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Microbial contamination and associated risk factors in retailed pork from key value chains in Northern Vietnam

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ABSTRACT

Pork and pork products are important staple food in the diet of Vietnamese consumers. The safety of pork, including biological contamination, is a concern to several public authorities and value chain actors. This cross-sectional study aimed to identify *Salmonella* and total bacterial count (TBC) contamination of cut pork sold in different outlets, and determine the potential factors leading to contamination. A total of 671 pork samples were collected from different retail channels in three provinces in Northern Vietnam. Hygiene conditions and practices at pork vending premises were also observed and recorded. Data analysis used descriptive statistics and regression analysis. Overall, *Salmonella* prevalence in retailed pork was 58.1%. *Salmonella* contamination in pork from traditional retail, modern retail and food services were 60.5%, 50.9% and 80.5%, respectively. Eighty percent and 68% of fresh pork in canteen and street food was contaminated with *Salmonella*. Only a small proportion of a subset of the pork samples (6.2%) tested met the Vietnamese standard requirement for TBC contamination. Average concentration of TBC in fresh pork in traditional retail, modern retail and food services were 6.51 (SD: 0.64), 6.38 (0.65), and 6.96 (0.85) LogCFU/g, respectively. Transport time, use of the same tools for pork and other types of meat, storage temperature, and environment hygiene are important factors that might affect microbial contamination. The findings underline the high level of microbial contamination, which requires practical interventions to improve food safety hygiene practices and behavior of pork retailers.

1. Introduction

Pork and pork products play an important role in the diet of Vietnamese people, contributing over 52.7% of the total meat intake (Nguyen et al., 2014). Pork consumption per capita has been increasing from 8 kg in 1990 to 30 kg in 2019, which makes the Vietnamese among the highest pork consumers worldwide (OECD, 2019). Although pig production sometimes fluctuated due to diseases, such as porcine reproductive and respiratory syndrome in 2012 and 2016, foot-and-mouth disease and African swine fever in early 2019 (General Statistics Office, 2019), pig farming has experienced an upward pattern. There has also been a rise in the number of retail stores in Vietnam of both traditional and modern channels, including for pork products (Dang and Ngo, 2018). For example, the increase of wet markets offers consumers quick and affordable access to staple food products, while the emergence of convenience stores and boutique shops (high-end food stores) fulfills demand of some consumers, especially in big cities.

However, the increasing quantity of pork supply does not seem to

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lead to improvements in quality. Pork consumers are concerned about food safety issues, especially those associated with chemical and microbial hazards (Ha et al., 2019; USAID, 2015). Recent studies reported that microbial contamination was the main culprit of disease outbreaks which contribute most to the burden of food-borne illness (Latha et al., 2017; The World Bank, 2017a; World Health Organization, 2015). *Salmonella* is also one of the major food-borne pathogens, which causes diarrhoea in Southeast Asia (World Health Organization, 2015), and requires high cost for treatment (Hoffmann and Anekwe, 2015). Moreover, a recent study estimated an annual incidence rate of 17.7% for human salmonellosis in Vietnamese consumers that originated from pork (Dang-Xuan et al., 2017).

Microbial contamination in pork can occur at any stage, from pig slaughtering to pork distributing at retail or pork handling in the households (Dang-Xuan et al., 2016). Although the government makes efforts to upgrade the pork production and retail from the household level to modern and large scale retail stores, smallholder pig production is expected to continue contributing most of the pork sales in the country for many years (Lapar, 2014). This trend poses many challenges for policymakers to mitigate the risk of contaminated pork to consumers' health. Several previous studies revealed that *Salmonella* are prevalent in pork bought from different retail types (Dang-Xuan et al., 2019; Nguyen et al., 2016; Nhung et al., 2018; Phan et al., 2005). The food supply chain is undergoing significant transformation with the rapid growth of modern retail, which is providing chilled and traceable (i.e. labeled and veterinary stamped) pork (The World Bank, 2017a). Nevertheless, it is still unclear whether the pork purchased from modern shops, typically originating from large-scale and integrated companies, delivers a different level of risk of microbial contamination compared with pork from traditional shops. Varying levels of microbial contamination could be due to differences in origin, number of pigs slaughtered and hygienic practices used, and whether the pork is purchased from traditional or wet markets.

