Influence of Market Type and Time of Purchase on Bacterial Counts and *Salmonella* and *Listeria* Prevalence in Whole Chickens in Vietnam

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Abstract: The objective of the current study was to determine the influence of market type and sampling time on *Salmonella* and *Listeria* prevalence and bacterial counts of 180 whole chicken carcasses collected from 6 supermarkets (SM), 6 indoor markets (IM), and 6 open markets (OM) in Vietnam, at opening (T0) and 4 h after the opening (T4). *Salmonella* and *Listeria* prevalence was at least 25.6% and 42.7%, respectively. Whole birds in IM had greater *Salmonella* prevalence than birds from both SM and OM by 28.4% and 23.0% ($P = 0.006$ and 0.022, respectively). *Listeria* prevalence was lower in whole chickens from SM, at 56.6%, than those in IM and OM (78.6% and 73.2%, $P = 0.024$ and 0.089, respectively). Whole chicken carcasses had more than 10.1, 7.5, and 9.4 log colony-forming units (CFU)/g of aerobic bacteria, *Escherichia coli* (*E. coli*), and coliforms, respectively. Both *E. coli* and coliform counts were greater in IM than in SM ($P = 0.002$ and 0.006). However, only *E. coli* counts differed between SM (7.7 log CFU/g) and OM (8.3 log CFU/g; $P = 0.024$). These results highlighted high levels of bacteria and high prevalence of *Salmonella* and *Listeria* in whole chickens in retail establishments in Vietnam, posing potential food safety and public health risks.

Introduction

Poultry primary processing in developed countries is commonly divided into the "dirty zone," including stunning, bleeding, scalding, defeathering, and evisceration, and the "clean zone," including washing and chilling (González-Miret et al., 2006). However, not all processing operations in developing countries can decontaminate and chill carcasses rapidly, which is required to control microbial loads (Belluco et al., 2016). Most European poultry processing plants use air-based chilling, whereas water immersion chilling is standard in the United States (Sánchez et al., 2002). Chilling is the final step in poultry primary processing because it is an essential stage to apply antimicrobials to reduce initial microbial count (Allen et al., 2000; Carroll and Alvarado, 2008). However, in developing countries such as Vietnam, most vendors in open markets (OM) and indoor markets (IM) harvest their birds

and have neither the intention nor the resources to chill carcasses immediately (Burgos et al., 2007). On the contrary, vendors in the supermarkets (SM) receive frozen and packaged whole chickens from standardized and sanitary processing plants.

Poultry meat is the second most popular animal protein in Vietnam after pork. Approximately 1.5 thousand tons of poultry meat were produced in 2020 (General Statistics Office of Vietnam, 2021). The annual average poultry meat per capita consumption in Vietnam is 7.1 kg (General Statistics Office of Vietnam, 2021). When purchasing whole chickens in Vietnam, consumers prefer to keep the viscera and internal organs with the carcasses in the same bag. This poses serious microbiological safety implications because the gastrointestinal tracts of birds are colonized with bacterial pathogens such as *Salmonella*. Moreover, during slaughter, leakage of intestinal contents may occur, which leads to fecal contamination of meat (Adeyanju and Ishola, 2014). In the US, although various interventions are available and applied during poultry primary processing at critical control points to lower overall bacterial counts (Lues et al., 2007; Mead, 2004; Svobodová et al., 2012), *Salmonella* prevalence in young chicken meat has been observed at 3.8 % in 2013 and 2014. Moreover, *Salmonella* prevalence in ground chicken was consistently reported at 44.6%. Although whole chicken is one of the most commonly consumed poultry products in developing countries such as Vietnam, there has not been any comprehensive study on *Listeria* levels in whole chickens. A few researchers such as Kuan et al. (2013) reported a 20.8% to 33.3% incidence in chicken offal in Malaysia, which has a similar culinary culture of consuming offal to Vietnam. A few other authors have investigated bacterial pathogens in whole chickens in Vietnam (Luu et al., 2006; Ta et al., 2012; Van et al., 2007), but none has considered the impacts of market setting, time of purchase, and differences in merchandising of poultry meat. Therefore, the objective of the current study was to investigate the prevalence of *Salmonella* and *Listeria* and bacterial counts of generic *Escherichia coli* and coliforms at 2 sampling times and as influenced by vendors' practices in 3 market types in Ho Chi Minh City (HCMC), Da Nang (DN), and Ha Noi (HN) in Vietnam.

