The worldwide trend of *Campylobacter* spp., infection from duck-related isolates and associated phenotypic and genotypic antibiotic resistance, since 1985: identifying opportunities and challenges for prevention and control

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ABSTRACT *Campylobacter*, a leading cause of foodborne diseases, is well recognized worldwide. Poultry and poultry products are considered as major sites for *Campylobacter* infection in humans. The extensive uses of antibiotics mostly as growth promoters and for therapeutic purposes have led to the emergence of antibiotic-resistant strains of foodborne pathogens including *Campylobacter*. A key tenet of this paper is the need for reviewing the previous studies conducted around the globe on the prevalence and antimicrobial resistance of *Campylobacter* spp. isolates in duck to better understand the sources and trends of infection. Based on published data, the prevalence of *Campylobacter* spp. in duck and duck-related samples ranged from 0% to 100% and was largely influenced by the isolation method.

Among *Campylobacter* spp., *C. jejuni* was the predominant cause of campylobacteriosis, followed by *C. coli*. *Campylobacter* spp. from ducks were mostly resistant to fluoroquinolones and tetracycline and a lesser extent to gentamicin, chloramphenicol, and erythromycin. Some studies showed that ducks may pose a risk for acquiring campylobacteriosis because they had genotypes quite similar to human isolates detected previously. A continued monitoring approach is needed, at national and international levels, with enhanced surveillance and reporting of trends, as well as harmonization of surveillance systems toward a one-health approach to monitoring antimicrobial resistance in animal production particularly if increased resistance rates are being demonstrated.

Key words: antibiotic resistance, *Campylobacter*, duck, genotyping, prevalence

INTRODUCTION

Foodborne pathogens (e.g., *Campylobacter*) which are human infections transmitted through food are natural reservoirs in vertebrate animal species (Carrique-Mas and Bryant, 2013). It has been reported that *Campylobacter* spp., are the leading cause of foodborne illnesses compared with other foodborne pathogens (Adzitey et al., 2012). Among *Campylobacter* spp., the most prevalent cause of campylobacteriosis is *C. jejuni*, which is followed by *C. coli*. Poultry and poultry products are considered as major sites for *Campylobacter* infection in humans. Ducks are important food sources around the world especially in Asia which their production plays a significant role in the agricultural economy.

The prevalence of *Campylobacter* spp. from duck isolates showed to vary from study to study as well as country to country. In Malaysia, the prevalence of *Campylobacter* spp. has been increased among duck isolates (Adzitey et al., 2012). In a recent study, duck isolates showed an even higher prevalence of *Campylobacter* spp., compared to chicken isolates (77.5 vs. 32%) in South Korea (Chon et al., 2018). It has also been reported that horizontal transmission through environmental contaminants are also responsible for *Campylobacter* infection in ducks (Saengthongpinit et al., 2014).

Campylobacter infections do not cause a threat for ducks since *Campylobacter* is commensal in the gastrointestinal tract of the bird, however, in humans, treatment with antibiotics is required in specific clinical circumstances. Therapy with antibiotics may be complicated by the fact that antimicrobial resistance in *Campylobacter* isolates from human infections has become increasingly common worldwide. (Mason et al., 2017). Consistently, Lee et al. (2017) reported that most of the isolates from ducks showed resistance to nalidixic acid (NAL) and

ciprofloxacin (CIP). A high multidrug-resistant rate to CIP, NAL, and tetracycline (TET) was also observed from duck isolates from markets in Iran (>60%). As mentioned earlier, ducks and their products are commonly consumed around the world especially in the Asian diet, so, it is important to understand the prevalence and antimicrobial resistance in *Campylobacter* isolates with the contribution of ducks to reduce the burden of infection and to implement safety strategies.

Currently, numerous papers have been published on the prevalence of *Campylobacter* spp., from duck-related isolates and associated antibiotic resistance during the past few years. However, to the best of our knowledge, there is not a compelling review study to put them on perspective. Therefore, the authors of the present manuscript have put their best efforts to fill the current need by conducting precise literature reviewing on peer-reviewed publications about the effects of the above mentioned. Therefore, a thorough study has been conducted to elucidate the prevalence of antimicrobial resistance of *Campylobacter* spp. isolates in ducks and highlight gaps in research for the development of control policies to limit the impact of *Campylobacter* infection worldwide.

Worldwide Prevalence Rate, Antibiotic Resistance and Genetic Diversity of Campylobacter *spp. from Duck Isolates*

We reviewed the available published literature in English worldwide since 1985. We searched mostly PubMed and Google scholar for articles using the following combinations of terms in either the title or the abstract with the keywords of "Antibiotic resistance," "antimicrobial resistance," "prevalence," occurrence," "duck," and *Campylobacter*." We also documented available data on diverse samples tested from duck, as well as prevalence and/or incidence data within animal reservoirs, with a specific focus on the worldwide prevalence of *Campylobacter* infection during years.

The prevalence, antimicrobial resistance rates and genetic diversity of *Campylobacter* spp. isolates in duck since 1985 are shown in Tables 1 and 2, respectively. The early studies on the prevalence of *Campylobacter* spp. from duck isolates were conducted in the US . As an example, a study about the prevalence of *C. jejuni* in ducks and duck meat were conducted at the farm and processing plant levels in the US in 1985 to 1986 (Kasrazadeh and Genigeorgis, 1987). Results showed that the ducklings were colonized with *C. jejuni* as early as the 4th day of the age and showed colonization rates of 100% by the 7th to 8th day of age. These results were in contrast with the other studies on chicken-related isolates who suggested that the infection in the broiler chicken houses usually occurred after the first 2 weeks. The isolation of *C. jejuni* as early as the 4th day of age could suggest vertical transmission of the organism. However, no *C. jejuni* was detected in the eggs which rejected the likelihood of the vertical transmission of C.

jejuni in ducks. Isolation rates of *C. jejuni* in liver, gizzard, heart, and skin samples were also reported as 34, 20, 6, and 6.7%, respectively. Kasrazadeh and Genigeorgis (1987) concluded that duck meat had not been incriminated in *C. jejuni* foodborne illness and the *C. jejuni* carrier rats and mice found on the premises were related to their finding as a source of colonization by *C. jejuni*. In 1985, 73% of cloaca1 swabs obtained from ducks in central Washington were contaminated with *Campylobacter* spp. (Pacha et al., 1988). It was also suggested that waterfowl as well as other migratory birds may play a role in the waterborne spread of *C. jejuni*. In 1987 to 1988, the prevalence of selected domestic and wild ducks in Louisiana showed that almost 6% (5/89) of isolates obtained from cloacal swabs were colonized with *C. jejuni* (Yogasundram et al., 1989). Their results showed that ducks (6%) had lower colonization of *C. jejuni* as compared with other fowl species such as Galliformes (25%), Columbiformes (8%) and Falconiformes (7.7%). Consistent to the study of Pacha et al (1988), it was also reported that free-living and migratory waterfowl may serve as carriers of *C. jejuni* infection. In Africa (1988), the isolation of *Campylobacter* spp. from domestic animals and human patients in Kenya showed that healthy ducks (29.4%) had higher prevalence of *Campylobacter* than other species; healthy goats (6.3%), healthy cattle (5.8%), diarrhoeic humans (3.1%), and healthy sheep (2.0%), but they had lower prevalence of *Campylobacter* than diarrheic pigs (55. 1%), followed by healthy chicken (51.5%), diarrheic dogs (47.2%), and healthy pigs (44%). (Turkson et al., 1988). It was also declared that *C. jejuni* was more prevalent than *C. coli* in all animal species. In Poland (1989), 48.0% of the ducks were colonized with *Campylobacter* spp. (Kwiatek et al., 1990). Moreover, the most frequent species of *Campylobacter* was *C. jejuni* (63.5%), followed by *C. lari* (18.8%), and *C. coli* (17.7%) which were consistent to the study conducted in Kenya. Modified charcoal cefoperazone deoxycholate agar (mCCDA) medium was also known for more sensitivity and selectivity than *Campylobacter* brucella agar plate (CampyBAP) medium (93% vs. 62%) for the isolation of *Campylobacter* spp. from poultry carcasses. In Portugal (1989-1990), the incidence of *Campylobacter* isolated from rectal swabs and stool specimens in ducks was 40.5% which was lower than chicken (60.2%) and swine (59.1%) but higher than cows (19.5%) and sheep (15.3%) (Cabrita et al., 1992).

