

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

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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 ( $6.4 \log_{10} \text{CFU/g}$  and  $6.9 \log_{10} \text{CFU/cm}^2$ , 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

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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 García, 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

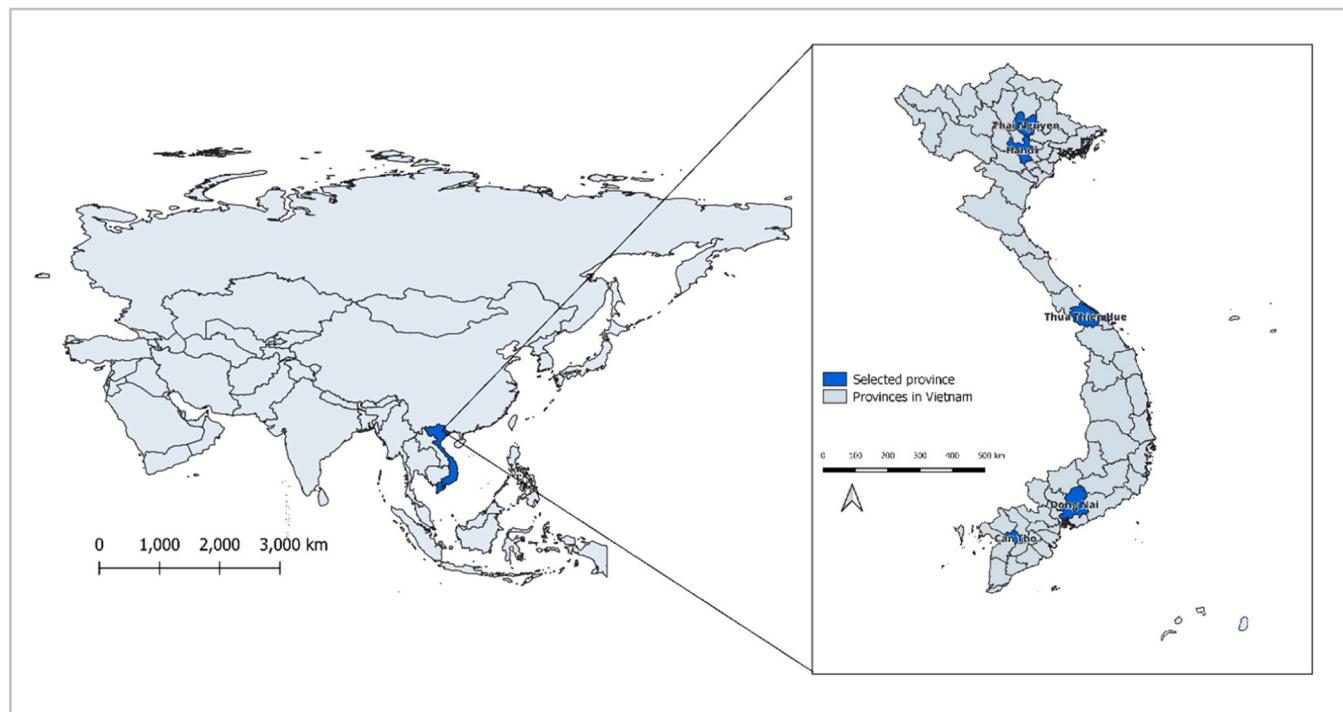
Initially, discreet observations were conducted early on the sampling day for around 10 min. Enumerators either observed vendors from a distance or posed as customers, purchasing at least raw pork from each vendor. For vendors offering multiple types of products (raw meat, viscera, and cooked meat), 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  $10 \times 10$  cm area ( $100 \text{ cm}^2$  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

