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Risk factors associated with *Salmonella* spp. prevalence along smallholder pig value chains in Vietnam

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ABSTRACT

The objective of this study was to investigate the prevalence of, and risk factors for, *Salmonella* contamination along the smallholder pig value chain in northern Vietnam. Repeat cross-sectional (for farm and pork shops) and longitudinal (for slaughterhouses) studies were carried out in Hung Yen and Nghe An provinces in four sampling periods over a year (April 2014 to February 2015).

In total, 72 pig farms and 217 pork shops were visited during the period, and 13 slaughterhouses were visited four times. Information on management and hygiene practices was collected using checklists and questionnaires, and risk factor analyses at the farm, slaughterhouse, and pork shop levels were performed using generalized mixed-effects models with the significant levels 10%.

Salmonella prevalence was 36.1%, 38.9%, and 44.7% on pig pen floors, pig carcasses in slaughterhouses, and cut pork in pork shops, respectively. The risk factor for *Salmonella* prevalence on pig pen floors were having a pig pen next to a household ($p = 0.06$) and free access to the farm by visitors ($p = 0.06$). Our slaughterhouse model found a single risk factor for carcass contamination: slaughter area close to lairage without hygienic measures ($p = 0.03$). For pork shops, presence of flies or insects on pork at shop ($p = 0.02$) and use of a cloth at pork shop ($p = 0.02$) were risk factors. The *Salmonella* prevalence on pig carcass and cut pork was significantly lower in winter compared to that in other seasons. Our study results highlighted the need of improving farm hygiene at farm level, and pork hygiene practices to avoid cross-contamination at the slaughterhouse and market levels, to reduce the risk of salmonellosis through pork consumption in northern Vietnam.

1. Introduction

Salmonella is an important foodborne pathogen worldwide. There are an estimated 22.8 million human salmonellosis cases in the South East Asia region each year (Majowicz et al., 2010), whereas reported cases of human salmonellosis in the United States in 2009 and in the European Union in 2015 were approximately 40,000 (CDC, 2009) and 94,000 (EFSA and ECDC, 2016), respectively. Pork has been implicated as one of the most important sources of *Salmonella* (together with egg and poultry) in several countries (Davidson et al., 2011; EFSA, 2008; Havelaar et al., 2008; Pires et al., 2014). The estimated annual cost of human *Salmonella* infections in 2008 from all sources was about € 608 million in the European Union (FCC, 2010) and about $3.4 billion in the US in 2013 (USDA, 2013). This economic burden of *Salmonella* infection is significant in both low and middle income countries (LMIC), and high income countries, implying the need for enhanced monitoring and reporting systems, improved food safety, and greater consumer awareness (Schwartz, 1999). However, intervention programs to control *Salmonella* in pork production are costly, requiring investment in biosecurity facilities and training on hygiene practices in farms, slaughterhouses, processing plants, and retail outlets. Therefore, understanding risk factors is expected to facilitate the targeting of effective intervention points and reducing associated costs.

Salmonella prevalence and related risk factors in the pig value chain have been well characterized in the United States, Australia, and Canada, as well as in European Union countries. *Salmonella* contamination of

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finished carcasses can be linked to farm level *Salmonella* infection in pigs destined for slaughter (Berends et al., 1996). At the slaughterhouse, cross-contamination has been shown to significantly affect the occurrence of *Salmonella* on pig carcasses (Duggan et al., 2010). At the distribution level, *Salmonella* contamination has been found to be related to the type of retail outlet (Hansen et al., 2010). Contamination of pork has important health and financial implications: in the Netherlands and Germany, it has been estimated that 15–20% of *Salmonella* infections in humans are caused by consumption of contaminated pork or processed pork (Berends et al., 1996; Steinbach and Kroell, 1999).

Pork consumption in Vietnam is relatively high compared to that in other countries with similar GDP (29.1 kg pork per capita yearly) (OECD, 2016); most (80%) of this pork is produced by small-scale producers and sold by small-scale retailers (Lapar and Tiongco, 2011). Recent studies in the Mekong Delta revealed poor hygiene at smallholder pig farms: 8.2% of drinking water for pigs sourced from local rivers or ponds was contaminated with *Salmonella* (Tran et al., 2004). Pig abattoirs in Hanoi that processed 10–30 pigs/day had *Salmonella* prevalences of 52.1%, 62.5%, and 95.7% for caecal content, tank water, and carcass swab samples, respectively (Le Bas et al., 2006). In Hue province in central Vietnam, similar results were found after sampling various surfaces in slaughterhouses, such as cooking boards (28.6%), weighing bowls (38.1%), and floors (47.4%) (Takeshi et al., 2009). At the retail level, most pork in Vietnam is sold in informal "wet" markets. These open-air markets, which can take the forms of central markets, village markets, or roadside vendors, can consist of as many as 20 pork stalls or as few as 1–2 (Dang-Xuan et al., 2017). Studies in northern Vietnam found prevalences of *Salmonella* in pork wet markets of 39.6% (Thai et al., 2012) and 25% (Yokozawa et al., 2016), and a study in southern Vietnam detected a prevalence of 69.9% (Phan et al., 2005). The *Salmonella* serotypes reported in Vietnam were *S. typhimurium*, *S.* Anatum and *S.* Weltevreden in pig faeces at farm (Tran et al., 2004; Vo et al., 2006); *S. typhimurium*, *S. derby* on pig carcasses at slaughterhouse (Dang-Xuan, 2013); and *S. derby*, *S.* Weltevreden, *S.* London (Dang-Xuan, 2013; Phan et al., 2005), *S.* Anatum and *S. infantis* (Thai et al., 2012) in pork at market. In particular, *S. typhimurium* was one of the most isolated *Salmonella* serotype (21/56, 37.5%) from diarrheal and febrile patients in Vietnam (Vo et al., 2006). These studies illustrate that *Salmonella* prevalence varies widely in different settings along the Vietnamese pig value chain.

