumption of compromised ASF contributes immensely to the overall FBDs burden (Heredia and Garcia, 2018; Li et al., 2019).

Traditional markets play a crucial role in Southeast Asia, serving as primary sources of fresh ASF, enhancing local economies, and preserving cultural food practices (WHO, 2023, 2006). In Vietnam, pork is the most consumed ASF, predominantly sold through traditional retail markets. These markets are characterized by stalls located near residential neighborhoods, where a variety of fresh foods are sold in an open environment with limited oversight and weak enforcement of food safety regulations (Nga et al., 2015; USDA, 2020). Despite their importance in local food systems and livelihoods, traditional markets often lack essential food safety infrastructure, such as cold chains, standardized hygiene practices, regular inspection, and product traceability (Dang-Xuan et al., 2016; Nga et al., 2015).

Studies over the past two decades have documented a concerning increase in *Salmonella* contamination in pork at the traditional retail level, from approximately 40 % between 2007 and 2015 to over 60 % in the following years (Takeshi et al., 2009, Thai et al., 2012, Dang-Xuan et al., 2019, Nhung et al., 2018, Ngo et al., 2021, Vu et al., 2021). Evidence suggested that over half of the *Salmonella* found in pork originated from contamination during slaughter (Yokozawa et al., 2016), followed by market level conditions (Nguyen-Viet et al., 2022; Wallace et al., 2022). However, there has been a lack of relevant studies covering the different regions of Vietnam. Most studies focused on the southern region, emphasizing targeted sampling and antibiotic resistance (Phan et al., 2005, Van et al., 2007, Vu et al., 2021), or covering a small sample size such as 22 pork samples (Nhung et al., 2018). Studies on practices and risk factors have been conducted in the north but did not focus on knowledge or attitudes, or how these translate into vendor food safety practices (Dang-Xuan et al., 2019; Ngo et al., 2023, 2021; Thai et al., 2012; Yokozawa et al., 2016).

A national action plan on food systems transformation toward transparency, responsibility, and sustainability has recently been launched in Vietnam, with a key priority to improve food safety for consumers in the direction of integrating resources and through motivational mechanisms and policies (Prime Minister, 2023). To date, implementation has largely focused on developing detailed action plans and monitoring frameworks. There is now a timely need for practical interventions at the market level to inform this plan and accelerate the pace of the transformation. Furthermore, low-cost interventions, which combining feasible infrastructure upgrades to pork stalls, training, and a creation of an enabling environment, have been recently piloted and showed promise in improving food safety situations at a small scale (Ngo et al., 2023). Building a deeper understanding of food safety perceptions and practices across different contexts in Vietnam could help interventions move beyond a pilot scale.

To bridge this knowledge gap, this study aimed to: i) assess TBC and the presence of *Salmonella* in pork sold at traditional markets across different regions of Vietnam and identify associated risk factors; and ii) evaluate pork vendors' food safety knowledge, attitudes, and practices and examine the association between them. In doing so, this study provides evidence linking human behavioral factors with microbiological outcomes. Such evidence can guide targeted interventions to promote safer behaviors and reduce foodborne risks in traditional retail settings in Vietnam. The findings may offer valuable insights for other Southeast Asia countries where similar traditional market systems are prevalent.

2. Material and methods

2.1. Study design

This study was designed as a cross-sectional survey, as part of a larger randomized controlled trial that compared the prevalence of *Salmonella* in pork from vendors in treatment and control groups. The present analysis used data collected during the baseline phase (October - December 2023) and included vendor observations, interviews, and microbiological sampling at pork stalls.

To detect a minimum 15 % difference in *Salmonella* prevalence between baseline and endline, a sample size of 68 markets and 340 vendors (i.e., 5 vendors per market \times 34 markets \times 2 groups: treatment and control) was calculated to acquire 80 % power at a 95 % confidence level, assuming a within-market correlation of 0.2. To allow for potential loss to follow-up, the sample size in the treatment group was doubled (i.e., up to 10 vendors per market \times 34 markets), while the control group remained the same (up to 5 vendors per market \times 34 markets).

2.2. Market and vendor selection and data collection

The study was conducted in five provinces across Vietnam, covering the north (Thai Nguyen, Hanoi), central (Thua Thien Hue), and south (Can Tho, Dong Nai) regions (Fig. 1). The north and central experience a wide temperature range, between 28 – 36°C in the summer and 10 – 15°C in the winter, while the south remains warm and humid all year round, within 25 – 35°C. Dong Nai and Hanoi have the largest pig farming operations in Vietnam, contributing approximately 15 % (approximately 738,000 tons) of the country's total live pig output in 2023. Although the combined output from the other three provinces is less than 1 %, pig farming remains a key sector across all of Vietnam (GSO, 2023).

Markets in each province were initially screened from the lists provided by provincial authorities based on the following criteria: (i) between 8 and 30 pork vendors are regularly present at the market; (ii) the market has a permanent structure; and (iii) groundwater is available at the market. After the first screening round, 90 eligible markets were identified for a pork vendor census. During the census round, market managers were consulted regarding their willingness to support the study activities. Then, data were collected on vendor name, contact information, stall location/number, days of operation, and source of pork. From the 90 eligible markets, 68 markets were randomly selected for inclusion in the study. Vendors were randomly drawn in each market, with a backup list prepared if any vendors declined to participate.

Data collection comprised four steps.

Discreet observations

Initially, discreet observations were conducted early on the sampling day for around 10 min. Enumerators either observed vendors from a distance or posed as customers, purchasing at least raw pork from each vendor. For vendors offering multiple types of products (raw meat, viscera, and cooked meat), raw meat and either viscera or cooked meat were purchased in the order of viscera, raw meat, and cooked meat, depending on their availability at the time of observation, to assess the cleaning practice between different product types. Vendors were discreetly observed to assess their practices for cleaning and displaying pork and pork products at their stalls. Once the discreet observation was completed, the research team disclosed this to the vendors and subsequently collected hand and knife swabs to measure their cleanliness, using a photo-based scale.

Structured questionnaire

Following the discreet observations, a structured questionnaire was administered to vendors, focusing on food safety conditions and knowledge, as well as business cost and revenue (the latter not discussed in this paper), lasting around 40 min.