The half of the fecal samples collected from free-living ducks in metropolitan parks in Ohio state in the US were *Campylobacter* positive (Fallacara et al., 2001). The authors also showed a high prevalence of resistance to multiple antibiotics in *C. jejuni* isolates from ducks . Contrastingly, a low multidrug resistance among *C. jejuni* isolated from raw poultry meat (including duck meat) was observed at retail level in Denmark (1999-2003) (Andersen et al., 2006). Moreover, most of isolates (80%) were fully sensitive to the antibiotics tested. However, a higher frequency of TET resistance was recorded among isolates from other poultry meat

(including duck meat) as compared with chicken meat (32% vs. 7.6%). In Taiwan (2000-2001), almost 44% of cloacal swabs in ducks from 100 duck farms were *Campylobacter* positive (Tsai and Hsiang, 2005). Furthermore, no colonization of *Campylobacter* was detected in ducks less than 3 weeks of age which was in contrast with the early study of Kasrazadeh and Genigeorgis (1987) in the US. The presence of maternal antibodies was likely attributed to the resistance in the initial period. In addition, the prevalence rate could be influenced by the specimen as well as methods used for the recovery of *Campylobacter* spp. As an example, the caecum was recognized as the major site for the colonization of *C. jejuni* in poultry as well as the use of enrichment and/or filtration methods could affect and possibly increase the chance of recovery of the organism. To confirm the efficiency of techniques for the isolation and identification of *Campylobacter*, a variety of techniques were used and compared in duck carcass and caecal content in the UK in 1997 (Ridsdale et al., 1998). The most effective methods for isolating *Campylobacter* spp. from duck carcass was identified as selective enrichment in *Campylobacter* enrichment broth, containing a cefoperazone, amphotericin, teiocoplanin supplement followed by plating onto mCCDA or plating onto non-selective blood agar after filtration with cellulose acetate filter. Contrarily, direct plating onto mCCDA was the most effective method for the recovery of *Campylobacter* from caecal content. In Germany, over seven years of studies (2001-2007) in 68 duck flocks, 59.6% of the Pekin duck flocks and 68.2% of the Muscovy duck flocks were *Campylobacter* positive (Weber et al., 2014). That study concluded that colonization of *Campylobacter* did not correlate with a specific age, which contradicted the previous studies about the infection of poultry at different age. In Sweden (2003), *C. jejuni* isolated from meats (e. g., duck) showed no resistance to gentamicin (GEN) or erythromycin (ERY) as determined by the microdilution method (Lindmark et al., 2004). *Campylobacter* isolates in Sweden were also shown as genetically diverse and propagation of resistant clones played a key role in the increase of resistant *Campylobacter* strains. In the UK (2003-2005), duck meat (50.7%) exhibited lower contamination rate of *Campylobacter* as compared with chicken (60.9%) but higher than turkey (33.7%) and other poultry meats (34.2%) (Little et al., 2008). The microbial drug resistance of *C. jejuni* was also reported as low as 0 and 11% versus 45.5% for *C. coli* as determined by the disk diffusion method.

Poultry meats in the UK were shown to be more frequently contaminated with *Campylobacter* as compared with other foodborne pathogens such as *Salmonella*. In 2004 to 2005, the prevalence of *C. jejuni* in duck faeces was reported as high as 63.5% around drinking water sources (ponds and wells) in north-central Nigeria (Ofukwu et al., 2008). Moreover, the incidence rate was highest in the month of February (80.0 and 83.3 % for wells and ponds, respectively) and lowest in October (wells, 40%) and March (ponds, 50%). From the study in Nigeria, it could be derived that the season variability could influence the prevalence rate of *Campylobacter*, which further studies are needed in this matter.

In Thailand (2004-2005), the identification of *Campylobacter* in ducks was conducted by two different detection methods (standard culture method and multiplex polymerase chain reaction) (Boonmar et al., 2007). The prevalence of *Campylobacter* spp. in duck isolates was higher for PCR (31%) as compared with standard culture method (20%). Using PCR over conventional methods was recommended for the detection and identification of *Campylobacter* spp. In Tanzania (2005), the prevalence of *Campylobacter* isolates from free range domestic ducks was reported as 80% (Nonga and Muhairwa, 2010). The results obtained were higher than those reported previously in Africa (Nigeria, 63.5% and Kenya, 29.4%). The isolation rate of *C. jejuni* (81.9%) was also reported higher than that of *C. coli* (18%). Adult ducks (91.3%) showed higher infection rate than that of ducklings (68.2%). Nonga and Muhairwa (2010) speculated that the high infection rates in adult ducks was because of longevity and feeding behavior on wet feeds which increased the chances of infection. The results of antibiotic susceptibility testing revealed that none of the *C. jejuni* isolates from adult ducks and duckling were resistant to Streptomycin (STR), Nitrofurantoin (NIT) and Amikacin (AMK). The highest prevalence of antimicrobial resistance of *C. jejuni* was reported for ampicillin (AMP, 58 and 24%) and TET (48 and 26%) for adult ducks and duckling, respectively. Overall, *C. jejuni* isolates from adult ducks showed higher rates of resistance to most antibiotics than did duckling isolates. It was suggested that the longer raising period of adult ducks (more than 6 months) could expose them to different types of antibiotics for a longer period and this may have accounted for the higher rate of resistant *Campylobacter* starins. The prevalence of *Campylobacter* spp. on farm, after transport, and at processing in poultry market in California showed that *Campylobacter*-positive birds (duck) were lower on the final products than on-farm level or during processing (McCrea et al., 2006). In a similar study in Bulgaria (2008), the presence of *Campylobacter* spp. during processing from live bird to prepackaged carcasses of Moulard ducks showed low percentage of *Campylobacter* detection in fatty liver which could be related to the increase of fat content in the liver and further unsuitable conditions for bacteria to grow (Stoyanchev et al., 2009). In 2008-2010, *Campylobacter* spp. was detected in 39.2% (90% *C. jejuni* and 10% *C. coli*) of duck intestinal content samples from wet markets in Tehran, Iran (Jamali et al., 2015). The results of antimicrobial susceptibility testing showed high levels of multidrug resistance among the *Campylobacter* spp. isolates. Moreover, CIP (87%), NAL (75%) and TET (75.4%) had the highest and GEN (0%), Neomycin (NEO, 3.5%), STR (3.5%), ERY (4.4%) and Chloramphenicol (CHL, 4.4%) had the lowest resistance rate among *Campylobacter* spp. as determined by Kirby-Bauer disc diffusion method. In New Zealand (2008-2009), faeco-prevalence of *C. jejuni* in urban wild birds and pets showed a higher

Table 1. Prevalence and antimicrobial resistance of *Campylobacter* spp. isolates in duck (since1985).