The Vietnamese Food Safety Law enacted in 2011 is an attempt to implement a risk-based food safety control system by the government (The World Bank, 2017a). It made a priority request for a necessary assessment of food safety risks, including in the pig industry, in Vietnam. To date, the majority of studies in Vietnam have provided information on microbiological contamination levels while comprehensive evaluations of underlying risk factors pertaining to the level of microbial contamination of different retailed pork are limited as are analyses of the relationship between microbial contamination and related factors (Pham et al., 2018). Most assessments have focused only on food safety practices (Vo et al., 2015) or microbial contamination (Nguyen et al., 2016; Nhung et al., 2018; Phan et al., 2005). Thus, this study aimed to (1) determine contamination levels of *Salmonella* and total bacterial count (TBC) in fresh pork sold in different market types in Northern Vietnam, and (2) explore the association between contamination of pork and market types, management, and hygiene practices.

2. Material and methods

2.1. Value chain description

The different pork-selling value chains in Vietnam are defined as follows:

Traditional retails can refer to traditional outlets such as "traditional markets", "wet/open markets", "public markets" or "fresh markets". In general, these retails can be divided into two main groups, that is, *traditional markets* and *wet markets* depending on management systems (Giddings, 2016; Unger et al., 2019). The traditional markets are characterized by their own management systems and often large and permanent operating locations; while the wet markets have either no or an "unofficial" management system, and are often located around residential areas to sell fresh food such as meat, fish, eggs, and vegetables (Nga et al., 2014).

Modern retails include supermarkets, convenience stores and boutique shops, depending on characteristics of location, scale and goods sold. Supermarkets are large and sell a wide variety of commodities such as food, clothes, electronic devices and so forth. Convenience stores have modern infrastructure and management and are often located in the main town streets or big residential apartments. These modern retails typically consist of one room mainly selling goods used daily such as food (especially snacks and beverages) or hygiene products (e.g. toothpaste, shampoo). The third category, boutique shops, sells the so-called environmentally friendly, traceable and organic or high-quality pork to consumers. Boutique shops sell pork at a cost that is 1.5 to 2 times higher than traditional retails because they target high- and middle-income customers who are concerned about the traceability and safety of the pork they buy (Unger et al., 2019).

Food services, in this paper, refer to street food vendors and canteens. Street food is characterized by a small food facility, located in the street which serves ready-to-eat food. There were about 5218 street food vendors in Hanoi in 2017 and managing food safety in street food has been a challenge for the government (Unger et al., 2019). A canteen is defined as a food facility that serves more than 30 ready-to-eat food meals at a time and is often located within a school, hospital or factory (Unger et al., 2019). High-end restaurants, often with indoor seating, are common in Hanoi but were not covered in this study.

2.2. Study site

The selection of the pork value chain and district in each province was based on the guidelines and criteria developed by the SafePORK project (ACIAR, 2016). Three provinces in the North of Vietnam, namely Hanoi, Hung Yen and Nghe An were chosen in the study (Fig. 1). Hanoi city represented an urban setting with a diversity of pork value chains including traditional, modern and food service retail. Hung Yen and Nghe An provinces represented rural areas where the pork value chain had been recently upgraded by two initiatives namely, the Livestock Competitiveness and Food Safety Project (LIFSAP) (The World Bank, 2017b) and the Vietnamese Good Animal Husbandry Practices (VietGAHP) (MARD, 2011) that aim to improve the quality and safety of pork.

2.3. Study design and sample sizes

A cross-sectional study was conducted between September 2018 and April 2019. In Hanoi, sampling was done at traditional and modern retails in five urban districts of the city, namely Ba Dinh, Cau Giay, Dong Da, Ha Dong and Hai Ba Trung. These five districts were selected as they represent important business hubs (e.g. Cau Giay) or populated residential areas (e.g. Dong Da) within Hanoi. In detail, a list of traditional markets, supermarkets, convenience stores, boutique shops located in these districts were made, then used for random sampling. Wet markets and street food vendors were selected but the latter were in Cau Giay only. In case of canteen, they were chosen through the Food Safety and Hygiene Division of Hanoi. Finally, the pork sold in traditional markets linked to VietGAHP cooperatives in Tien Lu District of Hung Yen and Dien Chau District of Nghe An were also sampled to represent traditional retails in rural areas. Hung Yen and Nghe An provinces are located northeast of the Red River Delta and the northwest of central Vietnam, accordingly, and have many livestock husbandry activities.