Microbiological sampling

At the same time, the research team collected microbiological

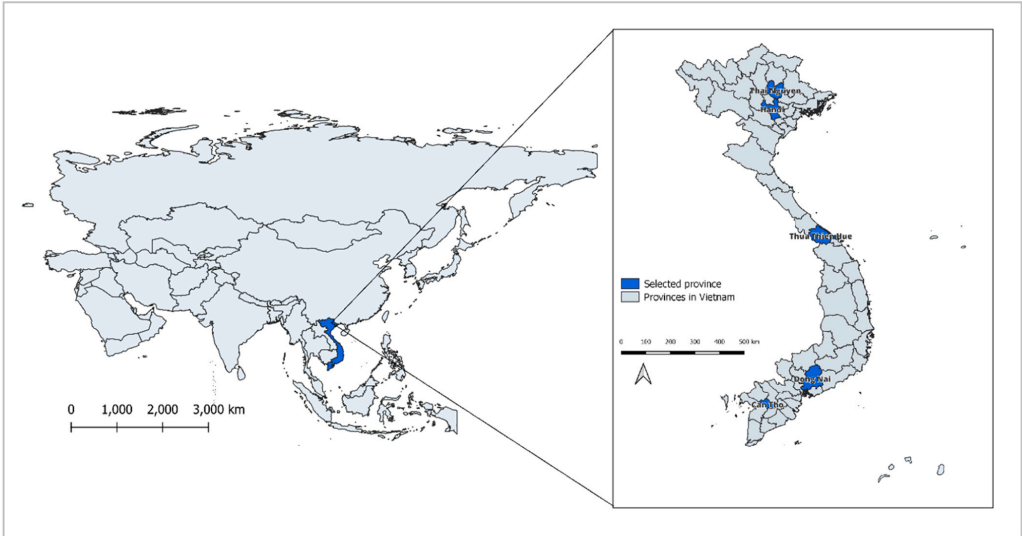


Fig. 1. Map of the Asia continent (left) with Vietnam marked in blue and a map of Vietnam (right) with five selected provinces marked in blue. (Source: qGIS3.28.1).

samples at each stall. Swab samples from cutting boards were collected in accordance with ISO 17604:2015 guidelines, using a pre-moistened sterile cotton gauze to swab a 10×10 cm area (100 cm^2 per sample). For cut pork samples, vendors were asked to cut 2–3 small pieces (totaling 200–300 g) from various parts of the pork, ensuring a representative sample that included skin, fat, and lean tissues, while excluding organs such as the heart, liver, and intestines. This part lasted around 30–60 min.

Direct observations

Direct observation was employed for 30 min at each stall after the interviewing phase, using similar criteria with discreet observations and added frequencies of observed practice.

The structured questionnaire and observational forms were developed by the research team to capture vendors' food safety knowledge, attitudes, and practices, as well as market hygiene conditions and business characteristics (Supplementary file 1). Their content was based on the study objectives and the research team's field experience, and it was reviewed by food safety experts for content validity. The entire process (including observations, sampling and interview) was pre-tested twice in Thai Nguyen and Can Tho. All enumerators received in-person training and participated partially in pilot studies. All interviews were conducted in Vietnamese.

2.3. Laboratory testing

All samples were transported in insulated cool boxes with frozen freezer blocks and were processed as soon as they were received at the local laboratories, except in some cases when samples could not be analyzed immediately and were stored in a refrigerator and analyzed within one day. Cutting boards were exclusively sampled for total bacterial counts (TBC), whereas cut pork samples were tested for both TBC and the presence of *Salmonella* spp. All samples were analyzed in provincial laboratories using standardized protocols. Laboratory technicians from provincial labs had received face-to-face training to harmonize the analytical protocol, and the research team conducted regular checks and confirmations with the laboratories throughout the analysis period to ensure quality control. *Salmonella* spp. was detected

according to TCVN 10780:2017 (GSO 6579–1:2017), which included detection and confirmation methods using O-H antiserum. TBC were determined following TCVN 4884–2:2015 (ISO 4833–2:2013).

2.4. Data analysis

The data collected from questionnaires was recorded using Open Data Kit (ODK). Data analysis was performed using R (R Core Team, 2021). Descriptive statistics were calculated, including percentages for categorical data and means, standard deviations, ranges, min - max for quantitative data. Pairwise Chi-square or Fisher exact tests (where appropriate), followed by Bonferroni correction were used to compare frequencies (such as *Salmonella* prevalence) between groups. The Wilcoxon rank-sum or Kruskal-Wallis test was used to compare values (such as total knowledge score, \log_{10} TBC from pork and cutting board) across different groups. For significant results, post-hoc pairwise comparisons with Bonferroni correction were conducted to identify significant differences between provinces. A linear mixed-effects model from the *lme4* package in R were used to examine associations between \log_{10} TBC CFU/g and the explanatory variables, while generalized linear mixed-effect models (GLMMs) from the same R-package was performed for investigating potential associations with spp. *Salmonella* presence in pork. These explanatory variables were determined through a causal diagram created at <https://www.dagitty.net/>, including vendor knowledge, shop management, vendor practice and temperature (Fig. 2), and are described below:

- *Vendor knowledge* was measured by structured open-ended questions about the causes of food contamination in their businesses and practices to minimize the risk of contamination. Respondents were asked to freely list their opinions, and their answers were coded according to predefined correct answers (based on pilot studies and research team agreement). For each question, we analyzed the proportion of correct responses provided by the respondent or used a binary variable when only one correct answer was applicable. We additionally sum these indicators to create a combined knowledge score on a five-point scale.

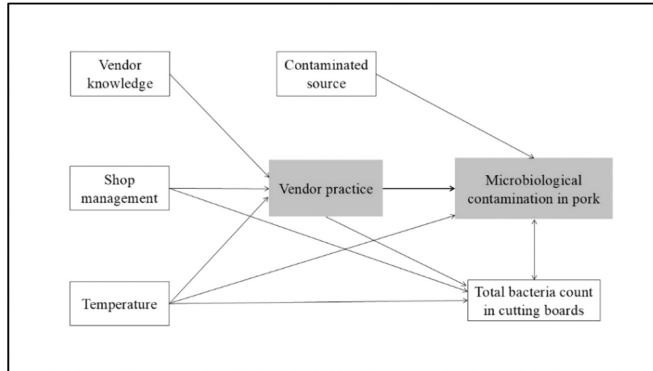


Fig. 2. Causal diagram at pork stalls to measure effects of exposure variable (vendors practice) to the outcome (microbial contamination in pork), in the interaction with related factors.

- *Shop management* includes variables related to equipment availability (tap water or container with spigot, soap/detergent, disinfectant; separate knives for separate products, trash bin, insect control methods, water), selling organs or other meat, sale volume, stall working hours per day and number of workers at the stall. An equipment total score was derived based on the presence of the following four necessary items: a way to wash hands without recontamination (container with spigot or tap); soap or detergent for cleaning surfaces and washing hands; disinfectants for cleaning surfaces or utensils; and separate knives for separate products.
- *Vendor practice* referred to five key hygienic actions: displaying pork on an easy-to-clean surface; keeping different products on separate trays; washing hands with soap or disinfecting hands or having a clean hand swab; washing or disinfecting knife or having a clean knife swab; and washing or disinfecting cutting boards. A total practice score was calculated by summing the number of correct actions observed during the discreet observations, to allow comparison with the microbial results collected immediately afterward.
- *Environment temperature* was identified as a confounding factor and was included in both univariable and multivariable analyses. The research team measured the temperature at the beginning of each sampling session using ambient thermometers.