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
1985−1986	US	Slaughterhouse. Ceca, heart, liver, gizzard, (n=50); neck skin, scalding water overflow, feather picker drip water, water left after wax treatment, chiller water overflow (n=30)	Isolation: direct plating Identification: biochemical procedures	*C. jejuni*: Ceca 50 (100%), heart 3 (6%), liver 17 (34%), gizzard 10 (20%), neck skin 2 (6.7%), scalding water overflow 2 (6.7%), feather picker drip water 29 (96.7%), water left after wax treatment 6 (20%), chiller water overflow 8 (26.7%).	-	-	Isolation rates of *C. jejuni* from the organs (liver, gizzard, heart) and neck skins were lower than the average rates reported for chicken and turkey processing plants.	Kasrazadehand Genigeorgis (1987)
1985	US (Washington)	Migratory ducks from the Pacific North American Flyway in central4 Washington. Fecal samples (n=113)	Isolation : enrichment method	*Campylobacter* spp.: 82 (73%)	-	-	The high frequency of isolation in the migratory ducks indicated that these bird populations may play a role in the dissemination of the bacterium.	Pacha etal. (1988)
1987−1988	US (Louisiana)	Samples from ducks killed by hunters in wetland. Cloacal swabs (n=89)	Isolation: selective enrichment Identification: microscopic morphology using basic fuchsin stain, motility under dark-field illumination, NAL sensitivity, and hippurate hydrolysis	*C. jejuni*: 5 (5.6%)	-	-	Free-living and migratory waterfowl could be a carrier of *Campylobacter*.	Yogasundram etal. (1989)
1988	Kenya (Nairobi)	Samples from slaughterhouses, farms, and private homes. Rectal swabs (n=85)	Isolation: direct plating, Identification: biochemical tests	*Campylobacter* spp.: 25 (29.4%), *C. jejuni*: 17 (68.0%), *C. coli*: 6 (24.0%)	-	-	Ducks may play a significant role in the epidemiology of human campylobacteriosis by serving as reservoirs.	Turkson etal. (1988)
1989	Poland	Slaughterhouse. Carcass (n=200)	Isolation:d irect plating	*Campylobacter* spp.: 96 (48.0%), *C. jejuni* (63.5%), *C. lari* (18.8%), *C. coli* (17.7%)	-	-	Ducks had a high prevalence of *Campylobacter* at the slaughterhouse level.	Kwiatek etal. (1990)
1989−1990	Portugal (Northeast Portugal)	Food-producing animals and wild animals. Rectal swabs and stool specimens	Isolation: selective medium Identification: morphology of the colonies, positive oxidase reaction and a microscopic aspect of Gram-negative spiral rods	*Campylobacter* spp.: 21 (40.5%)	-	-	The prevalence of *Campylobacter* infection in ducks (40.5%) was higher than other species such as cows (19.5%), sheep (15.3%) but lower than chicken (60.2%) in Portugal.	Cabrita etal. (1992)