This study was conducted as a part of a project, entitled "Reducing disease risks and improving food safety in smallholder pig value chains in Vietnam (PigRisk)", that sought to assess the impacts of pork-borne diseases on human health and to identify effective and feasible risk management options. The specific aim of this study was to investigate the prevalence of, and risk factors for, *Salmonella* contamination along the smallholder pig value chains in northern Vietnam.

2. Material and methods

2.1. Study sites and target population

This study was carried out in Hung Yen and Nghe An provinces between April 2014 and February 2015. Three districts were selected from each province to represent different value chain pathways: rural to rural, rural to peri-urban, and peri-urban to urban, according to a set of criteria developed by the PigRisk project which had identified these types of value chains as different domains for analysis and intervention (ILRI, 2013). Three communes were randomly selected from each of these selected districts, yielding a total of 18 communes: nine out of 161 communes in Hung Yen, and nine out of 469 communes in Nghe An. Hung Yen province is located northeast of the Red River Delta and Nghe An province is in the northwest of central Vietnam (Fig. 1). The scope of the research was the smallholder pig value chain (i.e., pig farm, slaughterhouse, and market), and slaughtering process, illustrated in Fig. 2. Therefore, farms, slaughterhouses, and markets in this study were selected to represent both small- to medium-scale farms (i.e., ≤10 pigs and 11–100 pigs, respectively), small- to medium-scale slaughterhouses (i.e., 1–10 pigs/day and 11–50 pigs/day, respectively) and wet markets (Dang-Xuan et al., 2017).

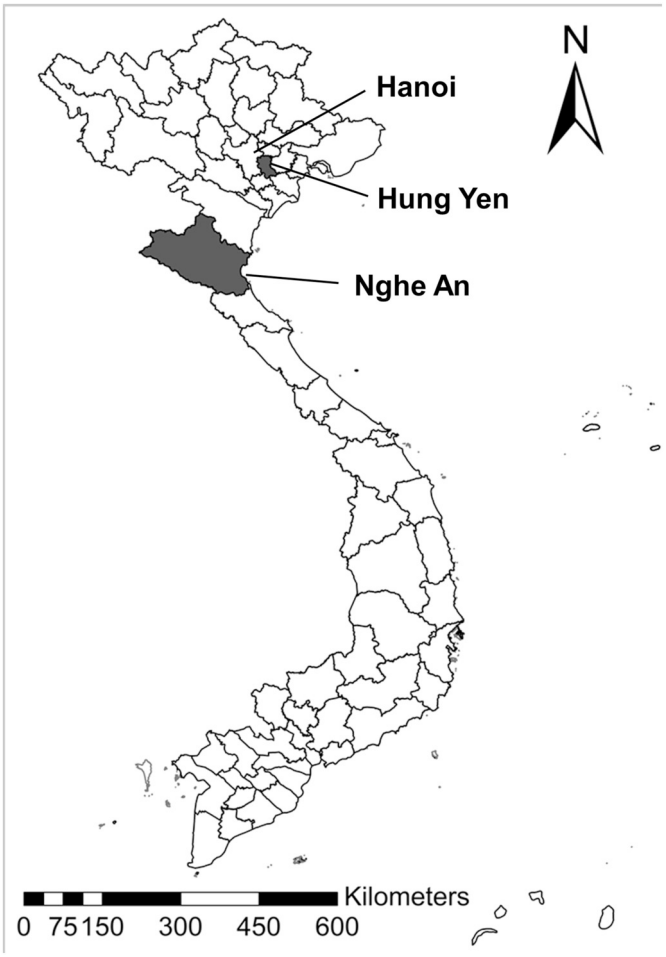

Fig. 1. A map showing the locations of study sites: Hung Yen and Nghe An provinces, and the capital city of Vietnam, Hanoi.

2.2. Study design

2.2.1. Study design and sample sizes

The study design included a repeat cross-sectional study for the farm and pork shops, and a longitudinal study for slaughterhouses. Sample sizes were based on a comparison of two proportions with a precision of minimum detectable difference of 10% in prevalence at a confidence level of 95% and power of 80%. Considering potential medium level of confounding for multivariable analysis, the calculated sample size was increased by 20% (Dohoo et al., 2009).

For the sample size at the farm level, the expected *Salmonella* prevalence on the pig pen floor was set at 25%, a value that fell approximately in the middle of reported range of prevalences (8.2% (Tran et al., 2004) and 49.4% (Vo et al., 2006)), and the difference in prevalence between exposed and non-exposed groups to detect was set at 15%. The expected *Salmonella* prevalences on slaughtered pig carcasses and retailed cut pork were determined to be 34.9% (Dang-Xuan, 2013) and 32.8% (Takeshi et al., 2009), respectively, as previously described, and the difference in prevalences between exposed and non-exposed groups to detect was set at 10% both for carcass and cut pork. Using epitools package in R (Aragon et al., 2017), the minimum required sample sizes were calculated as 60 farms, 146 pig carcasses, and 143 pork shops. The actual number of samples included 72 farms, 149 carcasses from 13 abattoirs, and 217 pork samples from 145 shops.