Each of the above variables was tested individually in the univariable analysis. Of note, contamination at slaughtering period might contribute significantly to the overall contamination level but was not directly observed in this study. TBC in cutting boards was an intervening factor and was excluded in all analyses. Market was set as a random effect to control confounding bias in both univariable and multivariable analyses. Variables that had a p -value ≤ 0.20 in the univariable analyses were included in the multivariable analysis. Model simplification was performed using a backward stepwise approach to identify the most relevant risk factors. In addition, the relationships between knowledge, equipment, and practice scores were assessed using Spearman's rank correlation coefficients. All statistical significance was set at a p -value ≤ 0.05 .

2.5. Ethical considerations

The Institutional Review Board of Hanoi University of Public Health approved all aspects of the project (Decision number: 458/2022/YTCC-HD3). Written informed consent was obtained from each participant prior to enrollment. All participants were informed that they could withdraw from the study at any time without any consequences. Meat

samples were purchased at the regular market price. Vendors were compensated \$3 USD in cash for their time spent with the survey team, consistent with practices for similar studies in the country.

3. Results

3.1. Demographic characteristics

A total of 68 markets and 486 vendors were recruited in this study. On average, each market had 26 ASF stalls, with pork stalls accounting for 66 % of them. The primary water sources were tap and well water. In all provinces, women participants made up the majority (97.5 %), with a mean age of 49 years, ranging from 21 to 72 years. Over 70 % of vendors had at least a secondary school education, with a notably higher proportion of those completing high school or higher in Hanoi and Thai Nguyen (over 40 %) compared to the other provinces (under 20 %). Only 28.6 % of vendors (139/486) reported prior participation in food safety training. Most vendors have been selling pork for 20 years, spent approximately 7.3 h per day at the market and sold 78.5 kg of pork daily. Almost half of businesses had two workers (48.8 %), while 33.7 % operated with a single worker. Dong Nai stood out with a higher proportion of stalls employing more than two workers (38.1 %), longer working hours (8.3 h on average) and greater sale volume (196 kg/stall per day mean). Around 5 % of the responding vendors sold other meat, such as beef and chicken. Over half reported selling pork intestines, although this was notably lower in Thua Thien Hue, where only 12.2 % of vendors did so. Regarding water access, 39.1 % of vendors collected from a pipe, and a similar number of vendors stored water in a bucket or basin. However, 19.3 % reported having no water available at their stalls, with limited water access most prevalent in Thua Thien Hue (54.4 %). The details of market and vendor characteristics are presented in [Table 1](#).

3.2. Vendors' knowledge and attitude on food safety

Vendor knowledge of food safety practices was generally poor, with substantial variation across provinces. Out of 486 interviewed vendors, 338 (69.5 %) mentioned that regularly washing food preparation surfaces helps pork stay clean, with higher numbers observed in the northern provinces (Hanoi and Thai Nguyen, [Table 2](#)). In contrast, only 13 (2.7 %) considered disinfection as necessary. Interestingly, 53 (10.9 %) and 32 (6.6 %) vendors believed that washing meat with water or using cardboard, respectively, were good practices for pork safety. Across most provinces, around 60 % of vendors selected metal or granite

Table 1
Traditional market and vendor characteristics across five provinces in Vietnam.

Characteristic	Hanoi	Thai Nguyen	Thua Thien Hue	Can Tho	Dong Nai	Overall
Market level						
Number of selected markets	20	12	12	12	12	68
Number of animal source food stalls / market (mean, min – max)	32 (21–51)	28 (15–42)	26 (16 – 36)	21 (11–34)	19 (14–35)	26 (11–51)
Proportion of pork stalls / animal source food stalls (%)	55.9	68.8	70.3	65.0	72.1	66.1
Water source at market (n, %)						
Tap water	13 (65.0)	4 (33.3)	10 (83.3)	8 (66.7)	7 (58.3)	42 (61.8)
Well water	6 (30.0)	6 (50.0)	0 (0.0)	2 (16.7)	5 (41.7)	19 (27.9)
Water from nearby	1 (5.0)	2 (16.7)	2 (16.7)	2 (16.7)	0 (0.0)	7 (10.3)
Vendors level						
Number of vendors interviewed and observed	140	89	90	84	83	486
Gender (n, %)						
Woman	137 (97.9)	88 (98.9)	90 (100)	76 (90.5)	83 (100)	474 (97.5)
Man	3 (2.1)	1 (1.1)	0 (0)	8 (9.5)	0 (0)	12 (2.5)
Age (mean, min - max)	47.9 (24–69)	49.1 (28–64)	50.8 (21 – 72)	48.2 (28–69)	49.7 (26–67)	49.0 (21 – 72)
Education (n, %)						
No school	3 (2.1)	0 (0)	17 (18.9)	23 (27.4)	6 (7.2)	49 (10.1)
Primary	17 (12.1)	12 (13.5)	31 (34.4)	33 (39.3)	33 (39.8)	126 (25.9)
Secondary	64 (45.7)	41 (46.1)	24 (26.7)	14 (16.7)	29 (34.9)	172 (35.4)
High school	49 (35.0)	26 (29.2)	16 (17.8)	8 (9.5)	12 (14.5)	111 (22.8)
College or higher	7 (5.0)	10 (11.2)	2 (2.2)	6 (7.1)	3 (3.6)	28 (5.8)
Attending food safety training (n, %)						
Yes	39 (27.9)	32 (36.0)	16 (17.8)	19 (22.6)	33 (39.8)	139 (28.6)
No	101 (72.1)	57 (64.0)	74 (82.2)	65 (77.4)	50 (60.2)	347 (71.4)
Years of selling meat (mean, min – max)	19.6 (1–40)	18.1 (1–40)	21.6 (1 – 40)	20.1 (1–52)	21.2 (2–50)	20.0 (1 – 52)
Stall working hours (mean, min – max)	6.8 (3–12)	7.5 (3–14)	6.6 (3 – 13)	8.3 (4–14)	7.4 (3.5–12)	7.3 (3 – 14)
Sale volume per stall in kg/day (mean, min - max)	108 (18–830)	119 (30–1300)	70.7 (7 – 390)	196 (30–2957)	86.6 (30–280)	78.5 (7 – 2957)
Number of workers involved in the business (n, %)						
One	46 (32.8)	30 (33.7)	37 (41.1)	21 (25.0)	30 (36.1)	164 (33.7)
Two	83 (59.3)	45 (50.6)	37 (41.1)	31 (36.9)	41 (49.4)	237 (48.8)
More than two	11 (7.9)	14 (15.7)	16 (17.8)	32 (38.1)	12 (14.5)	85 (17.5)
Selling other meats (e.g. beef, chicken) (n, %)						
Yes	4 (2.9)	4 (4.5)	7 (7.8)	1 (1.2)	8 (9.6)	24 (4.9)
No	136 (97.1)	85 (95.5)	83 (92.2)	83 (98.8)	75 (90.4)	462 (95.1)
Selling intestine (n, %)						
Yes	66 (47.1)	56 (62.9)	11 (12.2)	70 (83.3)	41 (49.4)	244 (50.2)
No	74 (52.9)	33 (37.1)	79 (87.8)	14 (16.7)	42 (50.6)	242 (49.8)
Water storage at stall (n, %)						
Piped water	77 (55.0)	28 (31.5)	4 (4.4)	41 (48.8)	40 (48.2)	190 (39.1)
Bucket/Basin	55 (39.3)	38 (42.7)	34 (37.8)	32 (38.1)	31 (37.3)	190 (39.1)
Plastic bottle/can	2 (1.4)	3 (3.4)	3 (3.3)	3 (3.6)	1 (1.2)	12 (2.5)
No water	6 (4.3)	20 (22.5)	49 (54.4)	8 (9.5)	11 (13.3)	94 (19.3)