The sample size calculation was based on the two proportions comparison with an expected *Salmonella* prevalence in pork at Hanoi modern and traditional retails of 45% and 60%, respectively, as well as an intra-cluster correlation (ICC) of 0.2, average cluster (market) size of 5, and design effect of 1.2. For street food, we used a single proportion calculation with an expected prevalence of 50%, ICC of 0.2, average cluster size of 3, precision of 0.1. For other value chains: canteens (Hanoi) and upgraded traditional retails in Hung Yen and Nghe An, the number of samples were set up to be at least 20. In total, 671 pork samples were

Fig. 1. Locations of the three studied provinces in Northern Vietnam.

collected. Details on samples collected by districts and value chain are presented in Table 1 below.

2.4. Sampling frame and collection

Number of samples collected and tested for *Salmonella* detectable in 25 g cut pork and TBC across retail types, locations and value chains are shown in Table 1. Raw pork samples (approximately 300 to 400 g per sample) of raw pork were collected from different retails following a hierarchical structure including district, markets, retailers (only for the traditional value chain). In modern retail, four to five samples were collected per supermarket, while two samples were taken in each selected convenience store or boutique shop. In the wet markets, two pork shops were chosen for sampling with one sample per shop. For the

Table 1
Number of samples collected and tested for *Salmonella* detectable in 25 g cut pork and TBC across retails, locations and value chains.

Retail types	Location	Value chain	No. of samples collected	No. of samples tested	
				Salmonella	TBC[c]
Traditional ($n = 266$)	Hanoi	Traditional market	114	114	27
	Hanoi	Wet market	112	112	26
	Nghe An	LIFSAP[a] pork	20	20	10
	Hung Yen	VietGAHP[b] pork	20	20	10
Modern ($n = 328$)	Hanoi	Supermarket	115	115	18
		Boutique shop	93	93	11
		Convenience store	120	120	24
Food service ($n = 77$)	Hanoi	Canteen	24	24	12
		Street food	53	53	27
Total			671	671	165

[a] LIFSAP: The Livestock Competitiveness and Food Safety Project.
[b] VietGAHP: Vietnamese Good Animal Husbandry Practices.
[c] TBC: Total bacterial count.

traditional markets, five shops were selected with one sample per shop collected. Street food vendors next to public places, schools or kindergartens were selected for sampling with one sample per vendor. Within each canteen in a hospital or school in Cau Giay District, identified with the help of local authorities, four samples were collected. At the street food vendor and canteens, only raw pork was selected for sampling. Samples were aseptically collected and placed in sampling bags and preserved in cool boxes with ice packs. The samples were then transported to the lab within 3 h and immediately processed (MOST, 2002).

2.5. Data collection

During the sampling process, a checklist was used to observe and inquire about management and cleanliness of the shop and food safety practices of retailers. Observers were researchers at the Center for Public Health and Ecosystem Research, Hanoi University of Public Health. The checklist was first developed in the Vietnamese language and pre-tested to evaluate its suitability before it was used for all markets. The content of the checklist is included in Tables 2, 3, and 5.

2.6. Sample preparation and microbiological analysis

Collected samples were analyzed for the presence/absence of *Salmonella* spp., a major food-borne disease hazard, and TBC, the latter being used as a proxy for hygienic conditions.

2.6.1. Salmonella isolation

Salmonella isolation procedure was applied following the ISO-6579-1:2017 (ISO, 2002). First, 25 g of cut pork was mixed with 225 ml Buffered Peptone Water (BPW; Merck-Germany) in a sterile plastic bag using a stomacher. The BPW homogenate then was incubated for 16–18 h at 37 °C as a pre-enrichment step prior to inoculation of selective media. A Muller Kauffmann Tetrathionate broth (TT; Merck, Germany) and a Modified Semisolid Rappaport-Vassiliadis agar plate (MSRV; Merck, Germany) were used for the first selection step. Both inoculated media were incubated (16–20 h at 37 °C for TT and 40–48 h at 42 °C for MSRV) prior to move to the second selection by using one loop (approximately 10 μl) of TT and MSRV to inoculate Xylose Lysine Tergitol 4 (XLT4; Merck, Germany) and Rambach (Merck, Germany) agar plate. The suspect colonies were cultured on nutrient agar and confirmed by biochemical reactions (e.g. lactose, indol, lysine, H_2S, and urease phenotypes) and serology (Antiserum *Salmonella* Polyvalent-O [Bio-Rad, France]) (Dang-Xuan et al., 2019).

