Impact of human *Campylobacter* infections in South-East Asia: the contribution of the poultry sector

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ABSTRACT

Campylobacter is globally recognized as a major cause of foodborne infection in humans, whilst the development of antimicrobial resistance and the possibility of repelling therapy increase the threat to public health. Poultry is the most frequent source of *Campylobacter* infection in humans, and South-East Asia is a global leader in poultry production, consumption, and exports. Though three of the world’s top 20 most populated countries are located in South-East Asia, the true burden of *Campylobacter* infection in the region has not been fully elucidated. Based on published data, *Campylobacter* has been reported in humans, animals, and food commodities in the region. To our knowledge, this study is the first to review the status of human *Campylobacter* infection in South-East Asia and to discuss future perspectives. Gaining insight into the true burden of the infection and prevalence levels of *Campylobacter* spp. in the South-East Asian region is essential to ensuring global and regional food safety through facilitating improvements in surveillance systems, food safety regulations, and mitigation strategies.

Keywords

Foodborne pathogens, *Campylobacter*, poultry, food safety

INTRODUCTION

Foodborne diseases have become more challenging with increased globalization, advances in food production systems, changing dynamics in human demographics, and changes in sociocultural behaviours. Food- and waterborne diarrhoeal diseases account for a majority of illnesses and deaths in developing countries (Schlundt et al., 2004; WHO, 2008). One study conducted in Korea indicated that only 1 in 20 patients hospitalized due to foodborne infection is identified by the national surveillance system (Kim et al., 2015).

In recent years, a large and consistent increase in travelling has been noted by the World Tourism and Travel Council (WTTC) (Turner, 2014), accounting for a total of 1,184 million tourist arrivals in 2015 (UNWTO, 2016). Internationally, regulatory bodies related to health have recommended differentiating infectious diseases as domestic or travel-related cases to understand the epidemiology of disease and to implement control measures (Horn and Lake, 2013; Thomas et al., 2013). Based on the 2007-2011 reports to the International Society of Travel Medicine and to the Centres for Disease Control and Prevention (CDC), the majority of diseases (32.6%) were reported from international travellers returning from Asia, with diarrhoea being the most common infection (34%) and *Campylobacter* a frequent cause (Leder et al., 2013). Furthermore, the European Surveillance System (TESSy) reported that travelling abroad from 2009-2010 accounted for more than 60% of the reported *Campylobacter* cases (Guzman-Herrador et al., 2012). According to Vlieghe and colleagues (2008), *Campylobacter* (n=303) was most frequently isolated from people who had traveller's diarrhoea after visiting Asia, and norfloxacin resistance increased significantly (p<0.001) from 47.7% in 1994-2000 to 60.5% in 2001-2006 (Vlieghe et al., 2008). *Campylobacter*-associated traveller's diarrhoea and the emergence of

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antimicrobial resistance have become alarming public health issues along with concerns for the treatment of choice and reduce efficacy to therapy that may be encountered in top tourist destination regions in South-East Asia (SEA).

Campylobacter is recognized as the main hazard that leads to foodborne infections around the globe; therefore, lots of surveillance, research findings and reviews are available for developed countries (Silva et al., 2011; Al-Sakkaf, 2012). However, there have been few evaluations of the status of *Campylobacter* in developing and middle-income countries in SEA (WHO, 2012). According to the United Nations geoscheme, the SEA region comprises Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic **(**Lao PDR), Malaysia, Myanmar (Burma), Philippines, Singapore, Timor-Leste, Thailand, and Vietnam. Of these, Indonesia, Philippines, and Vietnam are among the top 20 most populous countries in the world (UNSD, 2013). The SEA region is a top tourist destination in the world, and the associated commerce brings a huge economic and social benefit to the region (Turner, 2014). Provision of safe food will be a large issue with the emerging concerns over travel-related foodborne infections (Hall and Page, 2012). Therefore, it is essential to elucidate and understand the status of human *Campylobacter* infection in the SEA region to reduce the burden of infection and to implement mitigation strategies. Additionally, this study illustrates the latest available data on the microbiological, epidemiology, and clinical aspects of C*ampylobacter*.

Campylobacter

The family *Campylobacteraceae* includes three genera: *Campylobacter*, *Arcobacter*, and *Sulfurospirillum* (Garrity et al., 2005). With the development of science and technology, there have been a number of taxonomic revisions to the genus *Campylobacter* (Vandamme and De

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Ley, 1991). The List of Prokaryotic names with Standing in Nomenclature indicates 32 species and 13 subspecies within the genus *Campylobacter* (LPSN, 2012). *Campylobacter* spp. are Gram-negative, non-spore forming, small, slender, spirally curved rods that are approximately 0.2–0.8 μm wide × 0.5–5 μm long in size. When these bacterial cells group together, they form an “S” or a “V” shape gull-wing. The single polar unsheathed flagellum located at one or both ends of the organism aids in its corkscrew-like motility. Exceptions include *C. gracilis*, which is non-motile, and *C. showae*, which contains multiple flagella (Debruyne et al., 2008).

Most *Campylobacter* are found in the gastrointestinal tracts of birds and mammals, including poultry, cattle, pigs (Nielsen et al., 1997), goats (Salihu et al., 2009), sheep (Garcia et al., 2010), dogs, cats (Bruce et al., 1980), wild birds (Dipineto et al., 2014; Ryu et al., 2014), and mammals (Carbonero et al., 2014). Animal source food products can be easily contaminated with *Campylobacter* spp. during slaughtering and processing. Consumption of contaminated meat, raw milk, and water are the key sources of human Campylobacteriosis (Debruyne et al., 2008; Taylor et al., 2013). Contact with pet animals is also associated with *Campylobacter* infection (Doorduyn et al., 2010). International travelling has also been identified as a risk factor for *Campylobacter* infection (Friedman et al., 2004). American military troops sent to Thailand and Turkey account for approximately 50-60% and 12% of reported *Campylobacter* infections, respectively (Tribble et al., 2007; Porter et al., 2010).

BURDEN OF Campylobacter ILLNESS AND ASSOCIATED RISKS IN SOUTH-EAST ASIA

In developing countries, *Campylobacter* is a common cause of infant diarrhoea associated with contaminated food and water (Oberhelman and Taylor, 2000). Most of the existing data on the incidences of Campylobacteriosis cases in developing and middle-income countries have

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been generated from research programmes conducted for the detection of causative pathogens of diarrhoea (WHO, 2012). Among the SEA countries, only Singapore has included Campylobacteriosis into its national disease surveillance programme. Although *Campylobacter* is yet to be included in their national disease surveillance programmes, Cambodia, Malaysia, Philippines, and Thailand have been monitoring the incidences of diarrhoea or foodborne infections. Therefore, the data presented in this study were obtained from the Singapore national disease surveillance programme, several population-based studies on *Campylobacter* spp. conducted in the SEA region (Table 1), and monitoring data from travellers returning from SEA.

Singapore

On October 8th 1980, Singapore's first case of *Campylobacter* infection was reported in an adult male tourist, followed by another two cases in children reported in the subsequent month that were later confirmed to contain both *C. jejuni* and *C. coli* (Lam, 1981). Lim and Tay (1992) conducted a survey over a one-year period to monitor *Campylobacter* infection in diarrhoeic inpatients and found that more than 70% of *Campylobacter* species were isolated from children less than 5 years old. The isolated *C. jejuni* (89%) and *C. coli* (10.9%) demonstrated the highest resistance against erythromycin (Lim and Tay, 1992). Chau and colleagues reported a *Campylobacter* prevalence level of 5% in one hundred stool samples collected from adults presenting at the Tan Tock Seng Hospital, Singapore from 2013 to 2014 (Chau et al., 2016). From 1990 to 2015, a total of 5370 *Campylobacter* cases were reported in Singapore (Figure 1) (MoH Singapore, 2014).