as the best surface to display or store meat, except in Thua Thien Hue, where 64.4 % opted for less hygienic materials such as plastic, wood, cardboard, or cloth. There were 189 respondents (38.9 %) who answered correctly that viscera should be separated from meat, with notably lower corrected responses recorded in Hanoi (23.6 %) and Thai Nguyen (25.8 %) compared to the other provinces (approximately 50 %). In these two provinces, vendors reported that containing viscera on a tray or plate was sufficient, and that for the next questions, only 3 vendors out of 229 (1.3 %) from these two provinces recognized that contact with offal might be the contamination source while selling. Weather (heat and humidity) was cited as the most likely source of meat spoilage while selling (128/486, 26.3 %), followed by various sources such as flies, dirty surfaces, or dust from ground (each mentioned by less than 16 %). Only 20 vendors (4.1 %) mentioned the risk of dirty hands, while 28.2 % believed spoilage was unavoidable. In terms of hand-washing habits, 68.1 % (331/486) reported washing their hands before or after selling, while 31.7 % washed only when their hands felt dirty. Only 11.7 % reported that hands should be washed after each customer. The total mean score of knowledge was 1.4 (out of 5), with no significant difference between provinces.

Vendor attitudes towards food safety risks were mixed, with some provinces showing strong concern while others reflected high levels of confidence. When vendors were asked about the factors that influence consumers' choices when buying pork, "good quality" was the top factor overall (86.4 %) and consistent among all provinces, followed by

knowing the vendor (28.4 %). Cleanliness of stalls or vendors was rarely mentioned (7 % and 4.1 %, respectively). Vendor rating was especially important in Dong Nai (30.1 %) and Can Tho (22.6 %), while food safety was more frequently mentioned in Thua Thien Hue (26.7 %). In the next two questions about perceived risk, vendors were informed that pork might be contaminated before they or other vendors in the market purchased it, for example, during slaughter, and asked how likely illness would be if consumers were not careful when cooking pork sold either by others in the market or by themselves. Vendors in Dong Nai showed the highest concern, with 59.0 % of vendors believing that consumers could get sick from pork sold in their market and 56.6 % expressing concern about their own pork if not properly cooked. In contrast, Thua Thien Hue had the lowest perceived risk (26.7 % and 12.2 %, respectively). Vendors in Hanoi, Thai Nguyen, and Can Tho reported more moderate perceptions. Across all provinces, vendors generally perceived less risk from the pork they personally sold compared to pork sold by others in the market.

3.3. Observations of essential hygienic equipment and practice

Hygienic equipment at stalls was often incomplete, with very few vendors meeting all necessities. Among 486 facilities surveyed, 42.6 % had a handwashing setup that could prevent recontamination, such as a container with a spigot or tap (Table 3). More than 70 % of stalls had soap or detergent, whereas only 3.9 % had disinfectant. Additionally,

Table 2
Vendors' knowledge and attitude on food safety in traditional markets across five provinces in Vietnam.