Materials and Methods

Sample collection and preparation

Sample collection occurred between January and May of 2015 and followed a procedure similar to that described by McCain (2015) and McCain et al. (2015). Briefly, HCMC, DN, HN, and their surrounding areas were selected to represent regional variation in meat merchandising in Vietnam. The characteristics of SM, IM, and OM are described in Table 1. In addition to the differences in infrastructure, market types (SM, IM, OM) also differed in the marketing system, sources of products, methods of preservation, and display methods. Within each region, 2 of the most popular grocery markets per market type were selected, resulting in 6 markets per region. Domestically raised and processed whole chickens were purchased in each market at 2 sampling times, the opening time (T0) and 4 h after opening (T4). The opening time varied not only by region but also by individual markets, ranging from 4 and 5 AM (OM and IM) to 9 AM (SM). Five whole chickens averaging 1,000 g each were purchased individually from various vendors in each market at both sampling times, resulting in 180 samples. Vendors were randomized as described by McCain (2015) and McCain et al. (2015). Moreover, if a market had less than 5 vendors, at least one vendor was sampled repeatedly. There was no vendor randomization in SM because each SM was the sole poultry vendor; however, samples were purchased separately by different buyers. Moreover, whole chickens in SM were individually overwrapped on Styrofoam trays and displayed on refrigerated shelves. Vendors in IM and OM processed their birds at the time of purchase by defeathering, eviscerating, and rinsing carcasses in water. Samples were purchased individually and placed aseptically in sterile Nasco Poultry Rinse Bags (Nasco, Fort Atkinson, WI). Carcass surface temperature was recorded by a Fisher Scientific Traceable Infrared Thermometer Gun (Fisher Scientific, Waltham, MA). Bags were sealed, stored in an Igloo Super Tough Sportsman ice chest (Igloo, Katy, TX) with ice packs, and transported to a local university in each region.

Table 1. Characteristics used to classify supermarkets (SM), indoor markets (IM), and open markets (OM) across 3 regions of Vietnam

Market Characteristics	Market Type		
	SM	IM	OM
Multiple vendors		√	√
Air-conditioning	√		
Refrigeration	√		
Walls	√	√	
Roof	√	√	
Clean water availability	√	√	√

√ = Existing characteristics.

Weight of the whole chickens was recorded, and 90 mL of Buffered Peptone Water (BPW; 25.5 g/L; 3M, St. Paul, MN) was added to Nasco Poultry Rinse Bags (Nasco; Vipham et al., 2012). The volume of BPW used for the whole chicken rinse was evaluated previously by using a food color solution to ensure that it was sufficient to wash the surface and the body cavity of the whole chicken carcasses. Two sterile 15-mL polypropylene tubes (Greiner Bio-One, Monroe, NC) of BPW rinsate were transported on ice to HCMC University of Technology for further analysis.

Microbiological analysis

Salmonella was analyzed as described by McCain (2015) and McCain et al. (2015). Briefly, 2.5 mL of BPW rinsate was mixed with 22.5 mL of *Salmonella* Enrichment Broth (3M) in a sterile Whirl-Pak bag (Nasco) and incubated at 45°C for 24 h. After incubation, 1 mL of this solution was combined with 10 mL of Rappaport-Vassiliadis R10 Broth (RVR10; 3M) and incubated at 41.5°C for 24 h. A total of 10 µL of the incubated RVR10 solution was streaked onto 3M Petrifilm of the *Salmonella* Express System, and the Petrifilm was incubated at 41.5°C for 24 h. Presumptive positive *Salmonella* spp. colonies were identified as red colonies with yellow halo (3M, 2015c). *Listeria* spp. was detected as described by McCain et al. (2015). Similarly, a volume of 2.5 mL of BPW rinsate was combined with 22.5 mL of Demi-Fraser *Listeria* Enrichment Broth (3M) in a sterile Whirl-Pak bag (Nasco) and incubated at 30°C for 24 h. A volume of 0.1 mL of the incubated solution was spread onto an ALOA agar petri dish and incubated at 37°C for 24 h. Presumptive positive *Listeria* spp. colonies were identified as blue to green colonies with or without a halo. Analyses of aerobic bacteria (aerobic plate count [APC]), *E. coli*, and coliforms were performed as described by McCain et al. (2015). A volume of 15 µL of BPW rinsate was combined with 1,485 µL of sterile BPW broth and serially diluted (1:100). One milliliter (1 mL) of each dilution was spread onto an APC Petrifilm and *E. coli*/coliform Petrifilm. The Petrifilm was incubated at 35°C for 24 h. Colony-forming units (CFU) were counted according to 3M interpretation guides (3M, 2015a; 3M, 2015b).