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Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
1997	UK	Slaughterhouse. Carcass (n=10), Caecal content (n=8)	Isolation: direct plating onto mCCDA and selective enrichment in enrichment broth Detection: API Campy test followed by SDS-PAGE and biochemical characterization	*Carcass*: direct plating: *C. coli* (1/10), *C. jejuni* (1/10); Selective enrichment: *C. coli* (6/10), *C. jejuni* (0/10) *Caecal content*: direct plating: *C. coli* (4/8), *C. jejuni* (3/8); selective enrichment: *C. coli* (1/8), *C. jejuni* (2/8)	-	-	The most effective method for isolating *Campylobacter* from carcasses was selective enrichment in *Campylobacter* enrichment broth, while direct plating onto mCCDA was the most effective method for isolation of *Campylobacter* from caecal content.	Ridsdale etal. (1998)
1998−1999	US	Free-living ducks in metropolitan parks in Ohio. Fecal samples (n=82)	Isolation: direct plating onto Campy CVA agar Identification: biochemical tests and *Campylobacter* latex agglutination test	*C. jejuni*: 33 (40.2%)	Disk diffusion method	STR (38%), PEN (85.9%), LIN (89.1%), GEN (5.4%), NEO (33.7%), TMP (88%), VAN (76.1%), OXY (7.6%), ERY (23.9%), TOB (9.8%), AMK (19.6%),SXT (66.3%), NET (8.7%), BAC (94.6%), FEP (21.7%), CFZ (83.7%), CEF (88%), TZP (54.3%), PIP (58.7%), SAM (17.4%)	Free-living ducks can serve as potential reservoirs for *C. jejuni* infection in human.	Fallacara et al. (2001)
1999−2003	Denmark	Retail outlets and wholesale meat (n = 100)	Identification: hippurate hydrolysis and indoxyl acetate tests	-	Disk diffusion method	*C. jejuni*: TET (32%), GEN (0%), STR (7%), CIP (12%), NAL (12%).	A high prevalence of TET resistance among *C. jejuni* isolated from raw duck meat at the retail level was reported.	Andersen etal. (2006)
2000−2001	Taiwan	Duck farm (n=100), faecal samples (n=2,400)	Isolation: subculture on Preston agar Identification:b iochemical procedures	*Campylobacter* spp.: 92/100 (92%) for duck farm and 1,045/2,400 (43.5%) for faecal samples	Disk diffusion method and E-test	Disk diffusion method: AMX (84.4%), APR (7.6%), LEX (27.2%), CIP (17.4%), CST (22.8%), DOX (0%), FLO (88%), NAL (85.9%), TET (84.8%) E-test: AZM (54%), CHL (27.2%), CLI (64.1%), ERY (65.2%)	High prevalence of multi-drug resistance was observed in this study.	Tsaiand Hsiang (2005)
2001−2007	Germany (Hannover)	Duck flocks (n=68): Pekin duck (n=46) and Muscovy duck (n=22)	Isolation: direct plating Identification: morphology and motility, Gram-stain, catalase and oxidase reaction, and no growth under aerobic and anaerobic conditions	*Campylobacter* spp.: 59.6% in Pekin duck, 68.2% in Muscovy duck; *Summer season*: Pekin duck (80%), Muscovy duck (70%); *Winter season*: Pekin duck (60%), Muscovy duck (63%)	-	-	*Campylobacter* could be introduced into a duck flock by the presence of vectors as well as environmental and seasonal factors.	Weber etal. (2014)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
2003	Sweden	Imported meat (n=1)	Isolation and identification: selective enrichment and PCR methods, respectively	-	Broth microdilution method	None of the tested isolates was resistant to GEN or ERY.	Low frequency of antibiotic resistance was revealed.	Lindmark etal. (2004)
2003−2005	UK	Retail raw meat (n=77): Whole bird (n=7) and Portions (n=70)	Isolation: s elective enrichment in Boltonb roth	*Campylobacter* spp.: 2/7 (28.6%) for whole bird and 37/70 (52.9%) for portions	Disk diffusion method	*C. jejuni*: AMP (66.7%), CHL (0%), TET (77.8%), FZD (0%), GEN (0%), KAN (0%), NEO (0%), NAL (0%), CIP (0%), ERY (0%); *C. coli*: AMP (45.5%), CHL (0%), TET (54.6%), FZD (0%), GEN (0%), KAN (9%), NEO (9%), NAL (54.6%), CIP (54.6%), ERY (36.3%)	The overall rate of *Campylobacter* contamination (50.7%) in fresh chicken meat in the present study was higher than that previously reported in the UK.	Little etal. (2008)
2004−2005	Nigeria (Makurdi)	Duck feces (n=192)	Identification: oxidase and catalase production, and hippurate hydrolysis test	*C. jejuni*: 122 (63.5%)	-	-	The prevalence of *C. jejuni* in duck feces was quite high in Makurdi, Nigeria. Contamination of duck feces in water could cause *Campylobacter* infection in human.	Ofukwu etal. (2008)
2004−2005	Thailand (Nakhon Pathom)	Duck meat and intestine from a slaughterhouse (n=140)	Isolation and i dentification: standard culture method (SCM) and multiplex PCR method	*C. jejuni* (77.3%) and *C. coli* (22.7%)	-	-	High prevalence of *Campylobacter* contamination in duck in Thailand.	Boonmar etal. (2007)
2005	Tanzania (Morogoro)	Free-range duck flocks (n=15), intestinal content (n=90)	Isolation:e nrichment in Preston broth Identification: morphology and biochemical procedures	*Campylobacter* spp.: 72/90 (80.%); *C. jejuni*: 59/72 (81.9%) and *C. coli*: 13/72 (18.1)	Disk diffusion method	*C. jejuni*: STR (0%), NIT (0%), AMK (0%), NOR (10%), CIP (10%), AMX (20%), CLO (22%), GEN (24%), ERY (42%), CXM (48%), TET (74%), AMP (82%)	A high prevalence of thermophilic *Campylobacter* particularly *C. jejuni* in ducks. The high rate of antimicrobial resistance recorded may result from the indiscriminate use of antibiotics in animals and may pose a danger to public health.	Nongaand Muhairwa (2010)
2005	US (California)	Three flocks from two farms in California niche-market poultry	Identification: colony morphology, followed by oxidase and catalase tests and gram stain.	Cloacal swab: on-farm (60%), post-transport (33%); Carcass swab: post-picker (26%), post-wax (7%), post-evisceration (14%),p re-packaging (3%)	-	-	The prevalence of *Campylobacter*-positive birds were lower on the final product than on-farm or during processing.	McCrea etal. (2006)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
2008	Bulgaria	Moulard ducks flocks (n=4) during slaughter process (n=160)	Isolation: selective agar media Identification: oxidase and catalase production, hippurate and indoxyl acetate hydrolysis tests, and API Campy	*Campylobacter* spp.: caecal content (72.5%), skin surface (12.5%), breast meat with skin (7.5%), liver (12.5%); *C. jejuni*: caecal content (72.4%), skin surface (100%), breast meat with skin (100%), liver (100%); *C. coli*: caecal content (27.6%), liver (n/a)	-	-	The results showed a higher prevalence rate in the intestinal tract than other samples during processing. *C. jejuni* was the most commonly found species (81%), followed by *C. coli* (19%).	Stoyanchev etal. (2009)
2008 −2010	Iran (Tehran)	Wet market. Intestinal content (n=291)	Isolation: Preston agar as selective medium Identification: API Campy	*Campylobacter* spp.: 114/291 (39.2%); *C. jejuni*: 102/114 (89.5%) and *C. coli*: 12/114 (10.5%)	Disk diffusion method	*C. jejuni*: AMX (32.4%), AMP (12.7%), CHL (4.9%), CIP (89.2%), CST (21.6%), ERY (3.9%), GEN (0%), NEO (2.9%), STR (2.9%), TET (77.5%), NAL (72.5%); *C. coli*: AMX (16.7%), AMP (8.3%), CHL (0%), CIP (66.7%), CST (41.7%), ERY (8.3%), GEN (0%), NEO (8.3%), STR (8.3%), TET (58.3%), NAL (91.7%)	The presence of *Campylobacter* spp. as well as the detection of multidrug-resistant isolates in this study indicated that consuming of duck meat might be a potential campylobacteriosis risk in Iran.	Jamali etal. (2015)
2008−2009	New Zealand	The Esplanade, The Hokowhitu, Memorial park, Massey University, The Square. Fecal samples (n=906)	Isolation: direct plating Identification: PCR using 16s rRNA gene primers	*Campylobacter* spp.: The Esplanade (38%), The Hokowhitu (20%), Memorial park (32%), Massey University (22%), The Square (34%); *C. jejuni*: The Esplanade (25%), The Hokowhitu (17%), Memorial park (22%), Massey University (15%), The Square (24%)	-	-	Fecal contamination in environment is an important public health risk, particularly to small children who use the sampling sites for play.	Mohan(2015)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
2008	Northern Ireland (Belfast)	Retail sale (supermarkets and butcher shops) (n=17)	Isolation: selective enrichment in Bolton broth Identification: motility, Gram stain, presence of catalase and oxidase, hippurate hydrolysis, and resistance to NAL and cephalothin	*Campylobacter* spp. (100%)	-	-	Most retail poultry on sale in Northern Ireland may have the potential to cause human illness by *Campylobacter* infection if not handled appropriately.	Moran etal. (2009)
2009−2010	Iran (Gilan)	Retail outlets. Fresh raw meat (n=110)	Isolation:selective enrichment in Preston broth Identification: biochemical tests and PCR	*Campylobacter* spp.: 39/ 110 (35.5%)	Disk diffusion method	AMX (0%), AMP (9.6%), CHL (0%), CIP (40.4%), ENR (13.5%), ERY (0%), GEN (0%), NAL (30.8%), STR (1.9%), TET (32.7%)	The results showed that duck meat and goose meat from retail shops in Gilan province could be reservoirs of *Campylobacter*.	Rahimi etal. (2011)
2009−2011	Malaysia (Penang)	Commercial duck farms. Cloacal swabs (n=75), Wet market floor swabs (n=15), Intestinal content (n=102), Wash water (n=38), Cecal content (n=52), Intestinal content (n=50)	Isolation: enrichment followed by direct plating. Identification: Gram stain, oxidase and catalase tests, inability to grow aerobically at 25°C, glucose utilization test, Dry spot *Campylobacter* test, hippurate hydrolysis test and susceptibility to NAL and cephalothin Confirmation: multiplex PCR	Clocal swabs: *C. jejuni* (80%) and *C. coli* (20%); Wet market floor swabs: *C. jejuni* (33%) and *C. coli* (67%); Intestinal content: *C. jejuni* (71%) and *C. coli* (29%); Wash water: *C. jejuni* (50%) and *C. coli* (50%); Cecal contents: *C. jejuni* (86%) and *C. coli* (7%); Intestinal contents: *C. jejuni* (68%) and *C. coli* (32%)	Disk diffusion method	*C. jejuni*: AMP (81%), CTX (20%), CRO (51%), CEF (99%), CHL (7%), CIP (76%), ERY(1%), GEN (5%), NAL (84%), NOR (80%), STR (50%), SXT (96%), TET (96%); *C. coli*: AMP (21%), CTX (5%), CRO (68%), CEF (100%), CHL (0%), CIP (26%), ERY (0%), GEN (0%), NAL (100%), NOR (100%), STR (5%), SXT (26%),TET (100%)	The occurrence of *Campylobacter* spp. in the duck and duck related samples ranged from 0% to 85%. *Campylobacter* spp. from ducks were resistant to many antibiotics tested.	Adzitey etal. (2012)
2009−2010	South Korea	Fecal samples (n = 2,164)	Isolation: selective enrichment in Preston broth. Identification: multiplex PCR	*Campylobacter* spp.: 15.9% in Mandarin Duck, 11.9% in Mallard, 50% in Falcated Duck, and 12.7% in Spot-Billed Duck	MBinimum inhibitory concentration (MIC)	AZM (0%), ERY (0%), , GEN (0%), FLO (0%), TEL (0%), CLI (0%)	Moderate prevalence of *Campylobacter* was found in ducks, demonstrating that ducks might serve as significant reservoirs for *Campylobacter* pathogens.	Kwon etal. (2017)
2009−2011	Spain (Catalonia, Malaga, Galicia)	Free-range farm (n=29), Cloacal swab (n=30)	Isolation: selective enrichment in Bolton broth followed by direct plating Identification: PCR	*Campylobacter* spp. (80%) and *C. jejuni* (76.7%)	Disk diffusion method	CIP (100%), ENR (12.5%), TET (100%), CHL (0%), ERY (0%), GEN (0%), NAL (100%)	Ducks reared outdoor constitute a reservoir for *Campylobacter* spp. in Spain.	Antillés Silva (2014)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
2010	South and North Korea (Gyeonggi, Chungcheongnam-do, North Jeolla, North Gyeongsang)	Slaughterhouse. Feces (n=430)	Isolation: selective enrichment Identification: Vitek II compact system and multiplex PCR	*Campylobacter* spp. (32.9%)	Broth microdilution method	AZM (18.8%), CIP (86.6%), ERY (0.9%), GEN (15.2%), TET (80.4%), FFN (3.6%), NAL (87.5%), CLI (7.1%)	High resistance rates to fluoroquinolones and TET among duck isolates in Korea.	Kim etal. (2013)
2010−2011	Thailand (Nakhon Pathom, Phra Nakhon Si Ayutthaya, and Suphanburi)	Duck laying flocks confinement systems (n=7), free-grazing systems (n=7). Cloacal swabs (n=1,339) and environment (n=64)	Isolation:selective enrichment in Preston broth Confirmation:multiplex PCR	*C. jejuni*: 0.3% in cloacal swab samples and 20.9% in environmental samples	Broth microdilution method	Confinement system: MDR (16.5% in *Campylobacter* spp.); Free-grazing system: MDR (63.6% in *C. jejuni*)	The confinement system increased the risk of *Campylobacter* infection.	Saengthongpinit et al. (2015)
2010	UK	Wild and domesticated Mallard ducks. Fecal samples (n=60)	Isolation:selective enrichment	*Campylobacter* spp.: Wild ducks (9.2%−52.2%), Domesticated ducks (50.0%−52.2%)	-	-	Duck meat showed a high potential source of human *Campylobacter* infection.	Colles etal. (2011)
2011	Thailand (Kanchanaburi and Nakhon Pathom)	Laying duckling flocks (n=2). Cloacal swab samples (n=438), Environmental samples e.g. soil, drinking water, and feed (n=39)	Isolation:selective enrichment in Preston broth Confirmation: multiplex PCR	Cloacal swab samples: *C. jejuni* (37.9%), *C. coli* (42.1%); Environmental samples: *C. jejuni* (50%), *C. coli* (30%)	-	-	The prevalence of *Campylobacter* spp. increased as the age increased. Ducks are normally infected with *Campylobacter* spp. possibly originated from environmental contamination.	Saengthongpinit etal. (2014)
2011	UK	Duck liver pâté (n = 8)	Isolation:selective enrichment in Bolton broth	*Campylobacter* spp.: 6/8 (75%); *C. jejuni*: 5/6 (83.3%) and *C. coli*: 1/6 (16.6%)	-	-	The cooking process for the pâté was insufficient to kill bacteria inside the liver of a duck.	Abid et al. (2013)
2012	South Korea (Gyonggi, Chungnam, Chungbuk, Chonnam, and Chonbuk)	Duck farms (n=58). Cloacal swabs (n=5 from each farm)	Isolation:selective enrichment Identification: multiplex PCR	*Campylobacter* spp.: 56/58 (96.6%)	Agar dilution method	*C. jejuni*: AMP (64.4%), AZM (22.2%), CIP (86.7%), CLI (6.7%), ERY (11.1%), GEN (8.9%), NAL (84.4%), TET (84.4%); *C. coli*: AMP (100%), AZM (30%), CIP (80%), CLI (10%), ERY (30%), GEN (10%), NAL (80%), TET (90%)	High levels of contamination by *Campylobacter* in South Korean duck farms and the high prevalence of resistance to fluoroquinolones and tetracyclines indicated that South Korean ducks were a potentially important source of human infection.	Wei etal. (2014)
2012−2016	South Korea (Iksan)	Ducks and duck meat (n=155)	Identification: PCR	-	Agar dilution method	*Campylobacter* spp.: FOS (3.9%)	Fosfomycin may be a valuable treatment option as the last resort for the treatment of campylobacteriosis.	Weiand Kang (2018)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
2012	Vietnam (Dong Thap)	Duck farms (n = 20). Animal (fecal) and farm environment samples	Isolation:direct plating on selective agar Identification: hippurate hydrolysis test and PCR	*Campylobacter* spp.: 15/83 (18.1%) in animal samples, 5/7 (71.4%) in farm samples; *C. jejuni*: 11/83 (13.3%) in animal samples, 5/7 (71.4%) in farm samples; *C. coli*: 3/83 (3.6%) in animal samples, 2/7 (28.6%) in farm samples	Disk diffusion method	ERY (100%), SXT (99%), NAL (92%), OFX (92%), CIP (20.8%)	Campylobacteriosis was prevalent in animal production systems in Vietnam. The intensification of animal production systems and increased urbanization could result in a further increase in the incidence of this infection.	Carrique-Mas etal. (2014)
2013−2014	China	Meat samples at retail shops (n=385)	Isolation: selective enrichment Confirmation: API Campy system	*C. jejuni*: 57/385 (14.8%)	Disk diffusion method	CIP (88.5%), NAL (88.5%). Most isolates were multidrug-resistant (data not shown).	Poultry meat might be a major source of *C. jejuni* in China.	Zhong etal. (2016)
2013−2015	Poland	Fresh duck meat (n=54)	Identification: polymerase chain reaction (PCR)	*Campylobacter* spp. (80%), *C. jejuni* (23%), *C. coli* (14%)	-	-	*C. jejuni* was more prevalent than *C. coli* in duck meat in Poland.	Szosland-Fałtyn etal. , 2018
2013	South Korea (Jeonlado)	Retail meat samples (n=106): Whole carcass samples (n=52) and Sliced samples (n=54)	Isolation:s elective enrichment Confirmation: PCR assay	*Campylobacter* spp.: 52/52 (100%) in whole carcass samples, 50/54 (92.6%) in sliced samples; *C. jejuni*: 39/52 (75%) in whole carcass samples, 43/54 (79.6%) in sliced samples; *C. coli*: 13/52 (25%) in whole carcass samples, 6/54 (11.1%) in sliced samples	Agar dilution method	*C. jejuni*: AMP (69.5%), AZM (0.1%), CIP (87.8%), CLI (1.2%), ERY (4.9%), GEN (13.4%), NAL (92.7%), TET (97.6%); *C. coli*: AMP (68.4%), AZM (0.2%), CIP (100%), CLI (0%), ERY (26.3%), GEN (21.1%), NAL (100%), TET (100%)	Results showed that retail duck meat had a high prevalence of *Campylobacter* and a high prevalence of antimicrobial-resistant *Campylobacter* isolates. Retail duck meat was considered a potential risk of campylobacteriosis for humans living in South Korea.	Wei etal. (2016)
2014	Egypt	Fecal swabs from duckling (n=100)	Isolation: selective enrichment in Bolton broth Identification and confirmation: multiplex PCR	*C. jejuni* (11%) and *C. coli* (88.9%)	-	-	The high rate of *Campylobacter* spp. in duckling could be results of poor sanitation and hygienic measures.	Shawky etal. (2015)
2014	India (Erode district)	Duck farms and Slaughterhouses. Farm samples (feather, feed, feces) and slaughterhouse samples (intestine, anus, liver, skin,	Isolation:d irect plating Identification:u rease, nitrate reduction, catalase and oxidase tests	*C. jejuni*: feather (41.6%), skin (28.5%), liver (33.3%), anus (45.4%), beak (30%), nail (25%), intestine (61.5%), faeces	Disk diffusion method	AMX (100%), ERY (85%), NAL (68%), NOR (63%), DOX (45%), GEN (43%), CHL (35%), LEX (30%), CIP (18%)	The study revealed that *C. jejuni* was prevalent in ducks at both farm and slaughterhouse levels. High resistance rates to multiple antibiotics were	Sivasankari etal. (2015)