Of the cases reported from 2001 to 2014, *C. jejuni* (84-100%) was the predominantly isolated pathogen, followed by *C. coli* (0-4%), *C. lari* (0-0.2%), and other *Campylobacter* spp.

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(0-12%) (Figure 2) (MoH Singapore, 2014). The number of reported *Campylobacter* cases from 2010 to 2014 was highest in infants 0-4 years old, followed by children 5-14 years old, and then by adults over 55 years old. Except for the age group above 55, notification rates were higher among males, with a mean male to female ratio of 1.4:1 (Figure 3). From the largest three ethnic groups in Singapore, the highest *Campylobacter* incidence rate, ranging from 4.5-15.3, was reported in Indians during the period of 2010-2014, followed by Malay (4.1-10.5), while a 3.9-5.9 incidence rate was reported among foreigners in Singapore for the same period (MoH Singapore, 2014).

Thailand

During the period from January 1st 2016 to March 28th 2016, the annual incidence of reported diarrhoeal diseases was 424.16 per 100,000 people in Thailand, accounting for two deaths out of a total of 27,623 cases. During the same period, a total of 30,203 food poisoning cases were reported, with a male:female ratio of 1:1.47. However, 99.3% of these cases had unidentified causes (Bureau of Epidemiology, 2016). From 2000 to 2014, the mean annual incidence rates for acute diarrhoea and food poisoning cases in Thailand were 1,762 and 201, respectively. From 2000 to 2014, acute diarrhoea was consistently one of the leading causes of morbidity under surveillance in Thailand, with food poisoning among the top ten causes (Bureau of Epidemiology, 2016).

The incidence of *Campylobacter* infection has been better studied in Thailand compared to other countries in the SEA region (Taylor et al., 1991; Bodhidatta et al., 2002; Bodhidatta et al., 2010; Bodhidatta et al., 2013). The first study was conducted in 1987 with the goal of identifying the causative agent of infant diarrhoea in an orphanage. Of the 100 cases studied, *C.*

jejuni and *C. coli* were reported in 31% and 19% of the cases, respectively (Taylor et al., 1987). *Campylobacter jejuni* was also found to be the second-most leading cause of diarrhoea among children less than 5 years old in low-income families in Bangkok, Thailand (Varavithya et al., 1990). Using a membrane filtration technique, several *Campylobacter* spp. were isolated from stool samples from Thai children with diarrhoea at a prevalence level of 15% (93/631 total cases); of these, 62 were identified as *C. jejuni* isolates, and 14 were *C. coli* isolates. The remaining 17 strains were *C. upsaliensis* (0.2%), *C. jejuni doylei* (0.2%), and aero-tolerant *Campylobacter* (3%) (Taylor et al., 1991). *Campylobacter* was isolated from 28 travellers who visited Thailand and who were attended to at the outpatient travel clinic at the Institute of Tropical Medicine (ITM) in Belgium. In this study, Thailand was ranked the second-highest country with *Campylobacter* isolates from travellers (Vlieghe et al., 2008). Seventy-six *Campylobacter* species isolated from 2500 diarrheic stool samples collected from people at Bamrasnaradura in Thailand were characterised, and 43 were *C. jejuni*, 29 were *C. coli*, 1 was *C. fetus*, and 1 was *C. hyointestinalis*, the first *C. hyointestinalis* diarrhoea case reported in Thailand (Samosornsuk et al., 2015).

Campylobacter isolates from U.S. troops in Thailand showed an increasing trend for resistance to ciprofloxacin, from 0% in 1990 to 84% in 1995. Though all *Campylobacter* isolates (52) were susceptible to azithromycin in 1990, 7-15% resistance was reported in 1994-1995 (Hoge et al., 1998). Among 608 *Campylobacter* isolates from Thailand obtained between 1996 and 1999, 608 (100%) were resistant to nalidixic acid, 531 (87%) were resistant to ciprofloxacin, and 520 (85%) were resistant to azithromycin (Isenbarger et al., 2002). *Campylobacter jejuni* (968) and *C. coli* (200) were isolated from studies conducted between 1990 and 2000 on diarrhoeal diseases in children less than 10 years old in Thailand, and 75-85% of these cases were due to *C. jejuni*. Resistance to nalidixic acid increased from 5% (in 1992) to 86-100% (in 2000) for *C. jejuni* and *C. coli* isolates, both in Bangkok and in rural settings. A higher resistance rate was also detected against nalidixic acid and ciprofloxacin for *Campylobacter* isolates from Bangkok compared to that of the isolates from rural areas (Serichantalergs et al., 2007). According to the most recent findings of Bodhidatta et al. (2013), *C. jejuni*, *C. coli*, and *C. upsaliensis* were isolated from 124 faecal samples from diarrhoeic children at 61%, 19%, and 19%, respectively. More than 50% of the isolates were resistant to trimethoprim/sulfamethoxazole and nalidixic acid (Bodhidatta et al., 2013).

Vietnam

A total of 2147 foodborne outbreaks were reported in Vietnam during 2000-2010, resulting in 60,602 cases and 583 deaths (Sarter et al., 2012). Bodhidatta and colleagues detected a *Campylobacter* prevalence level of 1% in children less than 5 years of age with diarrhoea and none in the control group without diarrhoea (Bodhidatta et al., 2007).

Philippines

Acute watery diarrhoea cases reported in the Philippines decreased from 866,411 cases in 2000 to 235,110 cases in 2012, and acute diarrhoea was a leading cause of infant deaths (Philippines in Figures, 2016). A study was conducted to identify the bacterial and viral causes of diarrhoea by analysing stool samples from people admitted to the San Lazaro Hospital in Manila from 1983 to 1984. *C. jejuni* was reported in the stools of 29/888 (3.0%) and 7/567 (2.7%) people with diarrhoea and the sex- and age-matched control group, respectively. All the isolates were susceptible to kanamycin, chloramphenicol, gentamicin, neomycin, nalidixic acid,

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polymyxin B, and nitrofurantoin. The most frequently detected resistance was against cephalothin (100% of 54 isolates), followed by novobiocin (93% of 54 isolates). Multi-drug resistance (10 of 17 antibiotics tested) was detected for *C. jejuni* isolates (Adkins et al., 1987). Antibodies against *C. jejuni/coli* and *C. jejuni* O:19 were detected in 96.1% and 0.6% of the human serum samples, respectively, and a significant association ($p<0.05$) was detected between *C. jejuni* O:19 and poultry workers comparative to non-poultry workers (Manandhar et al., 2009). Furthermore, *Campylobacter* was isolated from 4 patients who presented at the ITM outpatient travel clinic in Belgium after returning from the Philippines between 1994 and 2006 (Vlieghe et al., 2008).

Brunei Darussalam

On February 24th 2016, the Ministry of Health in Brunei Darussalam reported 727 cases of gastrointestinal infections, the majority of which were among children of less than 5 years of age, compared to 605 cases reported the previous year (Borneo bulletin, 2016). The largest food poisoning outbreak, with a total of 177 cases, was reported in Brunei Darussalam in 2010 (The Brunei Times, 2010). Between 2005 and 2012, 25 *Campylobacter* cases were reported in Brunei Darussalam, with the highest number of cases (9) in 2011 (WAHIS, 2013).

Cambodia

Annual health reports for Cambodia from 2000 to 2012 reported a total of 199,235 inpatients and 4,284,483 outpatients with diarrhoea, which was ranked among the top ten diseases reported in the country (MoH Cambodia, 2016). Furthermore, *C. jejuni* and *C. coli* were isolated from 4.7% and 1.5%, respectively, of a total of 600 diarrhoeic stool samples from children hospitalized in Phnom Penh (Meng et al., 2011). However, a higher prevalence level of

C. jejuni (6.2%) and *C. coli* (2.4%) was also detected in the control group without diarrhoea (n=578). Approximately 50% of *C. coli* and 30% of *C. jejuni* isolates showed resistance to nalidixic acid and ciprofloxacin (Meng et al., 2011). Seven travellers returning from Cambodia between 1994 and 2006 were attended to at the ITM outpatient travel clinic in Belgium and tested positive for *Campylobacter* (Vlieghe et al., 2008).