Market characteristics

Outdoor temperature (°C), relative humidity (%), meat surface temperature (°C), type of retail display, availability of refrigeration, use of gloves and hairnets, knife cleaning, and water availability were recorded for individual samples on data collection forms.

Calculation and statistical analysis

Salmonella and *Listeria* prevalence was reported as the percentage of positive samples estimated by a logistic regression model. Counts of aerobic bacteria, *E. coli*, and coliforms were reported as log CFU/g of the carcass, as detailed by McCain (2015) and McCain et al. (2015). Market characteristic data were reported as a crude percentage without statistical analysis.

All statistical analyses were performed using a generalized linear mixed model estimated by the GLIMMIX procedure in SAS version 9.4 (SAS Institute, Inc., Cary, NC). Prevalence of *Salmonella* and *Listeria* were analyzed as a 3×2 factorial arrangement in a randomized complete block design with region as block, market type (SM, IM, and OM) and sampling time (T0 and T4) as 2 factors, and a specific market at a specific sampling time as experimental unit using logistic regression. However, in the same design, linear regression was used to analyze bacterial counts with whole chickens being the experimental unit. Market type, sampling time, and their interaction were the fixed effects, whereas region was the random effect. Means were separated by the protected t test by using the LSMEANS statement with the PDIFF option in the GLIMMIX procedure. Statistical significance was determined at $P \leq 0.10$.

Results and Discussion

Aerobic, E. coli, and coliform counts

There was no difference in bacterial counts of APC, *E. coli*, or coliforms between 2 sampling times in all market types ($P \geq 0.170$; Table 2). Some APC Petrifilm were too numerous to count at 10^{-6} dilution with pink color in the entire growth area (3M, 2015a) and therefore were estimated at 10^8 CFU, as recommended by the 3M guidelines. Average bacterial counts in whole chickens for all market types at T0 were 10.9, 8.1, and 9.9 log CFU/g of APC, *E. coli*, and coliforms, respectively (Table 2), and similar counts ($P = 0.170$) of 10.6, 8.3, and 9.8 log CFU/g at T4 were also observed. *E. coli* and coliform counts were greater in IM than in SM ($P = 0.002$ and 0.006, respectively; Figure 1). Furthermore, *E. coli* counts were also greater in OM than in SM (8.3 vs. 7.7 log CFU/g, respectively; $P = 0.024$), whereas both OM and SM had similar coliform counts ($P = 0.170$).

Table 2. Bacterial counts and the prevalence of *Salmonella* and *Listeria* in whole chickens procured from supermarkets (SM), indoor markets (IM), and open markets (OM) at the market opening (T0) and 4 h after the opening (T4) across 3 regions of Vietnam (Ho Chi Minh City, Da Nang, and Ha Noi)

Microbiological Measurement[*]	SM		IM		OM		P_{market}	P_{time}	$P_{market \times time}$
	T0	T4	T0	T4	T0	T4			
APC[1], log CFU/g	10.8 ± 0.1^{ax}	10.8 ± 0.1^{ax}	10.9 ± 0.0^{ax}	10.9 ± 0.0^{ax}	10.9 ± 0.0^{ax}	10.1 ± 0.5^{ax}	0.233	0.170	0.118
E. coli[2], log CFU/g	7.5 ± 0.5^{ax}	7.9 ± 0.5^{ax}	8.4 ± 0.5^{bx}	8.7 ± 0.5^{bx}	8.3 ± 0.7^{bx}	8.3 ± 0.7^{bx}	0.006	0.281	0.619
Coliform[3], log CFU/g	9.4 ± 0.4^{x}	9.7 ± 0.3^{ax}	10.1 ± 0.3^{bx}	10.2 ± 0.3^{bx}	10.1 ± 0.3^{abx}	9.6 ± 0.4^{abx}	0.024	0.874	0.162
Salmonella[4] prevalence, %	25.6 ± 12.3^{ax}	35.8 ± 12.0^{ax}	57.0 ± 9.6^{bx}	60.5 ± 5.2^{bx}	35.8 ± 8.0^{ax}	35.8 ± 9.6^{ax}	0.013	0.515	0.822
Listeria[5] prevalence, %	42.7 ± 16.7^{ax}	69.5 ± 13.3^{ax}	73.1 ± 10.0^{bx}	83.1 ± 7.3^{bx}	73.1 ± 12.4^{bx}	73.1 ± 13.4^{bx}	0.060	0.113	0.415

[1]Aerobic plate count, enumerated using 3M Petrifilm Aerobic Plate Count (3M).

[2]*Escherichia coli*, enumerated using 3M Petrifilm *E. coli*/Coliform Count Plates (3M).