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Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
		nail, and beak) (n=89)		(63.6%), feed (62.5%)			also observed among duck isolates in India.	
2014−2015	Finland (Lahti and Seinäjoki)	Fecal droppings collected from Mallard ducks (n=108)	Identification: colony morphology Confirmation: PCR	*C. jejuni*: 82/108 (75.9%)	-	-	Hygienic measures during slaughter and meat handling warrant special attention.	Kovanen etal. (2019)
2014−2015	Iran (Isfahan)	Duck eggs from different outlets. Eggshell (n=60), Egg white (n=60), Egg yolk (n=60)	Isolation:s elective enrichment in Preston broth Identification: biochemical procedures Confirmation:m ultiplex PCR	*Campylobacter* spp.: Eggshell (5%), Egg white (1.7%), Egg yolk (1.7%)	Disk diffusion method	NAL (47.1%), CST (29.4%), NEO (8.8%), SPT (2.9%), CIP (53%), ERY (5.9%), TET (73.5%), STR (8.8%), AMP (14.7%), AMX (14.7%), GEN (0%), CHL (5.9%), ENR (41.2%)	Duck eggs collected from different outlets in Isfahan province were highly contaminated with multiple antibiotic-resistant thermophilic *Campylobacter* species. The primary disinfection of egg surface with disinfectants and separation of contaminated eggs from a healthy one can reduce the risk of human campylobacteriosis.	Jonaidi-Jafari etal. (2016)
2014−2015	South Korea	Eighteen wet markets. Carcass samples (n=154)	Isolation:s elective enrichment in Bolton broth Identification: PCR	*Campylobacter* spp.: 15/80 (18.8%) in Summer and 15/74 (20.3%) in Winter	Disk diffusion method	AMK (44.4%), ERY (4.4%), TET (71.1%), CIP (91.1%), ENR (15.6%), NAL (93.3%), CHL (0%)	Although the prevalence of *Campylobacter* in South Korea was relatively low compared to that in other countries, antibiotic resistance rates were quite high and similar to those found in other countries.	Lee etal. (2017)
2014−2015	South Korea	Six slaughterhouses. Carcass samples (n=120)	Isolation: with enrichment or without enrichment Confirmation: colony PCR	*Campylobacter* spp.: 48/120 (40.0%) with enrichment and 91/120 (75.8%) without enrichment; 55/60 (91.7%) in Summer and 38/60 (63.3%) in Winter	Agar dilution method	*C. jejuni*: CIP (100%), ENR (93%), NAL (99%), TET (72.7%), ERY (0%), CHL (1.1%); *C. coli*: CIP (86%), ENR (79.1%), NAL (83.7%), TET (72.1%), ERY (9.3%), CHL (0%)	Most isolates were resistant to ciprofloxacin, enrofloxacin, nalidixic acid, and tetracycline, but only a few isolates were resistant to erythromycin and chloramphenicol.	Chon etal. (2018)
2015	Cambodia (Kampong Cham, Battambang and Kampot)	Rural households (n=10). Faecal samples (n=101)	Isolation:selective e nrichment in Bolton broth Confirmation: catalase and oxidase tests and multiplex PCR	*Campylobacter* spp. (24%), *C. jejuni* (19%) and *C. coli* (8%)	-	-	Results suggested that low prevalence of *Campylobacter* was found in ducks in Cambodia. Additionally, PCR should be used for detection of *Campylobacter* in livestock where samples need to be frozen and timely culture is not feasible.	Osbjer etal. (2016)
2015	Nigeria (Sokoto)			*Campylobacter* spp.: 9/16 (56.3%); *C. coli*: 7/	-	-	Transportation of poultry to live bird markets	Nwankwo etal. (2016)