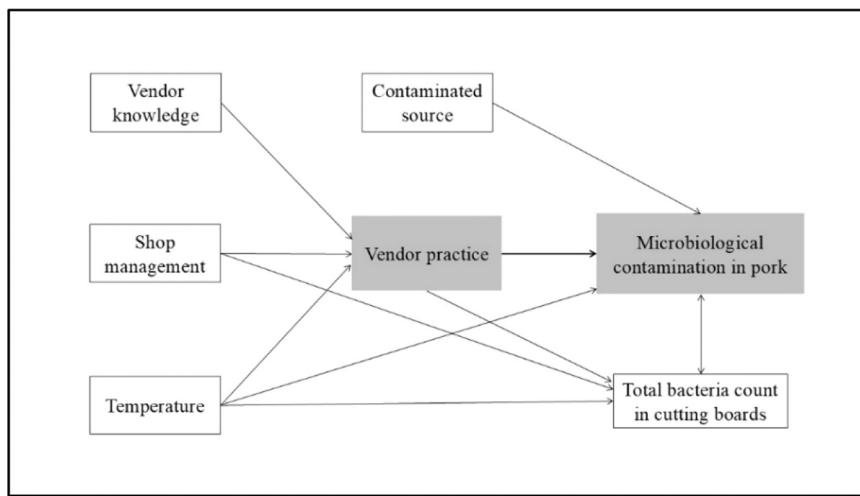
All samples were transported in insulated cool boxes with frozen freezer blocks and were processed as soon as they were received at the local laboratories, except in some cases when samples could not be analyzed immediately and were stored in a refrigerator and analyzed within one day. Cutting boards 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  $\leq 0.20$  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  $\leq 0.05$ .

## 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
<b>Market level</b>						
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)
<b>Vendors level</b>						
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)
<b>Knowledge</b>						
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)
<b>Mean total score of knowledge (out of 5)</b>	<b>1.3 (0.1)</b>	<b>1.5 (0.7)</b>	<b>1.3 (0.7)</b>	<b>1.5 (0.8)</b>	<b>1.6 (0.8)</b>	<b>1.4 (0.7)</b>
<b>Attitude</b>						
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)
<b>Equipment</b>							
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)
<b>Mean total score of equipment (out of 4)</b>		2.2 (0.8)	1.4 (0.9)	1.4 (0.9)	1.5 (0.8)	2.0 (0.8)	1.8 (0.9)
<b>Practice</b>							
<b>10 min of discreet observation</b>							
		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)
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)
3	Hand swab is clean	138 (98.6)	76 (85.4)	65 (72.2)	55 (65.5)	61 (73.5)	395 (81.3)
4	Knife swab is clean	125 (89.3)	62 (69.7)	38 (42.2)	34 (40.5)	30 (36.1)	289 (59.5)
<b>30 min direct observation</b>							
		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)
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)
7*	Washing hands with soap or disinfects hands	2 (1.4)	0 (0)	1 (1.1)	0 (0)	1 (1.2)	4 (0.8)
8*	Washing or disinfects the knife	2 (1.4)	1 (1.1)	0 (0)	0 (0)	2 (2.4)	5 (1.0)
9*	Washing cutting board with soap or sprayed disinfectant	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)
<b>Mean total score of practice (out of 5)**</b>		3.4 (0.7)	3.1 (0.9)	2.2 (1.1)	2.3 (1.1)	2.6 (0.9)	2.8 (1.0)

\* 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  $6.4 \log_{10}\text{CFU/g}$  and  $6.9 \log_{10}\text{CFU/cm}^2$ , 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 ( $5 \times 10^5$  or  $5.7 \log_{10}\text{CFU/g}$ , 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 ( $\log_{10}\text{CFU/g}$ ) in cut pork			
Factors	Coefficient $\beta$ (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) <sup>a,b</sup>	40 (44.9) <sup>a,b</sup>	83 (98.8) <sup>c</sup>	62 (74.7) <sup>d</sup>	255 (64.4)
TBC in cut pork ( $\log_{10}\text{CFU/g}$ )	mean (SD)	5.7 <sup>a,b</sup> (1.0)	5.8 <sup>a,b</sup> (0.6)	7.5 <sup>c</sup> (0.6)	6.9 <sup>d</sup> (0.7)	6.4 (1.1)
TBC in cutting boards ( $\log_{10}\text{CFU/cm}^2$ )	mean (SD)	43.6	59.6	100.0	96.4	70.2
Average temperature of sampling day <sup>o</sup> C (SD)		6.7 <sup>a,b</sup> (1.0)	6.9 <sup>a,b,d</sup> (0.7)	7.3 <sup>c</sup> (0.5)	7.0 <sup>c,d</sup> (0.8)	6.9 (0.9)
		15.1 <sup>a</sup> (3.9)	17.8 <sup>b</sup> (1.3)	27.5 <sup>c,d</sup> (2.6)	27.9 <sup>c,d</sup> (1.8)	20.8 (6.5)

<sup>a,b,c,d,e</sup> 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  $5 \times 10^5$  ( $5.7 \log_{10}\text{CFU/g}$ ) (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/cm<sup>2</sup> 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 Läm:** 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

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.prevetmed.2025.106757](https://doi.org/10.1016/j.prevetmed.2025.106757).