Options	Hanoi (n = 140)	Thai Nguyen (n = 89)	Thua Thien Hue (n = 90)	Can Tho (n = 84)	Dong Nai (n = 83)	Overall (N = 486)
Knowledge						
1. Things to do while selling to make sure pork stays clean**						
Wash food preparation surfaces regularly*	122 (87.1)	81 (91.0)	41 (45.6)	49 (58.3)	45 (54.2)	338 (69.5)
Disinfect food preparation surfaces regularly*	2 (1.4)	5 (5.6)	2 (2.2)	4 (4.8)	0 (0)	13 (2.7)
Use easy to clean food preparation surfaces*	1 (0.7)	6 (6.7)	15 (16.7)	7 (8.3)	11 (13.3)	40 (8.2)
Store raw viscera and raw meat separately*	2 (1.4)	1 (1.1)	3 (3.3)	7 (8.3)	2 (2.4)	15 (3.1)
Use different knives/cutting boards for raw meat, raw viscera, cooked products*	0 (0)	0 (0)	9 (10.0)	0 (0)	1 (1.2)	10 (2.1)
Wash hands regularly*	14 (10.0)	9 (10.1)	6 (6.7)	0 (0)	0 (0)	29 (6.0)
Clean/wash meat (with water, remove hair)	9 (6.4)	6 (6.7)	5 (5.6)	10 (11.9)	23 (27.7)	53 (10.9)
Use cardboard/cloth and/or change them	5 (3.6)	4 (4.5)	10 (11.1)	7 (8.3)	6 (7.2)	32 (6.6)
Hang meat	0 (0)	0 (0)	0 (0)	8 (9.5)	2 (2.4)	10 (2.1)
Ensure clean origin of pork or keep in cool temperature/frozen	5 (3.6)	0 (0)	2 (2.2)	3 (3.6)	2 (2.4)	12 (2.5)
Keep good appearance (organized meat display, wear gloves/aprons)	5 (3.6)	5 (5.6)	7 (7.8)	4 (4.8)	7 (8.4)	28 (5.8)
Other	11 (7.9)	11 (12.4)	11 (12.2)	6 (7.1)	3 (3.6)	42 (8.6)
Do not know (or do nothing)	1 (0.7)	1 (1.1)	5 (5.6)	9 (10.7)	11 (13.3)	27 (5.6)
Score - mean (SD)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)
2. Best surface to display or store meat						
Easy to clean materials (e.g. metal, granite, hanging...)*	90 (64.3)	68 (76.4)	32 (35.6)	50 (59.5)	52 (62.7)	292 (60.1)
Other materials (e.g., plastic, wood, cardboard, cloth...)	50 (35.7)	21 (23.6)	58 (64.4)	34 (40.5)	31 (37.3)	194 (39.9)
3. How to display viscera						
Separately from meat*	33 (23.6)	23 (25.8)	49 (54.4)	41 (48.8)	43 (51.8)	189 (38.9)
In a tray/plate/basket	105 (75.0)	64 (71.9)	20 (22.2)	37 (44.0)	35 (42.2)	261 (53.7)
Together with meat	0 (0)	0 (0)	2 (2.2)	1 (1.2)	1 (1.2)	4 (0.8)
Do not know	2 (1.4)	2 (2.2)	19 (21.1)	5 (6.0)	4 (4.8)	32 (6.6)
4. Contamination sources while selling**						
Flies*	18 (12.9)	22 (24.7)	8 (8.9)	14 (16.7)	12 (14.5)	74 (15.2)
Dirty hands*	7 (5.0)	5 (5.6)	2 (2.2)	1 (1.2)	5 (6.0)	20 (4.1)
Dust from ground*	17 (12.1)	21 (23.6)	5 (5.6)	5 (6.0)	9 (10.8)	57 (11.7)
Dirty knives*	16 (11.4)	6 (6.7)	2 (2.2)	0 (0)	1 (1.2)	25 (5.1)
Dirty surface*	27 (19.3)	17 (19.1)	4 (4.4)	7 (8.3)	17 (20.5)	72 (14.8)
Contact with offal*	1 (0.7)	2 (2.2)	6 (6.7)	10 (11.9)	15 (18.1)	34 (7.0)
Dirty water*	2 (1.4)	0 (0)	10 (11.1)	17 (20.2)	13 (15.7)	42 (8.6)
Weather (hot, humidity...)*	36 (25.7)	31 (34.8)	25 (27.8)	19 (22.6)	17 (20.5)	128 (26.3)
Contaminated at source	9 (6.4)	1 (1.1)	5 (5.6)	2 (2.4)	1 (1.2)	18 (3.7)
Long selling time	2 (1.4)	4 (4.5)	9 (10.0)	12 (14.3)	21 (25.3)	48 (9.9)
Don't know / there is no way	39 (27.9)	23 (25.8)	33 (36.7)	22 (26.2)	20 (24.1)	137 (28.2)
Others	7 (5.0)	4 (4.5)	3 (3.3)	18 (21.4)	12 (14.5)	44 (9.1)
Score - mean (SD)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
5. Time to wash hands while at work**						
After each customer*	15 (10.7)	16 (18.0)	7 (7.8)	5 (6.0)	14 (16.9)	57 (11.7)
After using the toilet*	3 (2.1)	0 (0)	9 (10.0)	6 (7.1)	1 (1.2)	19 (3.9)
After handling money*	1 (0.7)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.2)
At the beginning of the day*	28 (20.0)	19 (21.3)	33 (36.7)	10 (11.9)	18 (21.7)	108 (22.2)
At the end of the day*	63 (45.0)	48 (53.9)	50 (55.6)	23 (27.4)	39 (47.0)	223 (45.9)
When hands feel dirty*	43 (30.7)	33 (37.1)	16 (17.8)	35 (41.7)	27 (32.5)	154 (31.7)
After eating*	4 (2.9)	1 (1.1)	0 (0)	3 (3.6)	1 (1.2)	9 (1.9)
Before eating*	25 (17.9)	8 (9.0)	10 (11.1)	7 (8.3)	10 (12.0)	60 (12.3)
When selling viscera	21 (15.0)	9 (10.1)	9 (10.0)	8 (9.5)	3 (3.6)	50 (10.3)
No need	0 (0)	1 (1.1)	2 (2.2)	1 (1.2)	1 (1.2)	5 (1.0)
Whenever the vendor is free or as requested by customers	25 (17.9)	7 (7.9)	13 (14.4)	19 (22.6)	10 (12.0)	74 (15.2)
Other	16 (11.4)	4 (4.5)	3 (3.3)	4 (4.8)	8 (9.6)	35 (7.2)
Score - mean (SD)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)	0.2 (0.1)
Mean total score of knowledge (out of 5)	1.3 (0.1)	1.5 (0.7)	1.3 (0.7)	1.5 (0.8)	1.6 (0.8)	1.4 (0.7)
Attitude						
1. What do you think consumers look for when deciding from whom to buy pork						
Good price	29 (20.7)	10 (11.2)	6 (6.7)	16 (19.0)	17 (20.5)	78 (16.0)
Good quality	127 (90.7)	83 (93.3)	80 (88.9)	66 (78.6)	64 (77.1)	420 (86.4)
Has cuts/preparations I prefer	4 (2.9)	1 (1.1)	5 (5.6)	0 (0)	6 (7.2)	16 (3.3)
Know vendor	35 (25.0)	19 (21.3)	33 (36.7)	27 (32.1)	24 (28.9)	138 (28.4)
Stall is clean	17 (12.1)	3 (3.4)	3 (3.3)	5 (6.0)	6 (7.2)	34 (7.0)
Vendor is clean	9 (6.4)	3 (3.4)	2 (2.2)	2 (2.4)	4 (4.8)	20 (4.1)
Food is safe / not risky	8 (5.7)	8 (9.0)	24 (26.7)	14 (16.7)	11 (13.3)	65 (13.4)
Vendor has a high rating	0 (0)	0 (0)	9 (10.0)	19 (22.6)	25 (30.1)	53 (10.9)
2. If someone wasn't careful about how they cooked the pork from a typical vendor in this market sold, how likely do you think it is that they would get sick?						
Very likely	22 (15.7)	10 (11.2)	10 (11.1)	16 (19.0)	24 (28.9)	82 (16.9)
Somewhat likely	36 (25.7)	22 (24.7)	14 (15.6)	21 (25.0)	25 (30.1)	118 (24.3)
Neither likely nor unlikely	7 (5.0)	9 (10.1)	5 (5.6)	12 (14.3)	5 (6.0)	38 (7.8)
Somewhat unlikely	39 (27.9)	28 (31.5)	25 (27.8)	7 (8.3)	10 (12.0)	109 (22.4)

(continued on next page)

Table 2 (continued)