Table 1 (*Continued*)

Years	Country (Province/ state)	Sampling site, sample type, and number of samples tested	Detection and/or identification methods	Prevalence shown by no. of positive samples (%)	Susceptibility testing method	Resistance rates (%)	Conclusion	Citation
		Live bird market in four agricultural zones. Cloacal swabs (n=16)	Isolation:direct plating Identification: phenotypic tests	9 (77.8%) and *C. lari*: 2/9 (22.2%)			together with humans in the same truck should be discouraged.	
2015−2017	China	Slaughterhouse (n=220)	Isolation: selective enrichment Identification: biochemical assays and multiplex PCR	*Campylobacter* spp.: fecal samples (79.3%), after defeathering (6.5%), after evisceration (18.7%), raw meat (1.5%)	Broth microdilution method	TET (96.4%), CLI (92.3%), AZM (66.8%) ERY (47.3%), NAL (44.5%), CHL (42.7%), GEN (41.4%), CIP (37.3%)	High prevalence of antimicrobial-resistant *Campylobacter* spp. in duck samples collected from the slaughterhouse in China.	Han etal. (2019)
2016	Nigeria (Kebbi)	Poultry markets. Cloacal swabs (n=32)	Isolation: selective enrichment Identification: oxidase test, hippurate hydrolysis test, catalase test, hydrogen sulfide production test and sensitivity to cephalothin and nalidixic acid	*Campylobacter* spp.: 17/ 32 (53.1%); *C. jejuni*: 1/17 (5.9%), *C. coli*: 11/17 (64.7%), and *C. lari*: 5/17 (29.4%)	-	-	*C. coli* were more prevalent than *C. jejuni* and *C. lari*. Adequate environmental sanitation and strict hygiene measures should be implemented in the backyard poultry houses, slaughter slabs, and processing units in the state.	Abba Maiha etal. (2017)
2016−2017	South Korea	Whole carcasses collected in winter (n=28) and summer (n=33)	Isolation: selective enrichment in Bolton broth Identification: colony morphology	*Campylobacter* spp.: 21/33 (63.6%) in Summer and 17/28 (60.7%) in Winter	Broth microdilution method	5AZM (0%), ERY (0%), TEL (0%), CIP (97.8%), NAL (97.8%), TET (57.8%)	*C. jejuni* strains from retail duck meat were highly resistant to fluoroquinolones and tetracycline. Retail duck meat was an important vehicle that could potentially transmit *C. jejuni* to humans in South Korea.	Kim etal. (2019)
2017	Thailand	Three slaughterhouses (n=150)	Isolation : direct plating and selective enrichment Confirmation: multiplex PCR	*Campylobacter* spp.: cloacal swab sample after bleeding (2%), carcass rinse after evisceration (30%), and carcass rinse after chilling process (44%)	-	-	The predominant *Campylobacter* strain found in Thailand was *C. jejuni*. Cross-contamination could result in an increase of *Campylobacter* prevalence during the duck slaughtering process.	Chanawanit etal. 2018