Table 2
Characteristics of traditional pork shops.

Characteristics	n (N = 266)	%
Type of selling		
Retail only	141	53.0
Both wholesale and retail	125	47.0
Hygiene practice		
Pork had inspection stamp	6	2.3
Table higher than 60 cm	254	95.5
Water available at shop for washing	144	54.1
Soap available at shop for washing	8	3.5
Cloth is used for wiping meat	231	86.8
Cloth is cleaned after using	27	11.7
Sellers wore gloves	73	27.4
Sellers wore apron	189	71.1
Seller wore hygiene cap	11	4.1
Shop located in pork sales area	123	46.2
Stagnant sewage/water on the floor	97	36.5
Waste collected at/around the shop	85	32.0
Sell pork only	204	76.7
Pork is placed in proximity to raw organs or meat	135	50.8
Pork is stored in a cooler facility	5	1.9
Pork is covered or packed	3	1.1
Origin of the meat		
Self-slaughtering at home	93	35.0
Bought from wholesalers	42	16.9
Bought from slaughterhouses	121	45.5
No response	7	2.6
Transportation	**Mean**	**SD**
Distance to transport pork to the market (km)	25.5	20.8
Duration of transport (min)	47	26
Amount of pork sold per day (kg)	57	31

Table 3
Characteristics of modern retails (convenience store, boutique shop and supermarket) and their pork.

Characteristics	n	%
Type of surface to place pork at shops ($n = 123$)		
Stainless steel	21	17.1
Plastic	99	80.5
Not applicable	3	2.4
Selling and display pork at shops (n = 123)		
Sell pork only	20	16.3
Have cool facilities to store pork	117	95.1
Have facilities to cover pork	118	95.9
Pork is placed in proximity to raw organs or meat (n = 123)		
Yes	92	74.8
No	31	25.2
Number of days after packaging of pork samples ($n = 328$)		
0 day	235	71.6
1 day	59	18
2 days or more	32	9.8
No information	2	0.6
Number of days from sampling to expiry date of pork samples (n = 328)		
0 day	28	8.5
1 day	54	16.5
2 days	118	36
3 days	48	14.6
4 days or more	41	12.5
No information	39	11.9
Packing of pork (n = 328)		
Pre-packed in covered disposable tray	303	92.4
Prepacked in vacuum bag	14	4.3
Freshly cut and placed in plastic bag	11	3.3
Pork had inspection stamp (n = 328)		
Yes	120	36.6
No	208	63.4

2.6.2. Total bacterial count

A subset of 165 samples (Table 1) were randomly selected for total bacteria count analysis using the ISO-4833-2:2013 procedure (ISO, 2013). The ten fold serial dilution (from 10^{-2}, to 10^{-6}) was made using

Maximum Recovery Diluent medium (MRD; Merck, Germany). Each appropriate dilution (1 ml) was inoculated onto two plates of Plate Count Agar (PCA, Merck, Germany) using the surface plating technique. The plates then were incubated at 30 °C for 48 h to obtain the number of colonies.

2.7. Data and statistical analyses

Retailer checklist information and laboratory results were entered in Microsoft Excel 2016. All statistical analyses were conducted using R version 4.0.2 (R Core Team, 2020). The TBC count of CFU/g was transformed to logCFU/g to facilitate analyses. Descriptive statistics, such as mean, standard deviation, or frequencies were used. A Chi-squared test was used to compare the difference in *Salmonella* prevalence and the proportion of underqualified TBC contamination samples between value chains while ANOVA test was utilized for the difference in the mean of logCFU/g of TBC.

For all regression models, dependence variables were the presence/absence of *Salmonella* (using logistic regression model, glmer, lme4 package), and the logCFU/g of TBC (using linear regression model, lmer, lme4 package) of samples from traditional and modern retails only. Univariable analyses were carried out first to select variables which had *p*-value of ≤0.2. Second, these models were built following a backward stepwise elimination, starting from all variables selected from univariable analyses, then only variables that have p-value equal or less than 0.05 remained in the final models.