Options	Hanoi (n = 140)	Thai Nguyen (n = 89)	Thua Thien Hue (n = 90)	Can Tho (n = 84)	Dong Nai (n = 83)	Overall (N = 486)
Highly unlikely	28 (20.0)	15 (16.9)	27 (30.0)	16 (19.0)	8 (9.6)	94 (19.3)
Don't know /refused	8 (5.7)	5 (5.6)	9 (10.0)	12 (14.3)	11 (13.3)	45 (9.3)
3. If someone wasn't careful about how they cooked the pork they bought from you, how likely do you think it is that they would get sick?						
Very likely	13 (9.3)	8 (9.0)	2 (2.2)	14 (16.7)	20 (24.1)	57 (11.7)
Somewhat likely	38 (27.1)	22 (24.7)	9 (10.0)	17 (20.2)	26 (31.3)	112 (23.0)
Neither likely nor unlikely	7 (5.0)	5 (5.6)	7 (7.8)	7 (8.3)	7 (8.4)	33 (6.8)
Somewhat unlikely	43 (30.7)	28 (31.5)	18 (20.0)	15 (17.9)	7 (8.4)	111 (22.8)
Highly unlikely	31 (22.1)	18 (20.2)	47 (52.2)	23 (27.4)	16 (19.3)	135 (27.8)
Don't know /refused	8 (5.7)	8 (9.0)	7 (7.8)	8 (9.5)	7 (8.4)	38 (7.8)

* Correct answers to each question; ** Multiple answers are correct to the question - each question's score was calculated as the proportion of correct answers selected, relative to the number of pre-specified correct options. SD = Standard Deviation

Table 3

List of the availability of essential hygienic equipment and pork vendor practices observed during discreet and direct observations in traditional markets across five provinces in Vietnam (N = 486).

No	Content	Hanoi (n = 140)	Thai Nguyen (n = 89)	Thua Thien Hue (n = 90)	Can Tho (n = 84)	Dong Nai (n = 83)	Overall (N = 486)	
Equipment		Frequency n (%)						
1	Having a way to wash hands without recontamination (container with spigot or tap)	78 (55.7)	33 (37.1)	12 (13.3)	41 (48.8)	43 (51.8)	207 (42.6)	
2	Having soap / detergent for cleaning surfaces and washing hands	123 (87.9)	52 (58.4)	48 (53.3)	68 (81.0)	77 (92.8)	368 (75.7)	
3	Having disinfectant for surfaces / utensils	7 (5.0)	4 (4.5)	3 (3.3)	0 (0)	5 (6.0)	19 (3.9)	
4	Having separate knives for separate products	100 (71.4)	37 (41.6)	61 (67.8)	21 (25.0)	39 (47.0)	258 (53.1)	
Mean total score of equipment (out of 4)		2.2 (0.8)	1.4 (0.9)	1.4 (0.9)	1.5 (0.8)	2.0 (0.8)	1.8 (0.9)	
Practice		Frequency n (%)						
10 min of discreet observation		Frequency n (%)						Median (min - max)
1	Pork is displayed on an easy to clean surface	86 (61.4)	59 (66.3)	23 (25.6)	31 (36.9)	40 (48.2)	239 (49.2)	na
2	Different products are kept on separate trays	118 (84.3)	68 (76.4)	70 (77.8)	69 (82.1)	81 (97.6)	406 (83.5)	na
3	Hand swab is clean	138 (98.6)	76 (85.4)	65 (72.2)	55 (65.5)	61 (73.5)	395 (81.3)	na
4	Knife swab is clean	125 (89.3)	62 (69.7)	38 (42.2)	34 (40.5)	30 (36.1)	289 (59.5)	na
30 min direct observation		Frequency n (%)						Median (min - max)
5	Different products are kept on separate trays and not use the same knife, cutting board, weighing plate/scale, or cloth for different products	97 (69.3)	54 (60.7)	60 (66.7)	55 (65.5)	64 (77.1)	330 (67.9)	na
6*	Washing their hands in any way	12 (8.6)	5 (5.6)	8 (8.9)	6 (7.1)	7 (8.4)	38 (7.8)	1 (1 - 8)
7*	Washing hands with soap or disinfects hands	2 (1.4)	0 (0)	1 (1.1)	0 (0)	1 (1.2)	4 (0.8)	1 (1 - 8)
8*	Washing or disinfects the knife	2 (1.4)	1 (1.1)	0 (0)	0 (0)	2 (2.4)	5 (1.0)	1 (1 - 2)
9*	Washing cutting board with soap or sprayed disinfectant	0	0	0	0	0	0	0
10	Cleaning cutting board in any way (including scraped, washed, disinfected)	17 (12.1)	9 (10.1)	49 (54.4)	26 (31.0)	23 (27.7)	124 (25.5)	2 (1 - 8)
Mean total score of practice (out of 5)**		3.4 (0.7)	3.1 (0.9)	2.2 (1.1)	2.3 (1.1)	2.6 (0.9)	2.8 (1.0)	3 (0 - 4)

* Practice was assessed through 10 min of discreet observation, but the recorded values were 0 in all cases. na: not applicable for summary statistics. ** Total score of practice = items 1 + 2 + [either 3 or 7] + [either 4 or 8] + 9, based on discreet observations.

53.1 % of facilities used separate knives for different products, reducing the risk of cross-contamination. There were only 4 vendors (0.8 %) who had all the listed equipment, while 41 vendors (8.4 %) lacked all of them.

Vendor hygiene practices were generally poor, with differences observed between the discreet and direct observations and varied significantly across provinces. Only 49.2 % (239/486) of vendors placed pork on easy-to-clean surfaces such as stainless steel or granite, with significantly higher adherence in Thai Nguyen and Hanoi compared to Thua Thien Hue and Can Tho vendors. Most vendors (406/486, 83.5 %) were likely to keep different products on separate trays, whereas Dong Nai stood out with 97.6 % of practiced vendors and significantly higher than in other provinces. However, during the direct observation period, while vendors were additionally assessed to not use the same knife, cutting board, weighing plate/scale, or cloth for different products, the figures dropped to 330 (67.9 %). Although vendors' hands and knives often appeared visibly clean when assessed using the photo-based

cleanliness scale, no instances of washing them were observed during discreet observation at any markets. During the 30-minute direct observation period, washing events were rare (0 to less than 3 % of vendors). None of the vendors washed the cutting board with soap or sprayed disinfectant at any point. Looking at the association between knowledge and practices, we found no statistically significant correlation between keeping different products on separate trays and their knowledge that it should be done. In contrast, vendors who were aware of suitable surfaces for placing pork tended to apply correct practices (Chi-square test, $p < 0.01$).