C. jejuni (*Campylobacter jejuni*), *C. coli* (*Campylobacter coli*).

Resistance rate to AMK, amikacin; AMP, ampicillin; AMX, amoxicillin; APR, apramycin; AZM, azithromycin; BAC, bacitracin; CEF, ceftazidime;; CFZ, cefazolin; CHL, chloramphenicol; CIP, ciprofloxacin; CLI, clindamycin; CLO, cloxacillin; CRO, ceftriaxone; CST, colistin; CTX, cefotaxime; CXM, cefuroxime; DOX, doxycycline; ENR, enrofloxacin; ERY, erythromycin; FEP, cefepime; FLO, florphenicol; FOS, fosfomycin; FQ, fluoroquinolones; FZD, furazolidone; GEN, gentamicin; KAN, kanamycin; LEX, levofloxacin; LIN, lincomycin; NAL, nalidixic acid; NEO, neomycin; NET, netilmicin; NIT, nitrofurantoin; NOR, norfloxacin; OFX, ofloxacin; OXY, oxytetracycline; PEN, penicillin; PIP, Piperacillin; SAM, ampicillin/sulbactam; SPT, spectinomycin; STR, streptomycin; SXT, Trimethoprim/sulfamethoxazole; TEL, telithromycin; TET, tetracycline; TOB, tobramycin; TZP, pipercillin/tazobactam; VAN, vancomycin.

prevalence rate for duck isolates (20%) versus other species such as starlings (18%), Canadian goose (9%), dogs (5%) and cats (7%) (Mohan, 2015). The *C. jejuni* was also more prevalent during warmer months of the year in ducks. Using genotyping techniques such as multilocus sequence typing (MLST) and *flaA*-SVR typing were suggested for providing more insights into the role of different animal species as vectors in the transmission of *C. jejuni* to humans. In Northern Ireland (2008), a 1-year survey of the prevalence of *Campylobacter* spp. in fresh, retail poultry products showed that 100% of duck samples (n = 17) were *Campylobacter* positive by the selective enrichment method (Moran et al., 2009). It was also found that different incubation temperature of the enrichment medium, Bolton broth, at 42°C rather than 37°C, did not affect the range of *Campylobacter* spp. found.

In Iran (2009-2010), the prevalence of *Campylobacter* spp. isolated from raw duck meat was 35.5% (88.5% for *C. jejuni* and 11.5% for *C. coli*) which was higher than goose meat (26.5%) (Rahimi et al., 2011). Different methods of identification (conventional bacteriological method vs. PCR assay) did not also affect identification rates. Consistent with the previous studies, the highest incidence of *Campylobacter* spp. occurred in warmer seasons of the year; summer (48.6%) and spring (41.7%). The results of antibiotic susceptibility testing by Kirby-Bauer disc diffusion showed high resistance rates to CIP (40.4%), followed by TET (32.7%), and NAL (30.8%). No resistant rate was also reported for amoxicillin (AMX), CHL, ERY, and GEN. In Malaysia (2009-2011), the overall prevalence of *Campylobacter* species isolated from different parts of ducks, their rearing and processing environments (e.g., soil, drinking water, etc.) was estimated as 15.4% . In that study, duck isolates (e. g., intestinal and caecal contents) had higher prevalence rate than those of environment samples which could be due to the fact that *Campylobacter* spp. survive less in feed, soil, surfaces exposed to high oxygen tension, water and sunlight and dry environments. Adzitey et al. (2012) reported that poultry and poultry products were major sources of *Campylobacter* infection in humans (Adzitey et al., 2012). It was also shown that the method of isolation (enrichment vs. direct plating) significantly affected the isolation rate. The results of antimicrobial susceptibility testing as determined by disk diffusion method showed that both *C. jejuni* and *C. coli* were mostly susceptible to ERY and GEN which could be used for treating patients in Malaysia. Adzitey et al. (2012) also showed that random amplification of polymorphic deoxyribonucleic acid (RAPD) was a reliable method for typing *Campylobacter* isolates with high discriminatory power. In that study, RAPD analysis of *C. jejuni* and *C. coli* produced 58 and 12 distinct band patterns, respectively. Moreover, *Campylobacter* strains that belong to the same serotype were not always similar genetically and that most *C. jejuni*/*C. coli* serotypes comprised heterogeneous genotypes.

In South Korea (2009-2010), migratory birds or wild birds (e.g. falcated duck) showed higher rates of

Campylobacter infection than indigenous birds (Kwon et al., 2017). In line with previous studies, *C. jejuni* (79.3%) in South Korea study was the most prevalent *Campylobacter* species, followed by *C. coli* (9.3%) and *C. lari* (0.4%). All *Campylobacter* spp. isolates were also susceptible to Azithromycin (AZM), ERY, GEN, Telithromycin (TEL), and Clindamycin (CLI). The differences in the prevalence of *Campylobacter* in different studies could be because of detection method as well as habitat, diet and health status of the birds. A study in Spain (2009-2010) found that poultry reared outdoor were important reservoir of *Campylobacter* (Antillés Silva, 2014). The high genetic diversity of *Campylobacter* observed in wild birds as determined by Enterobacterial repetitive intergenic consensus PCR (ERIC-PCR) and Pulsed-field gel electrophoresis (PFGE) was attributed to the infections by multiple sources. Those results were attributed to the possibility of animal contact to the external environment. Almost 95% of *Campylobacter* isolates from poultry (duck) were resistant to at least one antimicrobial; the main resistances were to quinolones and fluoroquinolones, followed by TET. In Korea (2010), the prevalence and antimicrobial resistance patterns of *C. jejuni* from duck feces from slaughterhouse were reported (Kim et al., 2013). From 430 duck feces, almost 33% were *C. jejuni* positive. The highest resistance rate of *C. jejuni* was reported for NAL (87.5%), CIP (86.6%), and TET (80.4%) as well as low or moderate resistance rates for AZM (18.8%), ERY (0.9%), GEN (15.2%), Florfenicol (FLO, 3.6%), and CLI (7.1%). In Thailand (2010-2011), the prevalence of *Campylobacter* species isolated from cloacal swabs of laying duck flocks in confinement and free-grazing systems showed that confinement system (13.8%) had higher prevalence rate as compared with the free-grazing system (0.3%) (Saengthongpinit et al., 2015). In the confinement system, ducks are living in the same and limited area, which increased the chance of direct defecation to water source for drinking and dispersal of *Campylobacter* to other ducks. Therefore, the opportunity to acquire bacterial infection, including *Campylobacter*, in the confinement system is higher than the free-grazing system. Although the prevalence of *Campylobacter* was different between confinement and free-grazing systems, *C. jejuni* (68-81%) and *C. coli* (50-87.5%) isolated from both systems were similarly resistant to STR, NAL, CIP, and Levofloxacin (LEX).

The prevalence of *Campylobacter* populations among wild (9-52%) and domesticated (50.2-52 %) Mallard ducks were shown in the UK (Colles et al., 2011). Furthermore, almost 93% of *Campylobacter* isolates from farmed ducks had sequence types (STs) commonly associated with human disease, in contrast to just one isolate from the wild ducks. It was also concluded that domestic "niche" as well as host type may affect the distribution of *Campylobacter*; therefore, husbandry practices associated with intensive agriculture may be involved in generating a reservoir of human infection. In 2011, a longitudinal study of *Campylobacter* spp. from two laying duckling flocks in the central region of Thailand

Table 2. Genetic diversity of *Campylobacter* spp. in duck-related isolates.