[3]Coliform, enumerated using 3M Petrifilm *E. coli*/Coliform Count Plates (3M).

[4]*Salmonella*, detected using 3M Petrifilm *Salmonella* Express System (3M).

[5]*Listeria*, detected using ALOA media (bioMérieux, Hazelwood, MO)

[x]Within market type, means without common letters differ, $P \leq 0.1$.

[a,b]Within sampling time, means without common letters differ, $P \leq 0.1$.

[*]Values were reported as estimated least squares means ± standard error of the means.

CFU = colony-forming units.
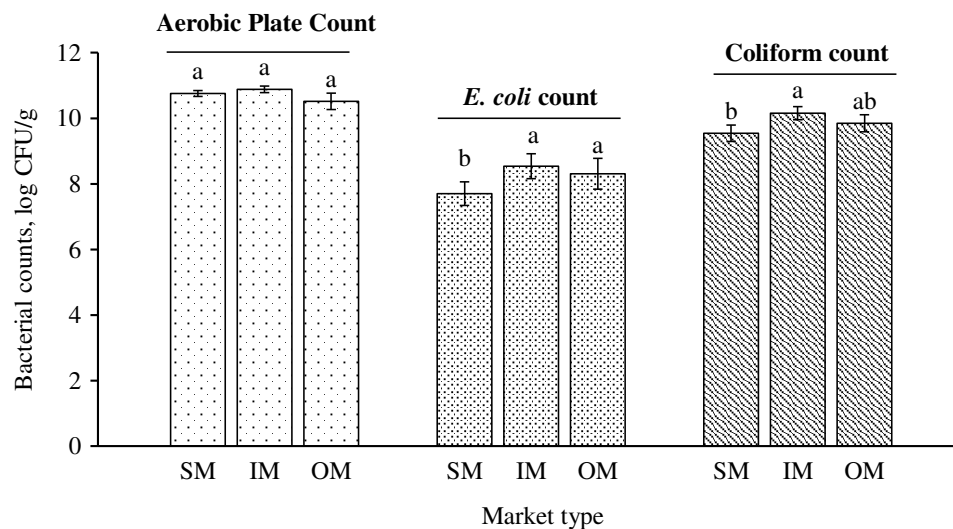
Figure 1. Aerobic plate count and *E. coli* and coliform counts of whole chickens ($N = 180$) purchased from supermarkets (SM), indoor markets (IM), and open markets (OM) in Ho Chi Minh City, Da Nang, and Ha Noi of Vietnam, averaged across 2 sampling times. Within a category of bacterial count, means without common letters differ ($P_{market\ type} = 0.233, 0.006, 0.024$, respectively). CFU = colony-forming units.

The high levels of bacterial counts indicated that the whole chickens in these markets had much higher initial bacterial loads than what is normally observed in developed countries. Good management practices during slaughtering and processing stages are important to minimize initial bacterial contamination (Buncic and Sofos, 2012). Understanding carcass hygiene or initial bacterial loads is very important to manage bacterial counts in poultry primary processing (Belluco et al., 2016). Aerobic bacteria and *E. coli* are commonly used as hygienic indicator organisms in poultry production (Adeyanju and Ishola, 2014). *E. coli* count was greater in *Salmonella*-positive beef and pork samples (Pearce et al., 2004; Ghafir et al., 2008; Biasino et al., 2018). Ghafir et al. (2008) suggested that *E. coli* count was a reliable index of *Salmonella* incidence in beef. In poultry carcasses, *Salmonella* prevalence has been routinely associated with processing hygiene, handling, and storage conditions (Whyte et al., 2004; Williams et al., 2015). The authors' observations during the

current study at IM and OM revealed that the conditions of cages used to house chickens before harvest and the water used to defeather birds and rinse carcasses could provide insights into increased levels of APC, *E. coli*, and coliforms. The cages and water were unsanitary with an abundance of fecal materials. Water used to rinse live chickens was also used for the final rinse of carcasses. In IM and OM, chilling was not available to all vendors, although some did have access to refrigeration (4°C) to store final products. Allen et al. (2000) observed a 1.28-log CFU/carcass reduction when water chilling was used. However, water chilling can also be a primary vehicle for foodborne pathogens (Demirok et al., 2013). Extensive bird-to-bird contact by water immersion chilling can result in pathogen cross-contamination to other carcasses (Bilgili et al., 2002). There is currently not much research in the US or other developed countries on *E. coli* enumeration in poultry, primarily because *Salmonella*, not *E. coli*, is a more challenging problem in the poultry industry. Moreover, there has not been any research on *E. coli* counts in whole chickens to be used as a hygienic indicator for market types in Vietnam. Therefore, the data in the current study provide important baseline information for the meat and poultry industries in Vietnam.