The mean total equipment and practice scores differed notably across provinces. Vendors in Hanoi and Dong Nai had significantly higher equipment scores compared to those in Thai Nguyen, Thua Thien Hue, and Can Tho. In contrast, practice scores were generally higher in northern provinces (Hanoi and Thai Nguyen) compared to other provinces. The total knowledge and equipment scores were both significantly positively associated with practice score (Kruskal-Wallis test, $p < 0.01$,

$r = 0.17$ and $r = 0.23$, respectively), while no significant association was found between knowledge and equipment scores. Vendors who had attended food safety training did not show higher total knowledge or equipment scores, but they had higher practice scores (Wilcoxon rank-sum test, $p < 0.01$). When examining each individual item within the knowledge, equipment, and practice categories, a significant positive association was found between having received training and better understanding as well as practice in using proper surfaces to display pork (Chi-square test, $p < 0.05$).

3.4. Microbiological results

Due to inconsistencies in laboratory facilities in Thua Thien Hue, which could not ensure the same testing protocol as other provinces, all microbiological test results ($n = 90$) from this province were excluded in the following analyses.

The overall *Salmonella* prevalence in pork was 64.4 % (255/396) and was significantly higher in the Can Tho and Dong Nai (southern provinces in the Mekong Delta, 86.8 %) compared to Hanoi and Thai Nguyen (northern, 47.5 %, Chi-square test, $p < 0.01$). The mean TBC in pork and cutting board were 6.4 \log_{10} CFU/g and 6.9 \log_{10} CFU/cm², respectively (Table 4). These levels of contamination were positively correlated and were significantly higher in the two southern provinces than those in the north. Nearly all samples from Can Tho and Dong Nai exceeded Vietnam’s permitted TBC concentration in fresh meat (5×10^5 or 5.7 \log_{10} CFU/g, MOH, 2012). The average temperature on sampling days was notably higher in these two southern provinces.

3.5. Factors associated with microbial contamination

Selling organs was associated with higher \log_{10} TBC concentration (coefficient = 0.13, 95 % confidence interval [CI]: 0.01–0.26, $p = 0.03$) and increased *Salmonella* positivity (odds ratio [OR] = 2.04, $p = 0.009$). Temperature had a significant impact on both models ($p < 0.001$). In addition, the practice of displaying pork on an easy-to-clean surface was linked to lower TBC concentration in pork (coefficient = -0.16, CI: -0.30 to -0.01, $p = 0.03$, Table 5).

4. Discussion

This study provided a detailed snapshot of vendors’ knowledge, attitudes, and practices, as well as microbial contamination at pork stalls in traditional markets across Vietnam. Our main findings showed that microbial contamination, especially *Salmonella*, can be high at the retail stage where food safety practices are not adequately followed, reflecting persistent challenges related to vendor knowledge/attitudes, market infrastructure, environmental and cultural factors.

In line with studies from other LMICs (Wallace et al., 2022), vendor knowledge, attitudes, and practices related to food safety were limited, with low overall mean score. We found misperceptions from vendors; for example, they believed that unhygienic materials like wood, cardboard, cloth were ideal for meat display, despite these being conducive to bacterial growth. They also tended to wash hands only when they “feel

Table 5

Multivariable analysis of risk factors associated with total bacterial counts and *Salmonella* presence in cut pork at stalls in traditional markets in Vietnam (N = 396).

Total bacteria count (\log_{10} CFU/g) in cut pork			
Factors	Coefficient β (Standard errors)	95 % CI	p-value
Temperature	0.12 (0.01)	0.10–0.15	< 0.001
Practice: Sell organs (Yes)	0.13 (0.06)	0.01–0.26	0.03
Practice: pork is displayed on an easy to clean surface (Yes)	-0.16 (0.07)	-0.30 to -0.01	0.03
<i>Salmonella</i> presence in cut pork			
Factors	Odds ratio	95 % CI	p-value
Temperature	1.17	1.10–1.25	< 0.001
Practice: Sell organs (Yes)	2.04	1.19–3.47	0.009

dirty.” Infrastructure limitations further exacerbated poor hygiene practices: one-fifth of vendors lacked access to water at their stalls, 42.6 % had handwashing setups that could prevent recontamination, and only 3.9 % of stalls had disinfection products available. Only 28.6 % of vendors in our study had received any prior food safety training, suggesting limited coverage of such programs. While trained vendors demonstrated better practices, particularly in using easy-to-clean surfaces, they did not show higher overall knowledge or equipment scores. However, knowledge and practice scores were positively associated overall, indicating that vendors with greater knowledge also tended to practice better hygiene. This suggests that previous training may have improved certain behaviors without substantially increasing knowledge, and that future programs should integrate identified knowledge gaps to enhance both understanding and practice. These findings highlight how both knowledge gaps and inadequate facilities constrain vendor practices, underscoring the need for holistic interventions that combine education with infrastructural support. In addition, clear provincial differences were observed in vendor food safety knowledge and practice. These geographic patterns may reflect differences in market infrastructure investment or previous exposure to local food safety programs. Understanding these contextual factors is crucial for designing targeted interventions, as provinces with weaker infrastructure and lower practice adherence may require more intensive combined efforts in both education and facility improvement.

The high levels of *Salmonella* contamination, along with nearly 70 % of pork samples exceeding Vietnam’s permitted TBC concentration in fresh meat, suggests a problem with the safety and quality of the pork being sold in traditional retail outlets in Vietnam. The *Salmonella* prevalence on cut pork in this study (64.4 %) was comparable to findings in China (67 %) (Chen et al., 2021), Thailand (73.2 %) (Patchanee et al., 2016), and the Laos-Thai border (72.73 %) (Meunsene et al., 2021), but higher than that examined in Cambodia (45.7 %) (Rortana et al., 2021). Compared to recent studies, the figure in the South exceeds that of previous reports by Nguyen et al. (2016) at 69.7 %, Nhung et al. (2018) at 72.7 %, and similar to the more recent findings by Vu et al. (2021) at 90.8 %, while the prevalence in the North is lower than the 60.5 % reported by Ngo et al. (2021). Additionally, the TBC

Table 4

Contamination of TBC from cutting boards and TBC and *Salmonella* from fresh pork at 56 traditional markets in Vietnam (N = 396).