Indonesia

A total of 1095 foodborne disease outbreaks occurred during the period of 2001-2009 in Indonesia, resulting in 51,945 cases of foodborne illness and 328 deaths (Dewanti_Hariyadi and Gitapratiwi, 2014). *Campylobacter jejuni* was isolated from 144 Indonesian children and 251 Indonesian adults with diarrhoea, accounting for 10% and 2% of all diarrhoeal cases, respectively (Ringertz et al., 1980). Later studies conducted on Campylobacteriosis in Indonesia revealed that *C. jejuni* was the most frequently isolated *Campylobacter* spp. (Oyofo et al., 2002; Tjaniadi et al., 2003). Among the 21,763 rectal swabs collected from patients with diarrhoea from 1995 to 2000, 3.6% cases were attributable to *C. jejuni*, and these isolates were susceptible to erythromycin; resistance to trimethoprim/sulfamethoxazole and cephalothin remained relatively stable during this study period. However, during the five-year period, resistance to ceftriaxone, norfloxacin, and ciprofloxacin markedly increased (Tjaniadi et al., 2003). In addition, ITM in Belgium reported that 28 patients tested positive for *Campylobacter* from 1994 to 2006 after returning from Indonesia (Vlieghe et al., 2008).

Lao PDR

In Lao PDR, *C. jejuni* and *C. coli* were isolated from 2.2% and 2% of 880 patients with diarrhoea, respectively (Yamashiro et al., 1998). Three travellers who visited Lao PDR were attended to at the ITM outpatient travel clinic in Belgium from 1994 to 2006 and were positive for *Campylobacter* (Vlieghe et al., 2008). A total of 8570 foodborne cases were reported by the 9th week of 2016, including 7298 cases of acute watery diarrhoea, 1060 cases of acute bloody diarrhoea, and 212 cases of food poisoning (MoH Lao PDR, 2015).

Malaysia

According to the national surveillance data from the Ministry of Health in Malaysia, the mean annual incidence of food- and waterborne diseases ranged from 60.9 cases per 100,000 people in 2000 to 49.76 cases per 100,000 people in 2013. The causative agent of the majority of the reported food- and waterborne diseases was not identified (MoH Malaysia, 2016).

In a study conducted in Malaysia, *C. jejuni* was isolated from 3.8% (8 of 212) of children and 4.3% (3 of 69) of adults afflicted with diarrhoea. *C. jejuni* was isolated in approximately 2.6% of children without diarrhoea; however, *Campylobacter* spp. were not apparent in the adult control group (Lim et al., 1984). A hospital-based study was conducted in Kuala Lumpur from 1978 to 1997 to investigate the bacterial pathogens causing diarrhoea in children less than 16 years of age. According to this study, *Campylobacter* was identified as one of the top five most common isolated organisms, with a prevalence of 5% in 2989 isolated organisms (Lee and Puthucheary, 2002). Furthermore, *Campylobacter* was isolated from 3 patients presenting to the ITM outpatient travel clinic in Belgium after returning from Malaysia from 1994 to 2006 (Vlieghe et al., 2008).

Myanmar

An aetiological survey was conducted with age and sex matched controls on acute diarrhoea in children aged 0-35 months who were attending a hospital in Myanmar for treatment from 1982 to 1985, and there was a 2% *C. jejuni* prevalence in both cases and the control group of Burmese children (Huilan et al., 1991). Three travellers who visited Myanmar and were attended to the ITM outpatient travel clinic in Belgium from 1994 to 2006 were positive for *Campylobacter* (Vlieghe et al., 2008).

Timor-Leste

According to the Global Burden of Disease Study 2010 profile of Timor-Teste, diarrhoeal diseases were identified as the second leading cause of premature deaths in Timor-Leste during the period of 1990-2010 (GBD, 2010). A total of 24 children died due to a diarrhoeal epidemic outbreak in Timor-Leste (Reliefweb, 2001). Timor-Leste is among the countries with the lowest health indicators in the Asia-Pacific region, and diarrhoea is a major reason for why this country has the highest mortality rate in children less than 5 years of age in the SEA region (USAID, 2016).

Between 1980 and 2016, the *Campylobacter* spp. isolation rates among countries in the SEA region varied from 2% to 85%. The highest level of *Campylobacter* spp. isolation was reported in Singapore, which was reported to the national surveillance system. Studies conducted in the SEA region on *Campylobacter* spp. have revealed that *C. jejuni* is the predominant *Campylobacter* spp. isolated from diarrhoeic patients, while *C. coli, C. fetus*, *C. hyointestinalis*, and *C. upsaliensis* have also been isolated in the region. *Campylobacter upsaliensis* has been identified only in human faecal samples from Thailand. Furthermore, in contrast to the latest findings in Thailand, the prevalence levels of *C. coli* and *C. upsaliensis* are equal (Taylor et al., 1991; Bodhidatta et al., 2013). In some countries, *C. upsaliensis* had become the second most prevalent *Campylobacter* spp. after *C. jejuni* (Goossens et al., 1995; Lastovica and le Roux, 2000). Of all the SEA countries, *C. fetus* had only been isolated from patients in Indonesia (Ringertz et al., 1980). The vast differences in the prevalence levels can be attributed to the availability of resources, identification methods, and the fastidious nature of the organism. A majority of the studies were conducted in children; unlike in developed countries, the disease was not reported to be a problem among adults in SEA countries. The national surveillance data from Singapore also confirmed the report of a higher incidence rate among people 0-4 and 5-14 years of age as well as in people over 55 years of age. Unhygienic conditions, lack of sanitary measures, and frequent contact with farm animals can result in exposure to *Campylobacter* spp., and acquiring pre-existing immunity will result in low prevalence levels in the young and adult populations of the region.

According to the WTTC, the contribution of the tourism sector to the gross domestic product (GDP) in the SEA region has been ranked as the second highest (12%) in the world (Turner, 2014). Therefore, reporting and isolating *Campylobacter* from international travellers visiting the region has caused great concern about the sustainability of this high-priority tourism industry and the resulting boost to the regional economy.

PREVALENCE OF Campylobacter SPECIES IN FOOD COMMODITIES FROM COUNTRIES IN SOUTH-EAST ASIA

The total bacterial counts of only *E. coli* and *Salmonella* are included in the national food regulations in the SEA region; therefore, regular monitoring data for *Campylobacter* is unavailable, and the only available data are from the limited prevalence studies conducted in the region (Table 2). However, no prevalence data on poultry are available for Brunei Darussalam, Lao-PDR, Myanmar, or Timor-Leste.

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Cambodia

Poultry carcasses collected from retail outlets in Cambodia were screened for *Campylobacter* spp., and an 80% prevalence level of contamination was detected. Poultry samples were positive for *C. jejuni* (50%), *C. coli* (29%), and *C. lari* (21%). Approximately 1.3% of the samples showed contamination levels higher than 10^7 or 10^8 CFU/g. Multi-drug resistant *Campylobacter* spp. are defined as those resistant to more than one of the seven antimicrobials tested. *Campylobacter jejuni*, *C. coli*, and *C. lari* exhibited 97.1%, 97.5%, and 96.7% resistance to cefalotin, respectively. Some *C. lari* (90.0%), *C. jejuni* (69.6%), and *C. coli* (15.0%) isolates were resistant to nalidixic acid. While all the *C. coli* isolates were susceptible to amoxicillin, azithromycin, and erythromycin, all *C. jejuni* isolates were susceptible only to gentamicin. However, all the *C. lari* isolates exhibited resistance to all the tested antimicrobials (Lay et al., 2011).