Prevalence of Salmonella

The prevalence of *Salmonella* ranged from 25.6% to 35.8%, 57.0% to 60.5%, and 35.8% in SM, IM, and OM, respectively (Table 2). Among market types, IM had 23% and 28% greater *Salmonella* prevalence than OM and SM, respectively ($P = 0.006$ and 0.022;

Figure 2). Sampling time did not affect *Salmonella* prevalence ($P = 0.515$), and there was no interactive effect of market type and sampling time ($P = 0.822$).

Currently, Vietnam does not have a foodborne disease surveillance system to monitor the annual incidence of human salmonellosis (Ta et al., 2012). *Salmonella* is a major cause of foodborne disease worldwide, especially in Southeast Asia (CDC, 2015; Ta et al., 2012). *Salmonella* is isolated more from raw poultry than from other foods (CDC, 2015) because the bacteria naturally occur in the intestinal tract of birds. A few studies have been published in Vietnam to investigate *Salmonella* in chicken; however, they are limited in geographical variation and sample size (Phan et al., 2005; Luu et al., 2006; Van et al., 2007; Ta et al., 2012). These authors reported 48.9%, 53.3%, 21.0%, and 45.9% prevalence, respectively, which were comparable to the levels found in whole chickens in the current study. However, the data collected throughout the country from 2005 to 2012 indicated a certain degree of variation. Van et al. (2007) reported a 21.0% prevalence compared with 53.3 % reported by Luu et al. (2006). Ta et al. (2012) reported 51.1% ($N = 239$), 45.5% ($N = 33$), and 44.7% ($N = 264$) prevalence in HN, DN, and HCMC, respectively. Averaged across all markets and sampling times for each region, the current study showed that *Salmonella* prevalence in HN, DN, and HCMC was at 47.1%, 25.0%, and 55.0%, respectively, similar to findings by Ta et al. (2012). Market types in Vietnam vary primarily in the processing and handling of poultry carcasses. SM receive frozen retail products that may have undergone interventions for decontamination and chilling. Vendors in IM and OM markets do not have the
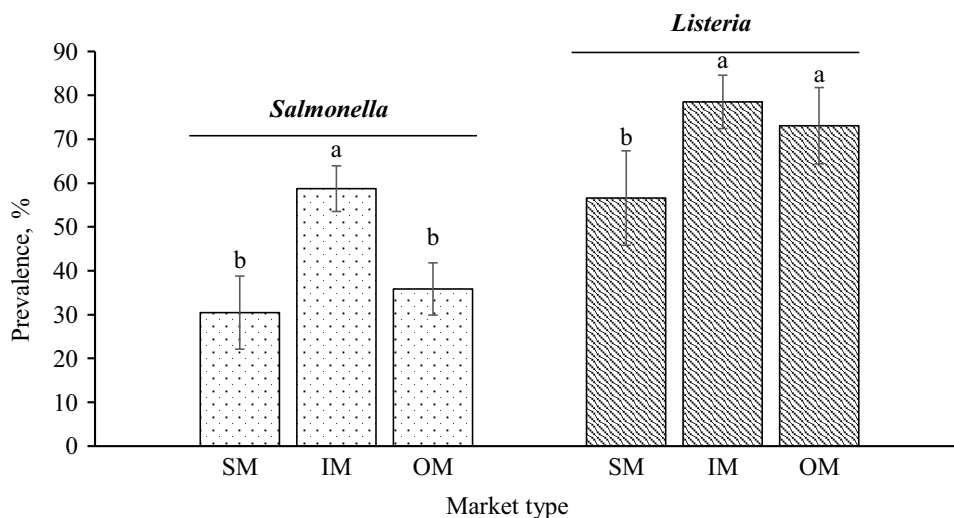
Figure 2. *Salmonella* and *Listeria* prevalence in whole chickens ($N = 180$) purchased from supermarkets (SM), indoor markets (IM), and open markets (OM) in Ho Chi Minh City, Da Nang, and Ha Noi of Vietnam, averaged across 2 sampling times. Within a pathogen category, means without common letters differ ($P_{market\ type} = 0.013$ and 0.060, respectively).