## References

- Bellido-Carreras, N., Argüello, H., Zaldívar-López, S., Jiménez-Marín, Á., Martins, R.P., Arce, C., Morera, L., Carvajal, A., Garrido, J.J., 2019. *Salmonella Typhimurium* infection along the porcine gastrointestinal tract and associated lymphoid tissues. *Vet. Pathol.* 56, 681–690. <https://doi.org/10.1177/0300985819843682>.
- Chen, Z., Bai, J., Zhang, X., Wang, S., Chen, K., Lin, Q., Xu, C., Qu, X., Zhang, H., Liao, M., Zhang, J., 2021. Highly prevalent multidrug resistance and QRDR mutations in *Salmonella* isolated from chicken, pork and duck meat in Southern China, 2018–2019. *Int. J. Food Microbiol.* 340, 109055. <https://doi.org/10.1016/j.ijfoodmicro.2021.109055>.
- R. Core Team, 2021. R: A language and environment for statistical computing. In.: R Foundation for Statistical Computing, Vienna, Austria.
- Dang-Xuan, S., Nguyen-Viet, H., Meeym, T., Fries, R., Nguyen-Thanh, H., Pham-Duc, P., Lam, S., Grace, D., Unger, F., 2016. Food safety perceptions and practices among smallholder pork value chain actors in Hung Yen Province, Vietnam. *J. Food Prot.* 79, 1490–1497. <https://doi.org/10.4315/0362-028X.JFP-15-402>.
- Dang-Xuan, S., Nguyen-Viet, H., Pham-Duc, P., Unger, F., Tran-Thi, N., Grace, D., Makita, K., 2019. Risk factors associated with *Salmonella* spp. prevalence along smallholder pig value chains in Vietnam. *Int. J. Food Microbiol.* 290, 105–115. <https://doi.org/10.1016/j.ijfoodmicro.2018.09.030>.
- Grace, D., 2023. Burden of foodborne disease in low-income and middle-income countries and opportunities for scaling food safety interventions. *Food Sec* 15, 1475–1488. <https://doi.org/10.1007/s12571-023-01391-3>.
- GSO, V., 2023. Live pig output by region and province in 2023.
- Havelaar, A.H., Kirk, M.D., Torgerson, P.R., Gibb, H.J., Hald, T., Lake, R.J., Praet, N., Bellinger, D.C., De Silva, N.R., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F.J., Devleesschauwer, B., 2015. World Health Organization Global estimates and regional comparisons of the burden of foodborne disease in 2010 (on behalf of World Health Organization Foodborne Disease Burden Epidemiology Reference Group). *PLoS Med* 12, e1001923. <https://doi.org/10.1371/journal.pmed.1001923>.
- Hennessey, M., Kim, S., Unger, F., Nguyen-Viet, H., Dang-Xuan, S., Nguyen-Thi, T., Häslér, B., 2020. Exploring the potential of using nudges to promote food hygiene in the pork value chain in Vietnam. *Prev. Vet. Med.* 181, 105003. <https://doi.org/10.1016/j.prevetmed.2020.105003>.
- Heredia, N., Garcia, S., 2018. Animals as sources of food-borne pathogens: a review. *Anim. Nutr.* 4, 250–255. <https://doi.org/10.1016/j.aninu.2018.04.006>.
- ILO, 2023. Women and men in the informal economy: A statistical update. International Labour Office – Geneva.
- Jaffee, S., Henson, S., Unnevehr, L., Grace, D., Cassou, E., 2019. The Safe Food Imperative: Accelerating Progress in Low- and Middle-Income Countries, Agriculture and Food Series. © World Bank.
- Li, M., Havelaar, A.H., Hoffmann, S., Hald, T., Kirk, M.D., Torgerson, P.R., Devleesschauwer, B., 2019. Global disease burden of pathogens in animal source foods, 2010. *PLoS ONE* 14, e0216545. <https://doi.org/10.1371/journal.pone.0216545>.