Indonesia

According to Rosyidi et al. (2011), though Indonesian local and broiler intestine samples were 80% positive for *Campylobacter* spp., poultry meat was free of *Campylobacter* spp. All isolated *Campylobacter* spp. were identified as *C. jejuni* by polymerase chain reaction (Rosyidi et al., 2011).

Malaysia

Studies in Malaysia have shown that between 80 to 90% of chicken meat and organ samples are contaminated with *Campylobacter* spp. (Tang et al., 2010; Usha et al., 2010). A comprehensive study conducted by Rejab et al. (2012) revealed changes in the prevalence levels of *Campylobacter* spp. along the Malaysian poultry processing line. The highest *Campylobacter* prevalence (83.3%) was noted in faecal droppings on crates arriving to the processing plant. *Campylobacter* spp. prevalence was reduced from 80.6% to 38.9% between the inside-out washing step and the post-chilling step (Rejab et al., 2012). Ilida and Faridah (2012) detected *Campylobacter* spp. prevalence levels ranging from 94% to 22% in fresh, chilled, and frozen chicken.

Philippines

In the Philippines, 57 out of 120 chicken meat samples collected from wet markets indicated the presence of *Campylobacter* spp. The predominant species was *C. coli* (54.4%), followed by *C. jejuni* (45.6%). Of the 44 tested isolates, 63.6% showed resistance to more than one of the five tested antimicrobials. The highest resistant percentage was identified for ampicillin (77.3%) (Sison et al., 2014).

Singapore

The Agri-food Veterinary Authority of Singapore found *Campylobacter* in both imported and locally produced poultry; 58% of imported chilled chicken parts, 54% of local freshly slaughtered chilled chicken parts, and 41.7% of local freshly slaughtered chilled whole ducks contained *Campylobacter*, 66.7% of which were *C. jejuni* and 32.3% of which were *C. coli* isolates (Epidemiological News Bulletin, 2001).

Thailand

Campylobacter spp. were detected at a prevalence level of 89.3% and 98.8% in chicken meat samples collected from supermarkets and fresh markets, respectively, in Bangkok, Thailand (Saiyudthong et al., 2015). A study during 2007-2008 reported that the prevalence level of *Campylobacter* spp. in chicken meat in retail stores in north-eastern Thailand was 28.8%

(556/1930), and a significant amount of chicken liver was contaminated compared to other parts. *Campylobacter coli* and *C. jejuni* had an average prevalence of 36.4% and 63.6%%, respectively (Noppon et al., 2011). According to Osiriphun and colleagues, a 100% *Campylobacter* prevalence level was detected in scalded poultry carcasses, scald water, plucked carcasses, plucked feathers, and eviscerated carcasses from a Thai poultry processing plant, whilst the prevalence level was lower in chilled carcasses (20%) and fresh breast samples (15%). However, with the exception of the breast samples, none of the other fresh chicken meat samples were positive for *Campylobacter* spp. (Osiriphun et al., 2011). Boonmar et al. (2007a) found a 31% prevalence level of *Campylobacter* spp. from a total of 140 duck meat and intestine samples collected from the slaughterhouse.

Vietnam

In three different studies conducted in Vietnam, *Campylobacter* spp. prevalence values were determined at 15% in chicken neck skin (Garin et al., 2012), 0% in chicken neck/breast (Schwan, 2010), and 30% in chicken breast (Huong et al., 2006). According to Garin et al. (2012), *C. lari* was the most abundant *Campylobacter* spp., with a prevalence of 73.9%. *Campylobacter coli* and *C. jejuni* were detected in only 8.7% and 4.3% of the samples, respectively. In contrast, in a study conducted by Huong et al.(2006), 45.2% samples were positive for *C. jejuni*.

The reported prevalence levels of *Campylobacter* spp. in the SEA region ranged from as low as 0% to as high as 90%. Most of the studies were conducted on poultry meat. *Campylobacter jejuni* was the predominant isolate in the SEA region. Only Cambodia and Vietnam reported the prevalence of *C. lari* (Lay et al., 2011; Garin et al., 2012). Apart from poultry samples, the presence of *Campylobacter* was also analysed in sushi in Malaysia (Tan et al., 2008), in vegetables in Lao PDR (Chai et al., 2007), and in bovine samples in Thailand (Boonmar et al., 2007b). Prevalence levels of *Campylobacter* in poultry samples from different countries in the world varied significantly. Forty-one percent of poultry meat collected from food stores in Alabama, USA from 2005 to 2011 was contaminated with *Campylobacter* spp. (Williams and Oyarzabal, 2012). A baseline survey was conducted in the European Union (EU) to determine the *Campylobacter* prevalence levels in broiler carcasses. According to this study, 75.8% of the broiler carcasses were contaminated with *Campylobacter* spp. (EFSA, 2010). The prevalence levels of *Campylobacter* spp. in poultry meat were reported to be as low as 25% and as high as 100% in Switzerland and the Czech Republic, respectively (Ledergerber et al., 2003; Suzuki and Yamamoto, 2009). When considering the Asian region, 71% of retail poultry samples in Japan were positive for *Campylobacter* spp. (Saito et al., 2005). High prevalence levels reported in the SEA region can be attributed to mishandling and cross-contamination at the different stages of poultry processing.

In general, high *Campylobacter* spp. colonization rates can be detected in the poultry caecum, colon, and crop (Musgrove et al., 2001). The 42°C body temperature of poultry may facilitate the growth of thermophilic *Campylobacter* spp. (Park, 2002). The optimum temperature found in poultry may be beneficial for the expression of genes required for motility and growth (Stintzi, 2003). These factors may correlate with the highest contamination levels of *Campylobacter* spp. in poultry compared to those in other food commodities.

Isolation of *Campylobacter* spp. from food commodities is challenging due to the presence of low cell numbers, the presence of other competitive organisms, and sub-lethal injury

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to cells. Sub-lethally injured *Campylobacter* cells are more sensitive to hydrogen peroxide and photochemically induced oxygen radicals. Furthermore, selective agents and antibiotics in the media can inhibit the growth of *Campylobacter* (Ray and Johnson, 1984; Humphrey, 1990). The viable but nonculturable (VBNC) state of *Campylobacter* spp. can interfere with the isolation of organisms. Hence, the application of an appropriate method is important for the identification of *Campylobacter* spp. in food commodities.

PREVALENCE OF Campylobacter SPECIES IN ANIMALS FROM COUNTRIES IN SOUTH-EAST ASIA

Several studies conducted in the SEA region have investigated the prevalence of *Campylobacter* spp. in animals, and no data are available from Brunei Darussalam, Cambodia, Lao PDR, Myanmar, Timor-Leste, or Singapore (Table 3).

Table 3 Prevalence of *Campylobacter* spp. in animals from countries in South-East Asia

Indonesia

Poultry serum samples collected from native chickens in Indonesia exhibited prevalence levels of approximately 35.6% for *C. jejuni*, while seropositivity was closely related to the age of the birds. Birds aged more than 3 months were prone to be colonized with *Campylobacter* spp. However, farm-related factors were less likely to be associated with the sero-prevalence (Rosyidi et al., 2011).

Malaysia

The prevalence levels of *Campylobacter* spp. in Malaysian broilers were as low as 0% and as high as 98%. Unexpectedly, some broiler farms were not colonized with *Campylobacter* spp., especially in the closed house. *Campylobacter jejuni* and *C. coli* were the predominantly isolated species from broilers (Yap et al., 2005, Tang et al., 2010). *Campylobacter* prevalence levels ranging from 0 to 98.2% (average of 72.6%) were detected in poultry cloacal samples collected from ten different poultry farms in Malaysia. Only one of ten farms was not colonized with *Campylobacter* spp. *Campylobacter jejuni* (73.2%) and *C. coli* (26.8%) were detected in broiler chickens. All 76 isolates were resistant to at least one antimicrobial agent, and approximately 76% of the isolates exhibited multi-drug resistance. Resistance to tetracycline was detected in all *C. jejuni* isolates (Saleha, 2002). *Campylobacter* spp. were detected in 60, 24, and 75% of the houseflies (Choo et al., 2011), house crows (Ganapathy et al., 2007), and ducks, respectively (Nor Fiza et al., 2013).