2.8. Ethical considerations

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

3. Results

3.1. Pork value chain characteristics

In traditional shops, most of the retailers were woman (91.3%) aged from 31 to 50 years old (81.6%, data not shown). On average, pork was transported about 26 (SD: 21) km to the markets for 47 (SD: 26) minutes. Only a small proportion of traditional retailers wore gloves (27.4%) or hygiene caps (4.1%). Cloth was used by 86.8% of the traditional retailers to clean or wipe pork and surfaces but it was rarely cleaned during the selling hours (11.7%). Although more than half of traditional shops (54.1%) had water for cleaning, only a few (3.5%) had soap for washing hands and equipment (Table 2).

Most pork in modern shops was kept in cool conditions (95.1%) and wrapped in a tray (92.4%). Besides, a majority of samples were collected on the same day the pork was processed (71.6%), and two days before the expiry date (36%). Only 36.6% of pork samples had inspection stamps from food safety authorities, and 74.8% of samples were kept in proximity to raw internal organs or other meat types (Table 3).

3.2. Salmonella prevalence and total bacteria count in pork and associated factors

The overall *Salmonella* prevalence in pork was 58.1%. Regarding retail type, *Salmonella* prevalence in traditional retail, modern retail and food service retail were 60.5%, 50.9% and 80.5%, respectively. *Salmonella* prevalence in food service retail was significantly higher compared to that in traditional and modern retail (p-value <0.01, Chi-square test). For specific value chain types, the highest *Salmonella* contamination was found in street food (84.9%) followed by traditional market (71.9%), canteen (70.8%) and upgraded traditional retail (LIFSAP and VietGAHP, 60–65%). Within traditional retails, *Salmonella* prevalence in traditional markets was significantly higher than in other value chain types (*p*-value <0.01, Chi-square test, Table 4).

Regarding to the overall TBC result, 93.8% samples did not meet the Vietnamese standard, which allows TBC contamination in fresh meat of below 5.7 logCFU/g (MOH, 2012). Among all types of retail, wet markets, VietGAHP and street food had 100% samples underqualified while boutique shops and convenience stores had higher qualified proportions. However, there was no difference among these proportions from each retail type (p-value >0.1, Chi-square test) although there is significant difference in TBC concentration among all value chains (p-value <0.01, ANOVA test). Among three retail types, pork samples from modern retail had the lowest TBC concentration (6.38 logCFU/g). Among all value chain types, LIFSAP pork had the lowest TBC concentration (6.07 logCFU/g, Table 4).

Regression models revealed that using different cloths to wipe pork and the equipment reduces the likelihood of *Salmonella* contamination (OR = 0.35, 95% CI: 0.13–0.96) in traditional retail. In contrast, *Salmonella* contamination in pork samples was positively associated with the presence of sewage or stagnant water on the shop's floor (OR = 2.1, 95% CI: 1.01–4.34). Moreover, pork samples from stores which sell other types of meat had higher *Salmonella* contamination. In addition, every 10 min of prolonged transport time, from slaughterhouse to the market, the TBC concentration increased by 0.09 LogCFU/g. The model also indicated that late sampling time could lead to higher log TBC (Table 5). In case of modern retails, increasing storage temperature by 1 °C increased the chance of *Salmonella* presence by 1.31 times.

4. Discussion

Our study revealed a high prevalence of *Salmonella* and TBC concentration in key pork value chains in Northern Vietnam and identified associated risk factors. This study also covered both rural and urban settings, which could help to increase the representation of the results across different pork sectors.

Overall, the presence of *Salmonella* in retail pork samples in our study (58.1%) was in the range reported in the review of Cook and Pham for Vietnam, from 25.0 to 72.7% (Cook and Pham, 2019). This figure is lower than that stated for the southern provinces (Nguyen et al., 2016; Nhung et al., 2018; Phan et al., 2005; Van et al., 2007), but higher than in Lam Dong, the central highland province, or Hung Yen and Nghe An, the same study sites (Dang-Xuan et al., 2019; Pham et al., 2018). These differences may be explained by the variation in study locations. In addition, we found a very high proportion of pork samples in all types of markets with TBC levels exceeding 5.7 logCFU/g (MOH, 2012). This finding is similar to results of previous studies conducted in Hanoi, Hung Yen, Nghe An and Lam Dong in Vietnam (Fahrion et al., 2013; Nguyen-Viet et al., 2019; Pham et al., 2018).