infrastructure or financial resources to decontaminate and chill whole chicken carcasses. This might explain the greater bacterial loads and pathogenic prevalence in the IM and OM compared to the SM. Moreover, a study conducted in wet markets in China reported 52.2% *Salmonella* prevalence, approximately 16.4% greater than the results in the current study (Yang et al., 2011). Retail surveys have revealed that *Salmonella* prevalence on raw chicken carcasses and retail meats, although varied among countries, tends to be higher in market settings without cold storage. In Ethiopia, chicken meats and giblets had a 68.2% positive rate (Tibaijuka et al., 2003), although chicken meat samples were only positive at a 28% rate. Barbour et al. (2015) reported 53.3% prevalence in chicken carcasses in 6 developing countries, with a 43.8% positive rate in SM and 50.0% from street vendors. In Portugal, Antunes et al. (2003) reported 60% *Salmonella* prevalence in chicken carcasses collected at 3 local sources, however, representing whole chickens from several national processors. These authors, instead of rinsing the whole carcasses, only sampled portions of skin from the neck and cloacal regions. The samples in these studies were from local sources without refrigeration and/or microbial control postharvest. Domínguez et al. (2002) also sampled the skin of chicken carcasses from retail outlets in Spain, which are mostly refrigerated (Álvarez-Astorga et al., 2002) at the time of sampling, and reported 35.8% prevalence. These authors acknowledged that the variation in *Salmonella* prevalence might be caused by sampling methods and culture techniques. However, in the greater Washington, DC, area in the US, *Salmonella* prevalence in whole chicken carcasses was only 4.2% (Zhao et al., 2001). These authors confirmed presumptive *Salmonella* colonies by polymerase chain reaction. In 2016, the US Food Safety and Inspection Service proposed a 15.4% positive rate as the performance standard for *Salmonella* in chicken parts (Federal Register, 2016). The most recent posting indicated that 64% of all processing plants met or exceeded this performance standard (FSIS, 2021), although there might be a great variation in *Salmonella* prevalence from 2.5% to 60% in postchill carcasses (Berrang et al., 2009). Most US processing plants employ various antimicrobials and carcass chilling to reduce *Salmonella* and *Campylobacter* prevalence (Kim et al., 2017).

Water washing is also important in poultry processing. This step can either decrease or increase the bacterial load. Increased bacterial loads, especially those of *E. coli*, could lead to increased *Salmonella* prevalence (Ghafir et al., 2008). A Spearman's rank correlation conducted in the current study revealed a correlation between *Salmonella* prevalence and *E. coli* counts ($r = 0.52$; $P = 0.001$). Moreover, proper washing with clean water has been shown to decrease *Salmonella* prevalence by the physical removal of injured or semi-attached cells (Cox et al., 2010). However, in IM and OM, clean water was not always readily available. Carcasses were rinsed in the same water throughout the day. This practice can lead to cross-contamination among poultry carcasses (Kuan et al., 2013). Yang et al. (2011) observed that wet markets in China, similar to OM in Vietnam, also had a limited supply of potable water. These authors reported that the eviscerated birds were rinsed with a minimal amount of water or dipped in a tank without frequent change of water. The vendors at these Chinese wet markets were so busy that they rarely had time to wash their hands, scales, and other tools. Therefore, it was suggested that cross-contamination between chicken carcasses with *Salmonella* was likely to cause an increase in *Salmonella* prevalence (Yang et al., 2011). This same observation could also be attributed to the prevalence of *Salmonella* in the current study, in which only 26.7% and 6.7% of IM and OM vendors, respectively, wore gloves. Gloves in these markets were used to keep the vendors' hands clean rather than to maintain carcass hygiene. Many consumers are not aware of the safety risks associated with contamination of raw chicken with *Salmonella* because chicken is usually cooked thoroughly by boiling before consumption (Othman, 2007). However, chicken meat is usually associated with direct hand-to-mouth exposure to pathogens and cross-contamination in the food preparation area (Yang et al., 2011). In the US, an estimated 11% of human *Salmonella* infections annually are attributed to exposure to live poultry (USDA, 2014), and 17% of all foodborne illnesses are associated with poultry (Painter et al., 2013). Moreover, undercooked chicken is a major source of salmonellosis (Yang et al., 2016). The potential risks of foodborne illnesses to consumers at retail markets could be decreased by implementing good manufacturing processing practices throughout the poultry production chain.

Prevalence of Listeria

Listeria prevalence in each market type at a specific sampling time is reported in Table 2. *Listeria* prevalence in the whole chickens ranged from 42.7% to 69.5%, 73.1% to 83.1%, and 73.1% in SM, IM, and OM, respectively. The prevalence of *Listeria* was lower in SM than in IM and OM ($P = 0.024$ and 0.089, respectively; Figure 2). There was no effect of sampling time or

market type × sampling time interaction on *Listeria* prevalence ($P = 0.113$ and 0.415, Table 2).