Philippines

From a total of 135 duck and chicken caecal contents collected from Laguna, Philippines, 2.2% were positive for *C. jejuni*, and 3.7% were positive for *C. coli* (Magistrado et al., 2001). *Campylobacter jejuni/coli* antibodies were detected in 80.5% of poultry serum samples, and *C. jejuni* antibodies were not detected (n=128) (Manandhar et al., 2009).

Thailand

Of the faecal and caecal samples collected from broilers in Thailand, 8.6% and 62.9%, respectively, contained *Campylobacter* spp., while *C. coli* was the predominant organism in caecal samples (Saengthongpinit et al., 2010). Niyomtham and Kramomthong (2003) reported the isolation of *C. jejuni* (51.2%), *C. coli* (35.5%), and *C. lari* (13.2%) from the intestinal parts of chickens from four Thai retail markets. The highest rate of resistance for all three *Campylobacter* species was to ciprofloxacin (>80%), whilst the lowest rate of resistance was to ampicillin. More than 45% of the *C. jejuni* isolates and 35% of the *C. coli* isolates were resistant to more than one antimicrobial agent out of the six tested (Niyomtham and Kramomthong, 2003).

Vietnam

Campylobacter was prevalent in 24% of the poultry faeces and in 18.1% of the duck faeces collected from farms in Dong Thap province, Vietnam. *Campylobacter jejuni* was the most abundant species detected in poultry (20%) and duck (13.3%) faeces (Saengthongpinit et al., 2010). All *Campylobacter* isolates were resistant to erythromycin, and more than 90% of the isolates were resistant to sulfamethoxazole–trimethoprim, nalidixic acid, and ofloxacin. According to the multivariable hierarchical modelling used in this study, chickens aged from 10-24 weeks were most at risk of being colonized by *Campylobacter* spp., and the occurrence of diarrhoea was associated with *C. coli* colonization in both ducks and chickens.

FUTURE PERSPECTIVES

Most of the reported foodborne outbreaks in the region have been related to street food vendors and schools. Lack of food safety awareness, cultural practices that include eating raw or undercooked food, and poor sanitary measures, including open defecation, improper waste disposal, scarcity of clean and safe water, and insufficient monitoring of street food vendors (Dewanti_Hariyadi and Gitapratiwi, 2014), were some of the key food safety concerns in the SEA region that need to be addressed.

Poultry, especially chicken, is a major source of *Campylobacter* infection in humans. Even in the SEA region, poultry contamination levels are as high as 90% and can be identified as a potential source for the transmission of *Campylobacter* infection. Chicken per capita consumption levels in countries in the SEA region, such as Brunei Darussalam and Malaysia, are

62 and 38 kg/capita/year, respectively (FAOSTAT, 2015). Furthermore, Indonesia, Malaysia, Thailand, Vietnam, Myanmar, and Philippines are among the key poultry meat producers in the world, contributing to 36% of the world poultry production, and they are predicted to expand production (OECD FAO, 2014). High consumption and production rates of poultry pose a substantial risk for *Campylobacter* infection in the SEA.

Although much research has focused on reducing the contamination of *Campylobacter* spp. in poultry at the farm level, consistently preventing contamination remains a challenge. Three main approaches are indicated for controlling *Campylobacter* at the farm level: 1) reduce environmental exposure, 2) increase host resistance, and 3) reduce or eliminate *Campylobacter* spp. (Lin, 2009). Clear identification of risk factors is necessary for implementing various strategies to reduce environmental exposure (Wagenaar et al., 2008). Hence, factors related to the dynamics of the colonization of broiler flocks with *Campylobacter* spp. must be further evaluated.

Host resistance-increasing mechanisms include competitive expulsion, the use of probiotics, vaccination, and genetic selection. Vaccines have been developed against *Campylobacter* for poultry. However, most of the killed whole cell vaccines were unable to provide effective protection against *Campylobacter* colonization (de Zoete et al., 2007). Live attenuated *Salmonella* (Buckley et al., 2010) and *Eimeria* (Clark et al., 2012) vaccines were able to provide protection against *C. jejuni*. Lack of proper identification of the major proteins that lead to colonization and pathogenesis has become a major obstacle in the development of a vaccine against *Campylobacter* in poultry.

The application of competitive expulsion (CE) cultures to reduce *Salmonella* has been effective, although CE cultures against *Campylobacter* spp. in poultry have led to inconclusive results (Stern et al., 2001, Mead, 2002). A study conducted by Bhaskaran et al. (2011) found that poultry enteric isolates can inhibit the growth of *C. jejuni* and *C. coli in vivo*. Insights into the commensal flora in the poultry intestine, as well as its symbiosis and interaction with *Campylobacter* spp., will be essential for the successful identification of CE cultures.

Campylobacter was not always considered a potential pathogen for poultry; however, according to Humphrey et al. (2014), depending on the breed of *C. jejuni*, it can elicit an innate immune response that leads to developing clinical signs. No association has been detected between the colonization and persistence of *Campylobacter* spp. and the genotype of the broilers (Gormley et al., 2014). Research into improving poultry resistance against colonization with *Campylobacter* spp., and research characterizing the ecology and dynamics of *Campylobacter* in poultry flocks in tropical climates, is necessary to prevent contamination at the farm level as well as safeguard and sustain the poultry industry in the region.

Several studies have focused on the usage of different probiotics for controlling *Campylobacter* spp. in poultry with varying success. *In vivo* and *in vitro* experiments with *L. acidophilus* and *E. faecium* (Willis and Redi, 2008); *B. longum* (Santini et al., 2010) and *E. faecium*; and *P. acidilactici*, *L. salivarius*, and *L. reuteri* (Ghareeb et al., 2012) have indicated promising results of reducing *Campylobacter* levels in poultry. The beneficial effects on poultry and possible human application of these probiotics need further elucidation.

Application of bio-control measures, including bacteriophages, has shown favourable effects in reducing the colonization of *Campylobacter* spp. (Wagenaar et al., 2005, Carvalho et

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al., 2010). Genome analysis, consumer safety, and large-scale production of phages are some of the areas that need further study. Bacteriocins have emerged as a solution for growing concerns of antimicrobial resistance. A number of potent bacteriocins against *Campylobacter* spp. have been isolated from various sources, including SRCAM 602 from *Paenibacillus polymyxa* (Stern et al., 2005; Svetoch et al., 2005), OR-7 (Stern et al., 2006) and SMXD51 (Messaoudi et al., 2012) from *Lactobacillus salivarius*, and E-760 and E 50– 52 from *Enterococcus spp.* (Line et al., 2008; Svetoch et al., 2008).

Physical treatments, such as temperature treatment, are capable of reducing contamination levels, but they can lead to changes in the physical appearance of the final product. Combinations of steam with ultrasound (Musavian et al., 2014) and electrolysed oxidizing water with lactic acid (Rasschaert et al., 2013) have reduced the contaminant levels without changing the organoleptic properties. According to Burfoot et al. (2014), spraying with electrolysed water was only able to provide a less than 0.3-log reduction in *Campylobacter*. Chemical methods are effective against controlling *Campylobacter* contamination and do not change the physical appearance of the product. However, in some countries, the use of chemical treatments is prohibited by food legislations. The application of a mixture of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, polypropylene glycol (Zhao and Doyle, 2006), lactic acid (Riedel et al., 2009), and a combination of trisodium phosphate with capric acid sodium salt (Koolman et al., 2014) were able to reduce *Campylobacter* contamination levels. Some research has been conducted to assess the efficacy of different plant extracts on reducing *Campylobacter* spp. in food commodities. According to these studies, plant extracts, including grape phenolic extract (Mingo et al., 2014), and the *Alpinia katsumadai* seed phenolic extract, essential oil, and post-distillation extract (Kovac et al., 2014), have demonstrated the capacity to control *Campylobacter* spp. Usage of spices common in the SEA region and low *Campylobacter* spp. prevalence levels can be attributed to this culinary habit. Insight into the association of culinary habits and socio-cultural food consumption behaviours provides effective platforms that can be utilized in controlling *Campylobacter* contamination at the processing and consumer levels. In-depth studies to assess the efficacy of various spices and herbs against *Campylobacter* spp. are needed, as is the identification of active ingredients and mass scale production of these compounds. Commercial application, cost effectiveness, legal requirements, consumer safety, and acceptance must be further evaluated for the intervention strategies to be applied at the processing level.