Among all retail types in this study, raw pork sold by street food vendors showed the highest *Salmonella* contamination, followed by pork from canteens and traditional markets. This result implies that unhygienic pork handling in the street food stall or kitchen can increase its microbial contamination which is supported by findings from Dang-Xuan et al. (Dang-Xuan et al., 2018) who evaluated cross-contamination during pork preparation. This prevalence was much higher than that in food service in Taiwan and Philippines (8–12%), Thailand (7.7%) and Madagascar (5–10%) (Cardinale et al., 2015; Manguiat and Fang, 2013; Polpakdee and Angkititrakul, 2015). The discrepancy can be explained by differences in sampling methods as pork was analyzed after being cooked in those studies. While *Salmonella* might be inactivated through heat, the risk of bacteria cross-contamination via utensils which have touched contaminated surfaces is still a prominent factor (Dang-Xuan et al., 2018). This risk is especially high for food handlers who may lack the awareness and skill to ensure food safety (Tran et al., 2018).

In addition, we found that pork in traditional retails had high contaminations of *Salmonella* (60.5%), which can be explained by several

Table 4
Contamination of *Salmonella* and total bacterial count in pork sold in difference retail and value chain types.

Type of market	*Salmonella* prevalence ($n = 671$)			TBC (LogCFU/g, $n = 165$)			
	No. of positive samples/n	Percentage (%)	p-value	Mean	SD	% exceed standard***	p-value
Retail type							
Traditional retail	161/266	60.5[a]	<0.01*	6.51	0.64	97.3	>0.1*
Modern retail	167/328	50.9[a]		6.38	0.65	88.0	<0.01**
Food service retail	62/77	80.5[b]		6.96	0.85	94.6	
Retail and value chain types							
Traditional retail							
Traditional market	82/114	71.9[a]	<0.01*	6.67	0.78	96.0	>0.1*
Wet market	54/112	48.2[b]		6.52	0.55	100	<0.01**
LIFSAP pork	13/20	65.0[b]		6.07	0.32	91.7	
VietGAHP pork	12/20	60.0[b]		6.54	0.63	100	
Modern retail							
Supermarket	59/115	51.3[b]		6.27	0.33	95.5	
Boutique shop	47/93	50.5[b]		6.23	0.87	81.8	
Convenience store	61/120	50.8[b]		6.57	0.76	82.4	
Food service retail							
Canteen	17/24	70.8[b]		6.24	0.73	83.3	
Street food	45/53	84.9[b]		7.31	0.68	100	
Overall	390/671	58.1		6.57	0.73	93.8	

[a,b]Different letters indicate significant difference.
* Chi-square test for proportion.
** ANOVA test for meant TBC.
*** 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)CFU/g) (MOH, 2012).

Table 5
Factors associated with the presence of *Salmonella* and TBC contamination in pork.

Variables	*Salmonella* contamination			TBC contamination (LogCFU/g)			
	OR	95% CI	p-value	Coef.	LS-mean	95% CI	p-value
Traditional retails							
Duration of transport pork to the market (10 min)				0.09	6.79	6.55–7.04	0.03
Value chain							
Traditional market				Ref.	6.5	6.23–6.76	
VietGAHP				0.95	7.45	6.83–8.07	0.01
Time of sample collection							
Before 8 am				Ref.	6.15	5.84–6.47	
Between 8 and 9 am				0.46	6.62	6.22–7.02	0.14
Between 9 and 10 am				1.04	7.2	6.78–7.62	<0.01
After 10 am				1.05	7.2	6.68–7.73	<0.01
Used separate cloths for wiping pork and equipment							
No	Ref.						
Yes	0.35	0.13–0.96	0.04				
Presence of sewage or stagnant water on the shop's floor							
No	Ref.						
Yes	2.1	1.01–4.34	0.05				
Modern retails							
Preservation temperature (+1 °C)	1.31	1.04–1.65	0.02				
Only pork is sold							
No	Ref.						
Yes	0.14	0.03–0.64	0.01				

reasons. First, pork may be contaminated at the slaughterhouse due to several critical hygiene practices leading to microbial (cross-) contamination (Yokozawa et al., 2016). Second, transport of pork or carcasses to traditional markets–which usually happens on motorbikes without covering or any chilling facilities–is also a critical point of contamination (Yokozawa et al., 2016). Pork in wet markets was less contaminated than that in traditional markets although the former are often informal and temporary (i.e. on the side of the road), while the latter requires a better organized and located area of the city. Our study found that retailed pork at LIFSAP and VietGAHP value chains, under food safety improvement programs, was not necessarily more hygienic than that from the informal value chain (i.e. wet markets). These findings should be interpreted with caution due to the limited number of samples analyzed in this study. Further studies are needed to explain the unsatisfactory food safety outcomes in the LIFSAP and VietGAHP chains.