There was a great within-market variation in *Listeria* contamination. The high level of *Listeria* prevalence might be attributed to the widespread occurrence of *Listeria* spp. in the environment (Chiarini et al., 2009) because *Listeria* survives harsh conditions in food processing plants for an extended time (Loura et al., 2005; Lundén et al., 2003). Moreover, *L. monocytogenes* can colonize the floor drains and persist in this environment for years (Berrang et al., 2013). Recent research on the prevalence of *Listeria* in whole chickens is not widely available in both developed and developing countries. *Salmonella* is studied more because it is present in the intestines of birds, whereas *Listeria* is mostly from environmental contamination. *Listeria* prevalence in raw broiler carcasses was reported to be from 41% to 84% (Uyttendaele et al., 1999). Studies have indicated that improper cleaning and disinfecting of equipment in poultry processing facilities can lead to the contamination of poultry carcasses (Adeyanju and Ishola, 2014; Loura et al., 2005). Uytttendaele et al. (1999) reported an increase in *Listeria* contamination rate as carcasses moved through cutting and further processing. Contamination rates of whole carcasses, carcasses with parts, and retail products were 41.3%, 46.7%, and 61.0%, respectively (Uytttendaele et al., 1999). Furthermore, additional handling of poultry carcasses during processing, especially after chilling, has been shown to be responsible for an increase in prevalence at the end of the processing line (Genigeorgis et al., 1990). This might help explain the high level of 42.7% to 69.6% prevalence of *Listeria* in SM, even though SM vendors received prepackaged frozen or refrigerated whole chickens, which remained refrigerated throughout the retail display. Contamination at the end of the processing line and the psychrotrophic nature of *Listeria* (Chiarini et al., 2009) explain the high prevalence of poultry carcasses in SM. However, it was still less than in IM and OM because poultry products in these 2 market types were temperature-abused. *Listeria* has been isolated from raw poultry (Miettinen et al., 2001); however, prevalence is highly varied. Pini and Gilbert (1988) found 60% of *Listeria*-contaminated raw chickens in the United Kingdom, whereas Bailey et al. (1989) only observed 23% prevalence in raw poultry carcasses in retail establishments in the US. Moreover, Loncarevic et al. (1994) reported 0% to 64% prevalence of *Listeria* in raw broiler meat. The results from the current study were slightly greater than what was found in the previously mentioned studies. The current study was conducted in the retail setting, whereas others were in processing facilities. Miettinen et al. (2001) observed *Listeria* contamination in processing facilities at as low as 1% to 11% but as high as 62% in retail establishments. The increased prevalence at retail could be attributed to either poor vendor hygiene or the duration of retail display. Genigeorgis et al. (1989) observed workers' hygiene in poultry processing facilities and reported that 46.7% of the workers harbored *Listeria* spp. in their hands and gloves. Moreover, Loura et al. (2005) sampled the bare hands of food handlers and reported that 60% of samples had *Listeria*. Hygienic conditions in all markets in Vietnam were poor with only 16.7%, 16.7%, and 6.7% of SM, IM, and OM vendors at T0 and 16.7%, 26.7%, and 3.3% of SM, IM, and OM vendors at T4 using gloves, respectively. Hygienic conditions of IM and OM vendors might be the reason for the 15% and 20% greater *Listeria* prevalence in OM and IM, respectively, than in SM. It is recommended to cook poultry products to 74°C (FSIS, 2014), thereby assuming a low risk of *Listeria*.

Market characteristics

Characteristics of markets and vendors in Vietnam are summarized in Table 3. Cover displays for whole chickens were overwrapped packages or display cases as a physical barrier between the products and the consumers; both were only used at some SM and IM vendors. At T0, 50.0% and 73.3% of the SM and IM vendors used cover displays, respectively. However, at T4, 83.3% and 20.0% SM and IM used cover displays. Moreover, 100.0% of OM vendors exposed whole chickens to open air at both sampling times. From observations during sampling, if the chickens were harvested at the market, whole chickens were hung by feet after processing and displayed openly without wrapping until closing. If not being sold by the end of the day, the carcasses were overwrapped and stored for sale the next day. Likewise, in SM, whole chickens were processed at a central location, overwrapped, and frozen for transportation to SM. Refrigeration was used by 50.0%, 66.7%, and 6.7% of SM, IM, and OM vendors at T0 and by 100.0%, 23.3%, and 0.0% of SM, IM, and OM vendors at T4, respectively. Refrigeration was used in SM for display at T0 but for storage at T4. However, refrigeration in IM and OM was used for storage only. As mentioned previously, hygienic conditions in all markets were poor with only 16.7%, 16.7%, and 6.7% of SM, IM, and OM vendors at T0 and 16.7%, 26.7%, and 3.3% of SM, IM, and OM vendors at T4 using gloves.