Though high prevalence levels of poultry contamination are reported in the region, the prevalence of *Campylobacter* infection is comparatively low. However, only very limited and out-dated data are available on *Campylobacter* and its associated risks for the region. Irrespective of the availability of surveillance data, there can be deviances in the nature of *Campylobacter* infection in tropical countries compared to that in temperate countries where the disease is profoundly evaluated. The association of climate and demography with *Campylobacter* prevalence levels must be assessed. The monitoring systems in developing countries are not integrated into food safety systems and thus do no enable continuous monitoring of the whole food chain. Therefore, most of the food-borne infections are under-reported or undiagnosed. When reviewing the available data, *Campylobacter* emerges as an important food-borne infection and food contaminant in the SEA region. There is a scarcity of data for some countries in the SEA region. Lack of knowledge on morbidity, mortality, and related complications caused by human *Campylobacter* infection in the SEA region hinders assessing their impact. For insight into *Campylobacter* infection in a country, reliable baseline data supported by the national surveillance system are required. Therefore, prospective and retrospective studies on the prevalence and epidemiology of *Campylobacter* are necessary for a better understanding of the disease with respect to source of infection, risk factors, disease transmission, severity, and associated complications as well as to ultimately develop an intervention strategy at the population level.

Spices are an important element in SEA cuisines. Cooking patterns and culinary usage of spices in the region can be associated with low levels of human *Campylobacter* cases. Studies to assess the efficacy and safety of various spices in the region are essential to the development of applications that can be used in the food system.

Isolation of *Campylobacter* is tedious and requires specific growth conditions. Application of molecular detection methods (Manfreda et al., 2003; Barletta et al., 2013; Umesha and Manukumar, 2016) as well as epidemiological, modelling, and risks assessment tools (De Cesare et al., 2008; Behringer et al., 2011; Ragimbeau et al., 2014; Mikkela et al., 2016) will improve our understanding of the true burden of *Campylobacter* infection in the region, and a regional reference laboratory will enable monitoring and confirmation of *Campylobacter* and other foodborne pathogens.

CONCLUSION

The nature of *Campylobacter* in tropical countries has not been assessed in-depth. The prevalence levels of *Campylobacter* spp. and their antimicrobial resistance and cross-resistance in the SEA region must be further investigated. Coherent with the *Campylobacter*-associated food safety challenges, the SEA region must address the demand for the supply of wholesome and safe food for the growing population.

Travelling into a third-world country is identified as a risk factor for contracting *Campylobacter* infection. Internationally, there is an urge to differentiate infectious diseases as domestic cases and travel-related cases, and regulatory bodies related to health are concerned about understanding the epidemiology of the disease and implementing control measures. The majority of the countries in the SEA region are the top tourist destinations in the world, and tourism has a major contribution to their national economies. Provision of high-quality safe food to international travellers is another aspect that must be addressed in order for the tourism industry to thrive.

Malaysia, Indonesia, Vietnam, and Thailand are key poultry meat producers in the world. The contamination of poultry products may lead to trade barriers and limit the access to international markets, along with smirching the region's reputation in the international market for endangering the lives of people, breaching confidence, and non-transparency. Hence, *Campylobacter*-related issues must be intelligently addressed to safeguard the sustainability and success of the region. Therefore, effective, efficient, applicable, and cost-effective strategies must be developed and applied at each level of the food production system.

In spite of the advances in the detection and isolation of *Campylobacter*, countries in SEA still face difficulties in the isolation and identification of this organism. Lack of trained professionals and specialists in *Campylobacter* and low government priority for Campylobacteriosis are challenges that must be addressed in the region. Multilevel collaborative studies among SEA countries on the biology, ecology, and molecular mechanisms of

Campylobacter will be greatly beneficial for the development of control strategies and the establishment of an efficient surveillance system to ensure food safety.

CONFLICT OF INTEREST

There is no conflict of interest.

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Table 1 Isolation rates of *Campylobacter* spp. from countries in the South-East Asia

Country	Population	Sample size	Percent infected (%)	Species	Reference
Brunei Darussalam			25 cases from 2005-2012	*Campylobacter*	WAHIS, 2013
Cambodia	Children aged 3 months to 5 years with acute diarrhoea	600	4.7	*C. jejuni*	Meng et al., 2011
			1.5	*C. coli*	
	Children aged 3 months to 5 years without acute diarrhoea	578	6.2	*C. jejuni*	
			2.4	*C. coli*	
Indonesia	Patients with diarrhoea	3875	0.7	*C. jejuni*	Oyofo et al., 2002
	Control group	1118	0	*C. jejuni*	
	Patients with diarrhoea	21,763	3.6	*C. jejuni*	Tjaniadi et al., 2003
	Children 0-9 years with diarrhoea	144	10.0	*C. jejuni*	Ringertz et al., 1980
	Adults with diarrhoea	251	2.0	*C. jejuni*	
Laos	Patients with diarrhoea	880	2.2	*C. jejuni*	Yamashiro et al., 1998
			2.0	*C. coli*	
Malaysia	Children < 16 years	26444	5.0	*Campylobacter spp.*	Lee and Puthucheary, 2002
	Children with diarrhoea	212	3.8	*C. jejuni*	Lim et al., 1984
	Children without diarrhoea	192	2.6	*C. jejuni*	
	Adults with diarrhoea	69	4.3	*C. jejuni*	
	Adults without diarrhoea	100	0		
Myanmar	Children aged 0-35 months with diarrhoea	813	2.0	*C. jejuni*	Huilan et al., 1991

	Children aged 0-35 months	813	2.0	*C. jejuni*	
Philippines	Patients with diarrhoea	39	8.0	*C. jejuni*	Ventura et al., 2015
			8.0	*C. coli*	
	Control group	61	0		
	Patients with diarrhoea	2908	3.0	*C. jejuni*	Adkins et al., 1987
	Control group	576	2.7	*C. jejuni*	
Singapore	Adult patients	100	5.0	*Campylobacter spp.*	Chau et al., 2016
	Campylobacter enteritis cases	435	85.5	*C. jejuni*	MoH Singapore, 2014
			4.1	*C. coli*	
			0	*C. laridis*	
			10.3	*Other Campylobacter spp.*	
	Inpatients with diarrhoea	7344	1.2	*Campylobacter spp.*	Lim and Tay, 1992
Thailand	Adults and children with diarrhoea	2500	3.0	*C. jejuni*	Samosornsuk et al., 2015
				C. coli	
				C. fetus	
				C. hyointestinalis	
	Children with diarrhoea	124	61.0	*C. jejuni*	Bodhidatta et al., 2013
			19.0	*C. coli*	
			19.0	*C. upsaliensis*	
	Children with diarrhoea	236	22.0	*Campylobacter*	Bodhidatta et al., 2010
	Children non-diarrhoea controls	236	25.0	*Campylobacter*	
	Children 1month-12 years with mucous bloody diarrhoea	623	28.0	*C. jejuni*	Bodhidatta et al., 2002
	U.S. military personnel with diarrhoea in Thailand (From 1987-1995)		245.0	*Campylobacter*	Hoge et al., 1998