There were some improved hygienic practices (e.g. most pork was covered and stored in cool temperature) in modern retail. However, contamination in these retails was still unacceptably high with one in two samples contaminated with *Salmonella*. This was lower than in pork samples from traditional markets, where food safety deficits still exit. The limited food safety outcomes at modern retail despite the observed better pork handling practices, might be explained by pork contamination downstream in the value chain (e.g. during slaughter of pork prior to retail).

The overall food safety conditions at the pork shops contributed significantly to microbial contamination. First, we found that if the pork was kept at higher temperature or placed in the vicinity of other types of meat, it was more likely to have *Salmonella* contamination. Therefore, keeping temperatures cool during pork production is essential to slow down bacterial growth and limit further contamination (Cook and Pham, 2019). Second, transportation is a critical area to improve the safety of pork since time of transportation had a significant impact on

contamination. Third, the study found that various waste products (e.g. sewage, trash, or internal organs) nearby where pork was handled or sold influenced the level of *Salmonella* in pork samples. These conditions are likely to facilitate cross-contamination and accelerate bacterial growth. This means that the environment around pork shops needs to be kept clean to prevent *Salmonella* contamination. Fourth, poor hygiene practices of retailers can be another source of contamination. In our study, the use of separate cloths to wipe pork and surfaces helped to decrease *Salmonella* contamination in pork. This is in line with the findings of another study which demonstrated that using the same cloth in shops for wiping pork, surfaces, and hands of retailers could increase *Salmonella* contamination (Dang-Xuan et al., 2019). Nevertheless, the use of cloths in pork shops should be a critical consideration in reducing food contamination because such cloths can be carriers of bacteria from other surfaces to meat. Further research on the use of cloths in pork shops and bacteria contamination of food is needed in order to find ways of reducing such contamination (including through frequent cleaning and disinfection of surfaces and cloths).

4.1. Implication

High *Salmonella* contamination in pork across all retail types indicated a potential health risk for Vietnamese consumers. This situation could be attributed to unhygienic practices along the pork value chain, from slaughtering, transporting to selling, although this was not assessed by the present study, since the focus here was on retails. Therefore, interventions should be considered for implementation along the value chain, especially at pig slaughterhouses and pork markets in order to motivate changes in the pork handling practices of these actors. *Salmonella* contamination across different retails have been modeled to estimate health risk of acquiring salmonellosis pf pork consumers in Vietnam by Dang-Xuan et al. (Dang-Xuan et al., 2017). Finally, monitoring of retailer practices including hygiene inspections should be carried out more frequently by the local authorities in order to promptly detect and mitigate pork contamination. The active involvement of government is necessary to improve the management of the value chain.

4.2. Limitations

This study had the following limitations: Using observation, which may induce some bias due to the subjectivity of observers. To minimize that, observers were trained and practiced the evaluation criteria for the checklist before conducting the study. The other limitation is that only a few sellers at modern retails were willing and able to provide correct information, which is a hindrance for analyzing relevant risk factors in this channel. While the sample size for modern and traditional retail was representative, the sample sizes for the LIFSAP or VIETGAP value chains was limited due to logistical reasons and number of available retailers. It should also be noted that willingness to participate in the survey varied across actors and was lowest in the food services group.

5. Conclusions

Our study provides up-to-date evidence on the prevalence of *Salmonella* and TBC in pork samples in key pork retail types in Vietnam. Pork was contaminated with *Salmonella* across all retail types. Only a few pork samples across different retail types in the three studied provinces of Northern Vietnam met government food safety requirements. Unsatisfactory food safety outcomes were associated with management (long transportation time) and poor hygiene practices (i.e. not separating pork and other meat and storing pork at inappropriate temperature) in both traditional and modern channels in rural and urban areas. Efforts are needed to improve food safety practices in all the channels assessed in this study. This requires behavioral change and identification of suitable interventions that will be accepted by retailers to mitigate microbial contamination.

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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