Table 3. Observational and environmental data collected during the purchase of whole chickens from supermarkets (SM), indoor markets (IM), and open markets (OM) at the market opening (T0) and 4 h after the opening (T4) across 3 regions of Vietnam (Ho Chi Minh City, Da Nang, and Ha Noi)

Market Characteristics	SM		IM		OM	
	T0	T4	T0	T4	T0	T4
Outdoor temperature, °C	27.8 ± 1.0	29.0 ± 1.7	25.2 ± 0.5	28.7 ± 0.7	27.4 ± 1.7	31.2 ± 1.6
Humidity, %	68.2 ± 5.6	59.3 ± 3.8	83.3 ± 4.6	70.5 ± 5.7	73.3 ± 5.7	63.1 ± 5.7
Meat surface temperature, °C	15.4 ± 1.6	14.5 ± 2.6	24.2 ± 1.8	21.8 ± 2.0	30.7 ± 5.5	25.9 ± 1.3
Covered display, %	50.0 ± 0.2	83.3 ± 0.1	73.3 ± 0.2	20.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Hang display, %	0.0 ± 0.0	13.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Open display, %	50.0 ± 0.2	30.0 ± 0.2	26.7 ± 0.2	80.0 ± 0.2	100.0 ± 0.0	100.0 ± 0.0
Refrigeration, %	50.0 ± 0.2	100.0 ± 0.0	66.7 ± 0.2	23.3 ± 0.2	6.7 ± 0.1	0.0 ± 0.0
Gloves, %	16.7 ± 0.2	16.7 ± 0.2	16.7 ± 0.2	26.7 ± 0.2	6.7 ± 0.1	3.3 ± 0.0
Hairnet, %	33.3 ± 0.2	66.7 ± 0.2	50.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Cleaned knife before cutting, %	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	30.0 ± 0.2	20.0 ± 0.2	10.0 ± 0.0
Hot water, %	3.3 ± 0.0	0.0 ± 0.0	16.7 ± 0.2	0.0 ± 0.0	10.0 ± 0.1	23.3 ± 0.1
Fresh water, %	21.7 ± 0.1	41.7 ± 0.1	25.0 ± 0.1	20.0 ± 0.1	10.0 ± 0.1	5.0 ± 0.0

Chicken carcasses were rarely further processed because they were sold as whole birds. Furthermore, only 20.0% of OM vendors at T0 and 10% and 30% of OM and IM vendors at T4 cleaned knives. Because whole chickens were shipped to SM frozen and packaged, there was no knife usage in SM (0.0%). Hot water was used to wash knives by SM and IM only at T0 at 3.3% and 16.7%, respectively, whereas 10.0% and 23.3% of OM vendors used hot water at T0 and T4, respectively. Freshwater was available and used by 21.7%, 25.0%, and 10.0% of SM, IM, and OM vendors at T0 and 41.7%, 20.0%, and 5.0% at T4 by SM, IM, and OM vendors, respectively.

Vendors in IM and OM provide reasonably priced and conveniently available poultry products for the lower-income population. Chamhuri and Batt (2013) reported that consumers in Malaysia still preferred to shop at open and street vendors even though they were informed that meat in those markets was not as safe as meat in SM (Chamhuri and Batt, 2013). This attitude is important for the policymakers in Vietnam to consider because whole chicken is the most popular poultry product in Vietnam and much of the poultry supply chain was processed in poor hygienic conditions. Cross-contamination to other foods and risks of salmonellosis and listeriosis will increase tremendously if the whole chicken is not cooked properly.

prevalence of *Salmonella* and *Listeria* in whole chickens in various market types in Vietnam was greater than data from the current literature. Furthermore, there were 7.5 to 10.9 log CFU/g of indicator organisms such as aerobic bacteria, *E. coli*, and coliforms, among which *E. coli* counts were correlated with *Salmonella* prevalence. Refrigeration, cleanliness, water usage, and good hygienic conditions can improve the status of microbiological safety and quality of poultry products in Vietnam. Much research is needed to establish a baseline for contamination at critical control points during poultry processing in Vietnam's meat markets. These data justify enhanced enforcement of food safety regulations and the creation of educational programs for both consumers and vendors in Vietnam's meat markets.

Acknowledgments

Conclusion

Whole chickens had high levels of bacteria and a high prevalence of *Salmonella* and *Listeria*. The

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