Thailand	Children 1-3 years with acute diarrhoea	631	10.0	*C. jejuni*	Taylor et al., 1991
			2.0	*C. coli*	
			0.2	*C. upsaliensis*	
			0.2	*C. jejuni doylei*	
			3.0	Aerotolerant *Campylobacter*	
	Children <5 years with diarrhoea	345 episodes	12	*C. jejuni*	Varavithya et al., 1990
	Infants in orphanage with diarrhoea	100	31.0	*C. jejuni*	Taylor et al., 1987
			19.0	*C. coli*	
Timore-Leste					NAD
Vietnam	Children less than 5 years of age with diarrhoea	291	1	*Campylobacter*	Bodhidatta et al., 2007
	Children less than 5 years of age without diarrhoea	291	0		

NAD: No available data

Table 2 Prevalence of *Campylobacter* spp. in food commodities from countries in the South-East Asia

Country	**Sample**	**Total sample**	***Total Campylobacter* spp. *positive %***	**Species**	**Positive %**	**Reference**
Brunei Darussalam						NAD
Cambodia	Poultry neck skin	152	80.9	*C. jejuni*	50.0	Lay et al., 2011
				C. coli	29.0	
				C. lari	21.0	
Indonesia	Chicken intestine	5	80.0			Rosyidi et al., 2011
	Chicken meat	77	0			
Malaysia	Equipment (swabs)	72	40.3			Rejab et al., 2012
	Crates on arrival (fecal droppings)	72	83.3			
	Before inside-outside washing (neck skin)	72	80.6			
	After inside out washing (neck skin)	72	62.5			
	Post chilling (neck skin)	72	38.9			
	Raw chicken meat and marinated raw chicken (fresh)	94		*C. jejuni*	48.0	Ilida and Faridah, 2012
	Raw chicken meat and marinated raw chicken	35		*C. jejuni*	9.0	

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	(chilled)					
	Chicken-based products (frozen)	22		*C. jejuni*	0	
	Chilled chicken parts	80		*C. jejuni*	53.8	Usha et al., 2010
				C. coli	56.3	
	Fresh chicken parts	80		*C. jejuni*	92.5	
				C. coli	80.0	
Malaysia	Chicken skin and meat from slaughter house	150	84.0	*C. jejuni*	74.7	Tang et al., 2010
				C. coli	0.7	
				C. jejuni/ C. coli	8.7	
	Packed chicken	50	94.0	*C. jejuni*	38.0	
				C. jejuni/ C. coli	56.0	
	Chicken skin and meat, Wet Market	50	78.0	*C. jejuni*	70.0	
				C. jejuni/ C. coli	8.0	
	Chicken skin and meat, Hyper Market	75	92.0	*C. jejuni*	69.3	
				C. coli	2.7	
				C. jejuni/ C. coli	20.0	
	Chilled chicken parts	93		*C. jejuni*	91.4	Tang et al., 2009
				C. coli	34.4	

	Fresh parts	92		*C. jejuni*	70.7	
				C. coli	20.7	
Myanmmar						NAD
Philippines	Chicken meat	120	47.5	*C. jejuni*	45.6	Sison et al., 2014
				C. coli	54.4	
Singapore	Imported frozen poultry		19.7			Epidemiological News Bulletin, 2001
	Imported chilled chicken parts		58.0			
	Local freshly slaughtered chilledwhole chicken		54.0			
	Local freshly slaughtered chilled whole duck		41.7			
Thailand	Raw chicken from fresh market	108	98.8	*C. jejuni*	56.5	Saiyudthong et al., 2015
				C. coli	33.3	
	Raw chicken from super market	122	89.3	*C. jejuni*	80.3	
				C. coli	35.2	
	Poultry caeca	98	11.2			Chokboonmongkol et al., 2013
	Chicken skin	98	51.0			
	Poultry scalded	20	100			Osiriphun et al., 2011
	Scalded water	20	100			
	Plucked carcass	20	100			
	Plucked feathers	20	100			
	Eviscerated carcass	20	100			
	Chilled	20	20			

	carcass					
	Fresh breast samples	20	15			
	Fresh leg	20	0			
	Fresh thigh	20	0			
	Fresh wing	20	0			
	Chicken carcass	20	0			
	Gizzard	390	18.7			Noppon et al., 2011
	Heart	390	20.5			
	Liver	380	60.3			
	Upper wing	420	25.5			
	Lower wing	350	19.1			
Thailand	Duck meat and intestine	140	31.0	*C. jejuni*	24.2	Boonmar et al., 2007a
				C. coli	4.1	
	Intestinal parts of chicken	239	50.6	*C. jejuni*	25.9	Niyomtham and Kramomthong, 2003
				C. coli	17.9	
				C. lari	6.6	
Timore-Leste						NAD
Vietnam	Chicken neck skin	150	15.3	*C. jejuni*	4.3	Garin et al., 2012
				C. coli	8.7	
				C. lari	73.9	
	Chicken meat	96	0			Schwan et al., 2010
	Chicken breast	100	31.0	*C. jejuni*	45.2	Huong et al., 2006

NAD: No available data

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Table 3 Prevalence of *Campylobacter* spp. in animals from countries in the South-East Asia

Country	**Animal**	**Sample**	**Total sample**	***Total Campylobacter* spp. *positive %***	**Species**	**Positive %**	**Reference**
Brunei Darussalam							NAD
Cambodia							NAD
Indonesia	Native chicken	serum	216	35.6	*C. jejuni*	35.6	Rosyidi et al., 2011
Malaysia	Duck cloacal swabs		75	12	*C. jejuni*	22	Nor Fiza et al., 2013
					C. coli	88	
	Houes flies	External body surface and internal content	60	5	*C. jejuni*	1.6	Choo et al., 2011
					C. coli	3.3	
	Broilers in close house	Cocal swabs	152	0	0		Tang et al., 2010
	Broilers in open house	Cocal swabs	152	95	*C. jejuni*	94.0	
					C. coli	1.0	

	House crow	Swabs from the intestine or cloaca	24	25.3	*C. jejuni* *C. coli*		Ganapathy et al., 2007
	Chicken birds	**Faeces**	150	70	*C. jejuni*	83.8	Yap et al., 2005
Malaysia	Broilers	Cloacal samples	508	76.2	*C. jejuni*	73.2	Saleha, 2002
					C. coli	26.8	
Myanmar							NAD
Philippines	Chicken and duck	Caecal content	135	5.9	*C. jejuni*	2.2	Magistrado et al., 2001
					C. coli	3.7	
Thailand	Broilers	**Faeces**	70	8.6	*C. jejuni*	4.3	Saengthongpinit et al., 2010
					C. coli	4.3	
	Broilers	Caecum	70	62.9	*C. jejuni*	8.6	
					C. coli	54.3	
Timor-Leste							NAD
Vietnam	Chicken	**Faeces**	100	24.0	*C. jejuni*	20.0	Carrique-Mas et al., 2014

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					C. coli	4.0	
	Duck	**Faeces**	83	18.1	*C. jejuni*	13.3	
					C. coli	3.6	