- Meunsene, D., Eiamsam-ang, T., Patchanee, P., Pascoe, B., Tadee, Phacharaporn, Tadee, Pakpoom, 2021. Molecular evidence for cross boundary spread of *Salmonella* spp. in meat sold at retail markets in the middle Mekong basin area. *PeerJ* 9, e11255. <https://doi.org/10.7717/peerj.11255>.
- MOH, 2012. QCVN 8-3: 2012/BYT - National technical regulation of Microbiological contaminants in food.
- Nga, N.T.D., Lucy, L., Fred, U., Hung, P.V., Ha, D.N., Huyen, N.T.T., Long, T.V., Be, D.T., 2015. Household pork consumption behavior in Vietnam: implications for pro-smallholder pig value chain upgrading. Presented at the Conference on International Research on Food Security, Natural Resource Management and Rural Development, Tropentag 2015, Berlin, Germany, p. 8.
- Ngo, H.H.T., Nguyen-Thanh, L., Pham-Duc, P., Dang-Xuan, S., Le-Thi, H., Denis-Robichaud, J., Nguyen-Viet, H., Le, T.T.H., Grace, D., Unger, F., 2021. Microbial contamination and associated risk factors in retailed pork from key value chains in Northern Vietnam. *Int. J. Food Microbiol.* 346, 109163. <https://doi.org/10.1016/j.ijfoodmicro.2021.109163>.
- Ngo, H.H.T., Dang-Xuan, S., Målvist, M., Nguyen-Thanh, L., Pham-Duc, P., Nguyen-Hong, P., Le-Thi, H., Nguyen-Viet, H., Le, T.T.H., Grace, D., Lindahl, J.F., Unger, F., 2023. Effect of light-touch intervention and associated factors to microbial contamination at small-scale pig slaughterhouses and traditional pork shops in Vietnam. *Int. J. Food Microbiol.* 406, 110351. <https://doi.org/10.1016/j.ijfoodmicro.2023.110351>.
- Nguyen, D.T.A., Kanki, M., Nguyen, P.D., Le, H.T., Ngo, P.T., Tran, D.N.M., Le, N.H., Dang, C.V., Kawai, T., Kawahara, R., Yonogi, S., Hirai, Y., Jinnai, M., Yamasaki, S., Kumeda, Y., Yamamoto, Y., 2016. Prevalence, antibiotic resistance, and extended-spectrum and AmpC β-lactamase productivity of *Salmonella* isolates from raw meat and seafood samples in Ho Chi Minh City, Vietnam. *Int. J. Food Microbiol.* 236, 115–122. <https://doi.org/10.1016/j.ijfoodmicro.2016.07.017>.
- Nguyen Thi Thuy, M., Dorny, P., Lebailly, P., Le Thi Minh, C., Nguyen Thi Thu, H., Dermauw, V., 2020. Mapping the pork value chain in Vietnam: a systematic review. *Trop. Anim. Health Prod.* 52, 2799–2808. <https://doi.org/10.1007/s11250-020-02338-y>.
- Nguyen-Thi-Duong, N., Pham-Van, H., Duong-Nam, H., Nguyen-Thi-Thu, H., Ninh-Xuan, T., Dang-Xuan, S., Unger, F., Nguyen-Viet, H., Grace, D., 2022. Gender-focused analysis and opportunities for upgrading within Vietnam's smallholder pig value chains. *Front. Vet. Sci.* 9, 906915. <https://doi.org/10.3389/fvets.2022.906915>.
- Nguyen-Viet, H., Lam, S., Nguyen-Mai, H., Trang, D.T., Phuong, V.T., Tuan, N.D.A., Tan, D.Q., Thuy, N.T., Thuy Linh, D., Pham-Duc, P., 2022. Decades of emerging infectious disease, food safety, and antimicrobial resistance response in Vietnam: the role of One Health. *One Health* 14, 100361. <https://doi.org/10.1016/j.onehlt.2021.100361>.
- Nhung, N.T., Van, N.T.B., Cuong, N.V., Duong, T.T.Q., Nhat, T.T., Hang, T.T.T., Nhi, N.T., H., Kiet, B.T., Hien, V.B., Ngoc, P.T., Campbell, J., Thwaites, G., Carrique-Mas, J., 2018. Antimicrobial residues and resistance against critically important antimicrobials in non-typhoidal *Salmonella* from meat sold at wet markets and supermarkets in Vietnam. *Int. J. Food Microbiol.* 266, 301–309. <https://doi.org/10.1016/j.ijfoodmicro.2017.12.015>.