Indicator		Hanoi (n = 140)	Thai Nguyen (n = 89)	Can Tho (n = 84)	Dong Nai (n = 83)	Total (N = 396)
<i>Salmonella</i> in cut pork	Number of positive samples (%)	70 (50.0) ^{a,b}	40 (44.9) ^{a,b}	83 (98.8) ^c	62 (74.7) ^d	255 (64.4)
TBC in cut pork (\log_{10} CFU/g)	mean (SD)	5.7 ^{a,b} (1.0)	5.8 ^{a,b} (0.6)	7.5 ^c (0.6)	6.9 ^d (0.7)	6.4 (1.1)
	% exceed standard*	43.6	59.6	100.0	96.4	70.2
TBC in cutting boards (\log_{10} CFU/cm ²)	mean (SD)	6.7 ^{a,b} (1.0)	6.9 ^{a,b,d} (0.7)	7.3 ^c (0.5)	7.0 ^{a,d} (0.8)	6.9 (0.9)
Average temperature of sampling day °C (SD)		15.1 ^a (3.9)	17.8 ^b (1.3)	27.5 ^{a,d} (2.6)	27.9 ^{a,d} (1.8)	20.8 (6.5)

^{a,b,c,d,e} Difference superscripts indicate statistically significance at $p < 0.01$, Kruskal-Wallis for \log_{10} TBC, Chi-square for *Salmonella* and Bonferroni adjust method. * Vietnam national technical regulation of microbiology contaminants in food (TBC concentration in fresh meat samples is not allowed to exceed 5×10^5 (5.7 \log_{10} CFU/g) (MOH, 2012). TBC: total bacteria count. SD: Standard Deviation.

concentration in cut pork was 1 log CFU/g higher, while that on cutting boards was 0.5 log CFU/cm² lower than previously observed in northern Vietnam (Ngo et al., 2021). In this study, *Salmonella* prevalence was significantly higher in the southern provinces compared to the north, which was consistent with relevant literature (Dang-Xuan et al., 2019). This could be explained by the warmer climate in the south that accelerates bacterial growth, as well as different management and handling norms prevailing, for instance, greater sale volume and number of workers per stall in Dong Nai or fewer vendors using easy-to-clean surfaces in Can Tho.

Previous studies in Vietnam have shown that pork arrangement, storage conditions, and environmental hygiene influence microbial contamination (Dang-Xuan et al., 2019; Ngo et al., 2023). Consistent with these findings, our study identified several factors associated with both *Salmonella* prevalence and TBC levels, highlighting the need to improve hygienic practices among pork vendors. The use of hard-to-clean surfaces (e.g. cardboard, cloth) and selling organs were linked to higher contamination, likely due to the belief that absorbent materials keep meat dry and visually appealing to consumers and cross contamination from the gastrointestinal tract (Dang-Xuan et al., 2016; Bellido-Carreras et al., 2019). The strong correlation between pork and cutting board contamination underscores the role of surfaces as critical points for bacterial transmission, and the need for regular cleaning and replacement of equipment. High ambient temperature as well as the lack of water access, refrigeration or ice during long selling hours further facilitate bacterial growth, which are typical challenges in LMICs to maintaining the hygiene, safety and quality of pork (Wallace et al., 2022). Practical alternatives in the Vietnamese context such as limiting pork sales to cooler morning hours (Dang-Xuan et al., 2019), or use of insulated boxes with ice packs for storing meat or at least pork organs, may help reduce contamination. However, the feasibility of adopting such practices depends on cost, accessibility, and vendor willingness to adopt new practices. Further research is needed to assess the practicality of interventions in the context of Southeast Asian traditional markets.

Based on our findings, we propose a food safety intervention grounded in three integrated components: enabling environment, appropriate equipment, and behavioral incentives (Grace, 2023). Firstly, enabling environment requires leadership engagement and policy-level investment in market infrastructure, particularly in water supply to support vendors' compliance. Secondly, given that only four vendors had all the necessary hygiene equipment, future policies should enforce minimum hygiene standards at markets and promote the availability of low-cost, practical equipment, such as non-absorbent surfaces, separated tools, and easy-to-use disinfectants, which were successfully trialed in small size previously in Vietnam (Ngo et al., 2023). Thirdly, targeted education must address cultural norms and long-standing practices with incentives, showing for example how food safety can improve customer trust and lead to a higher income (Hennessey et al., 2020). Previous interventions have largely overlooked this aspect, which is essential to sustain voluntary change. We also suggest visual cues, nudges like signage or audio prompts, and recognition-based rewards to reinforce new practices. Given that 97.5 % of pork vendors were women, which aligned with existing literature highlighting women's central role in informal food retail across Vietnam and Southeast Asia (Nguyen Thi Thuy et al., 2020; Nguyen-Thi-Duong et al., 2022; ILO, 2023), interventions should be tailored to their unique role.

This study had limitations. First, microbiological analysis was conducted in four different laboratories across the country, introducing potential bias due to variations in technicians' skills and laboratory capacity. To minimize this, the research team organized a training session to standardize protocols and practice, provided on-site support, and maintained regular quality checks. Despite this mitigation effort, laboratory inconsistencies in one province in central Vietnam limit the comparability of microbiological results across all sites. Future work should include regular data quality control. Secondly, discreet

observation which was conducted over a short period to avoid revealing enumerators to vendors may not have fully captured typical routines. However, each stall was then observed for approximately 30 min to reduce this bias and allow for meaningful comparisons. Despite these limitations, the large and diverse sample of vendors offers a comprehensive and current overview of food safety knowledge, attitudes, and practices across Vietnam, providing a strong base for future intervention planning.

5. Conclusion

Vietnam's traditional markets remain a vital part of the food system, especially for ASF. This study highlighted the limited knowledge, mixed attitudes, and poor practices of pork vendors, as well as high level of microbial contamination – including *Salmonella* – with notable differences across provinces. The analysis suggests that vendor practices are shaped not only by knowledge or attitudes but also by structural factors such as market infrastructure and regulations. Interventions should therefore move beyond generic training to integrate context-specific education, low-cost equipment support, and infrastructural improvements, particularly in provinces with weaker food systems. The findings offer actionable insights for designing market-level interventions to improve food safety in Vietnam and other LMICs where traditional markets remain central to the food system.

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CRedit authorship contribution statement

Lindahl Johanna: Writing – review & editing, Visualization. **Sofia Boqvist:** Writing – review & editing, Visualization, Conceptualization. **Steven Lâm:** Writing – review & editing, Visualization. **Sinh Dang-Xuan:** Writing – review & editing, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Mike Murphy:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Kate Ambler:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Vivian Hoffmann:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Trang Thi Huyen Le:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Hung Nguyen-Viet:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Fred Unger:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Elisabeth Rajala:** Writing – review & editing, Visualization.

Declaration of Competing Interest

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

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Appendix A. Supporting information

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Foodborne diseases associated with pork consumption remain a major public health concern in low- and middle-income countries where traditional supply chains dominate. This thesis examined food safety interventions in pig slaughterhouses and traditional markets across five provinces in Vietnam using rigorous experimental designs. By integrating microbiological, behavioural, economic, and socio-cultural perspectives, the thesis provides new evidence on intervention implementation in real-world settings and highlights the need for integrated strategies addressing infrastructure, governance, and consumer demand to improve food safety.

Trang Le Thi Huyen received her doctoral education at the Department of Animal Biosciences, Swedish University of Agricultural Sciences, Sweden. She obtained Bachelor of Public Health in Vietnam and MSc degree in Bio-Veterinary Science in Thailand.

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