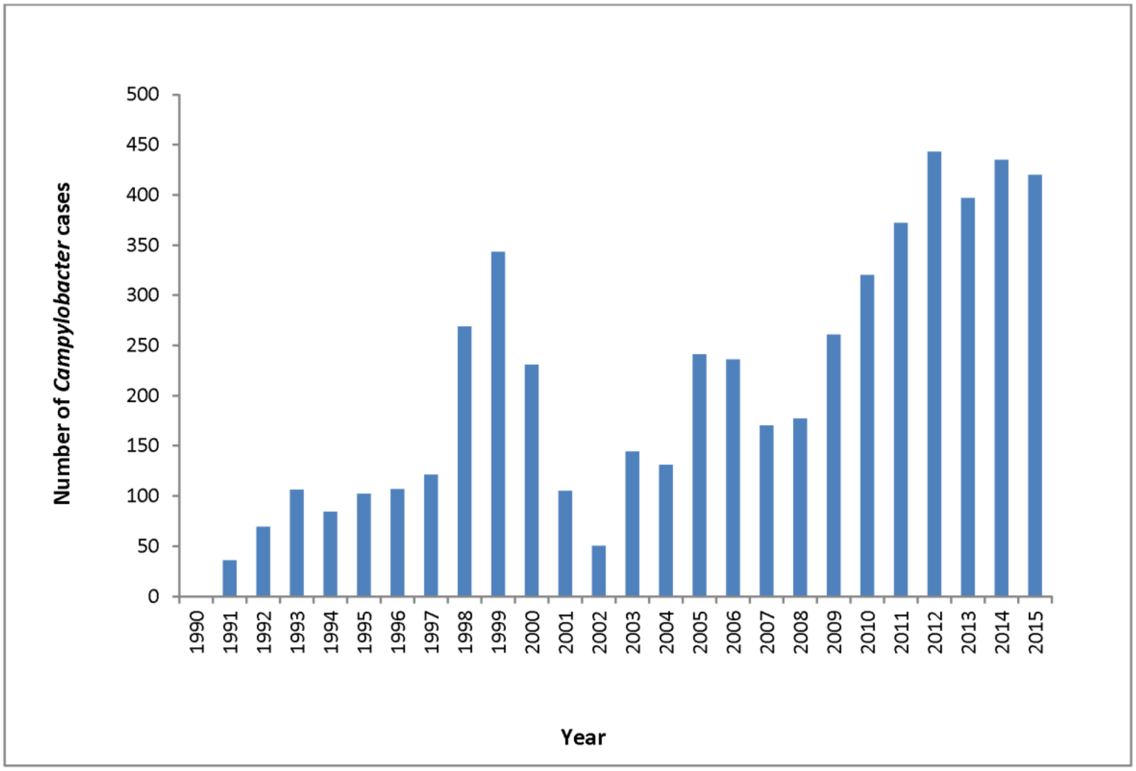

Figure 1 Incidences of *Campylobacter* in Singapore from 1990 to 2015

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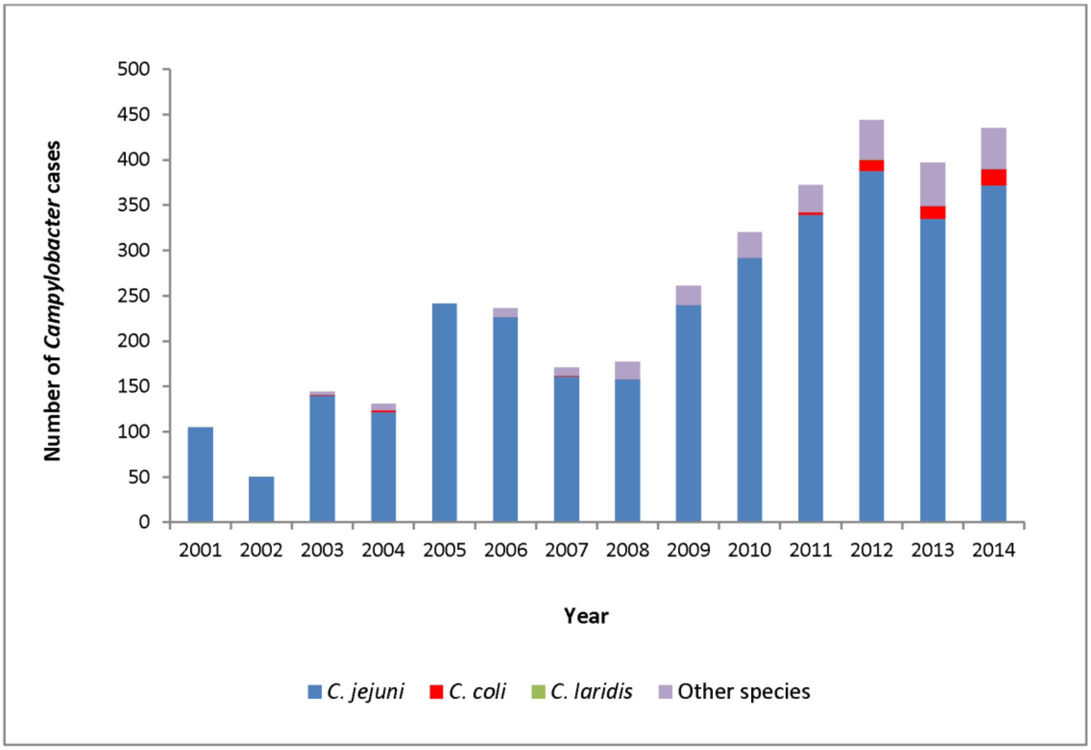

Figure 2 Incidences of *Campylobacter* species associated with enteritis in Singapore from 2002 to 2014

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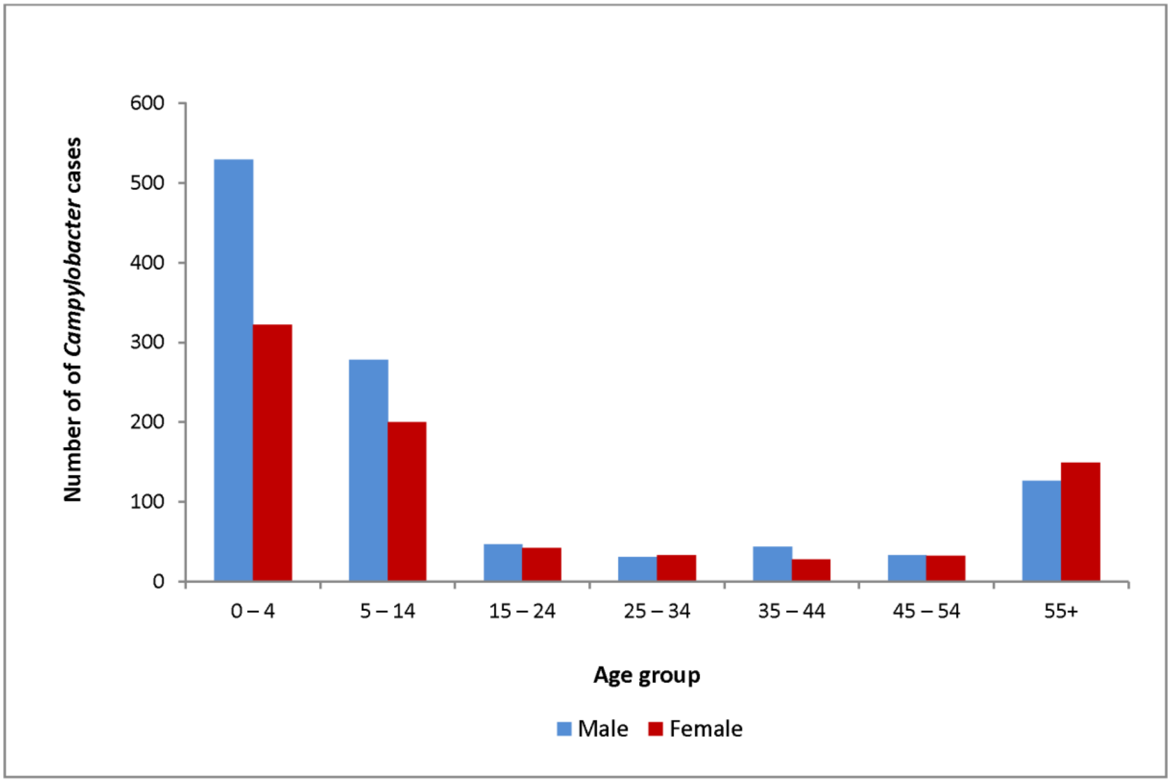

Figure 3 Age and gender distribution of *Campylobacter* cases in Singapore, 2010-2014