- Patchanee, P., Tansiricharoenkul, K., Buawiratlert, T., Wiratsudakul, A., Angchokchatchawal, K., Yamsakul, P., Yano, T., Boonkhot, P., Rojanasatien, S., Tadee, P., 2016. *Salmonella* in pork retail outlets and dissemination of its pulsotypes through pig production chain in Chiang Mai and surrounding areas, Thailand. *Prev. Vet. Med.* 130, 99–105. <https://doi.org/10.1016/j.prevetmed.2016.06.013>.
- Phan, T.T., Khai, L.T.L., Ogasawara, N., Tam, N.T., Okatani, A.T., Alkiba, M., Hayashidani, H., 2005. Contamination of *Salmonella* in retail meats and shrimps in the Mekong Delta, Vietnam. *J. Food Prot.* 68, 1077–1080. <https://doi.org/10.4315/0362-028X-68-5.1077>.
- Prime Minister, 2023. Decision No. 300/QĐ-TTg: Approving the national action plan to transform the food systems towards transparency, responsibility and sustainability in Vietnam by 2030.
- Rortana, C., Nguyen-Viet, H., Tum, S., Unger, F., Boqvist, S., Dang-Xuan, S., Koam, S., Grace, D., Osbjørn, K., Heng, T., Sarim, S., Phirum, O., Sophia, R., Lindahl, J.F., 2021. Prevalence of *Salmonella* spp. and *Staphylococcus aureus* in Chicken Meat and Pork from Cambodian Markets. *Pathogens* 10, 556. <https://doi.org/10.3390/pathogens10050556>.
- Takeshi, K., Itoh, S., Hosono, H., Kono, H., Tin, V.T., Vinh, N.Q., Thuy, N.T.B., Kawamoto, K., Makino, S., 2009. Detection of *Salmonella* spp. isolates from specimens due to pork production chains in Hue City, Vietnam. *J. Vet. Med. Sci.* 71, 485–487. <https://doi.org/10.1292/jvms.71.485>.
- Thai, T.H., Hirai, T., Lan, N.T., Yamaguchi, R., 2012. Antibiotic resistance profiles of *Salmonella* serovars isolated from retail pork and chicken meat in North Vietnam. *Int. J. Food Microbiol.* 156, 147–151. <https://doi.org/10.1016/j.ijfoodmicro.2012.03.016>.
- USDA, 2020. Vietnam Retail Foods (No. VM2020- 0069). Hanoi, Vietnam.
- Van, T.T.H., Moutafis, G., Istivan, T., Tran, L.T., Coloe, P.J., 2007. Detection of *Salmonella* spp. in retail raw food samples from Vietnam and characterization of their antibiotic resistance. *Appl. Environ. Microbiol.* 73, 6885–6890. <https://doi.org/10.1128/AEM.00972-07>.
- Vu, T.H.A., Hai, C.V., Ha, H.Y., Tu, N.H.K., 2021. Antibiotic resistance in *Salmonella* isolated from Ho Chi Minh City (Vietnam) and difference of sulfonamide resistance gene existence in serovars. *J. Pure Appl. Microbiol.* 15, 2244–2251. <https://doi.org/10.22207/JPAM.15.4.46>.
- Wallace, F., Mittal, N., Lambertini, E., Nordhagen, S., 2022. Vendor knowledge, attitudes, and practices related to food safety in low- and middle-income countries: a scoping review. *J. Food Prot.* 85, 1069–1078. <https://doi.org/10.4315/JFP-21-439>.
- WHO, 2006. A guide to Healthy food Markets. World Health Organization.
- WHO, 2023. Five keys for safer traditional food markets: risk mitigation in traditional food markets in the Asia-Pacific Region; Manila.
- Yokozawa, T., Dang-Xuan, S., Nguyen-Viet, H., Lapar, L., Makita, K., 2016. Transition of *Salmonella* prevalence in pork value chain from pig slaughterhouses to markets in Hung Yen, Vietnam. *J. Vet. Epidemiol.* 20, 51–58. <https://doi.org/10.2743/jve.20.51>.