Citation	Samples tested	Genotyping method	Results	Conclusion
Adzitey et al. (2012)	Large intestines and ceca samples	Random Amplification of Polymorphic Deoxyribonucleic Acid (RAPD)	*C. jejuni* (n = 94) produced 58 RAPD types and *C. coli* (n = 19) produced 12 RAPD types. High heterogeneity among the *C. lari* isolates. The determination of similar and different clones among *Campylobacter* spp. was confirmed by cluster analysis.	The RAPD could provide a rapid and relatively reliable method for typing *Campylobacter* isolates with good discriminatory power.
Carrique-Mas et al. (2014)	Fresh fecal samples	Multilocus sequence typing (MLST)	*C. jejuni* demonstrated a higher level of genetic diversity than *C. coli* in Vietnam. There was a strong association between the animal species of isolation and the clonal complex of *Campylobacter*.	Multilocus sequence typing technique showed a high level of genetic diversity within *C. jejuni*, and predicted *C. coli* inter-species transmission.
Chon et al. (2018)	Carcass samples	rep-PCR fingerprinting	No genetic relatedness among strains from the same slaughterhouse. All strains had less than 95% similarity according to the rep-PCR banding patterns.	Results indicated the diversity of *Campylobacter* isolates present in duck samples from slaughterhouses in South Korea.
Colles et al. (2011)	Fecal samples from farmed and wild ducks	Multilocus sequence typing (MLST)	Forty-seven sequence types (STs) and 10 STs were found among isolates from wild ducks and farmed ducks, respectively. The average diversity index for f armed ducks ranged 0.15−0.70 and for wild ducks ranged 0.91−0.96. One ST, ST-45, was shared between the two sources, accounting for 0.9% of wild duck isolates and 5% of farmed duck isolates.	The results showed that domestic "niche," as well as host type, may affect the distribution of *Campylobacter*.
Han et al. (2019)	Samples from slaughterhouse	Polymerase Chain Reaction (PCR)	The prevalence of virulence genes among *Campylobacter* isolates from ducks in China is as follows: *flaA* (77.3%), *cadF* (100.0%), *cdtA* (60.0%), *cdtB* (92.3%), *cdtC* (54.1%), *cheY* (92.7%), *virB11* (7.7%), *iamA* (71.8%), *ciaB* (42.7%).	The prevalence of *Campylobacter* virulence genes and their relationship with clinical severity in humans and the expression of virulence factors should be further investigated.
Kim et al. (2019)	Duck meat samples	Multilocus sequence typing (MLST)	*C. jejuni* strains belonging to clonal complex CC-21 and CC-45 were dominant on duck meats.	The genetic background of certain *C. jejuni* isolates from ducks may be different from that of chicken isolates.
Kovanen et al. (2019)	Fecal samples	Multilocus sequence typing (MLST)	Mallard duck ST-2314 isolates represented bacterial clones that were genetically highly similar to human isolates.	*C. jejuni* genotypes highly similar to human isolates were detected.
Lee et al. (2017)	Carcass samples from wet markets	DiversiLab System	More than 95% similarity between 84.4% of the isolates was observed. T hree *cdt* genes (*cdtA*, *cdtB*, and *cdtC*) were present in 71.1% of *Campylobacter* isolates.	No geographic genetic diversity was detected and a high proportion of *cdt* genes were present in *Campylobacter* isolates. Based on the findings , ducks sold in different wet markets

Table 2 (*Continued*)

Citation	Samples tested	Genotyping method	Results	Conclusion
				in Korea may be distributed from only a few slaughterhouses.
Antillés Silva (2014)	Fecal samples	Enterobacterial repetitive intergenic consensus (ERIC)- PCR	Isolates from the same bird had the same ERIC-PCR profile. Higher diversity was detected in *C. coli* compared to *C. jejuni*.	The study emphasized the importance of practicing good hygiene practices to avoid transmission of zoonotic bacteria to humans.
Sivasankari et al. (2015)	Duck-related samples (e.g., intestine, feathers, nails, anus, liver, etc.)	Polymerase Chain Reaction (PCR)	Most multidrug-resistant *C. jejuni* isolates had *cadF* and *v irB11* genes which were responsible for adhesion, colonization, and invasion.	Preventive steps should be taken to control the entry of *Campylobacter* into duck farms and slaughterhouses.
Wei and Kang (2018)	Duck meat samples	Pulsed-field gel electrophoresis (PFGE)	High genetic diversity among fosfomycin-resistant *Campylobacter* strains was revealed.	Fosfomycin resistance mechanism in *Campylobacter* should be further investigated.
Wei et al. (2014)	Cloacals wab samples	Multilocus sequence typing (MLST)	Twenty-eight different STs were identified among *Campylobacter* isolates. Three predominant STs (ST-21, ST-45 and ST-828) accounted for 60% of all isolates.	MLST is an important tool for elucidating the diversity and transmission routes of *Campylobacter*. The overlapped STs between duck and human isolates indicated that ducks could serve as potential sources of human infection.

revealed an overall isolation rate as 27% (56.6% *C. jejuni* and 43.4% *C. coli*) (Saengthongpinit et al., 2014). Moreover, the prevalence of *Campylobacter* spp. increased by the age increase (1 to 30-day-old). It was also concluded that the source of *Campylobacter* infection in ducks was normally from environmental contamination. Since *Campylobacter* spp. could contaminate and be found in duck liver, the correct cooking process for the pâté was emphasized to kill bacteria inside the liver (Abid et al., 2013). In 2012, the occurrence of *Campylobacter* spp. in 58 duck farms in South Korea was investigated (Wei et al., 2014). Almost 97% of the samples were *Campylobacter* positive. The antimicrobial susceptibilities of *C. jejuni* (n = 46) and *C. coli* (n = 9) strains as determined by the agar dilution method indicated that resistance to CIP was the most common (87.0%) for *C. jejuni*, followed by TET (84.8%) and NAL (84.8%). For *C. coli* strains, 100% were resistant to AMP and 88.9% were resistant to TET. However, a lower resistance rate was reported for macrolides (AZM and ERY). Moreover, the majority of *Campylobacter* isolates (91.5%) in this study were reported as multidrug-resistant strains. Molecular typing of *Campylobacter* by MLST showed that the most common clonal complexes in *C. jejuni* were the ST-21 and ST-45 complexes, while the ST-828 complex predominated in *C. coli*. It was also reported that some STs were associated with human infections with ducks as the only source. The results highlighted a high level of *Campylobacter* contamination in South Korean duck farms and the high resistance rates to antimicrobials, such as fluoroquinolones. The study revealed that South Korean ducks were a potentially important source of human infection and emphasized on the role of duck-associated *Campylobacter* risk to human health.

In 2012 to 2016, fosfomycin resistance of *Campylobacter* isolated from ducks was investigated for the first time (Wei and Kang, 2018). All eight fosfomycin-resistant *Campylobacter* strains were multidrug resistant as determined by the agar dilution method in which six of them were also resistant to fluoroquinolones, AMP, and TET, and two of them were resistant to fluoroquinolones, AMP, TET, and macrolides. The eight PFGE types showed genetic diversity among the eight fosfomycin-resistant *Campylobacter* strains (data not shown). It was concluded that fosfomycin resistance has been emerging and spreading in food animals threatens transmission to humans along the food chain. In an epidemiological investigation of *Campylobacter* in poultry farms in Vietnam (2012), the animal-level and farm-level prevalence of *Campylobacter* from duck isolates were 18% and 71.4%, respectively (Carrique-Mas et al., 2014). As compared with other species, ducks (24%) showed lower animal-level prevalence of *Campylobacter* compared with chickens (32%) and pigs (53.7%). *Campylobacter* isolates demonstrated high levels of antimicrobial resistance from 21% to 100% against ERY, Trimethoprim/sulfamethoxazole (SXT), NAL, Ofloxacin (OFX), and CIP. The intensified animal production systems and increased urbanization in Vietnam were attributed to the obtained results. It was also shown that there was a high level of genetic diversity within *C. jejuni*, and predicted *C. coli* inter-species transmission among duck isolates as determined by multilocus sequencing. In 2013 to 2014, most of *Campylobacter* isolates from poultry meat samples (e.g., duck meat) in China were multidrug resistant (Zhong et al., 2016). A high antibiotic resistance rate was observed for CIP (88.5%) and NAL (88.5%). There was no direct evidence to suggest a connection between antibiotic resistance and virulence genes.

The prevalence of *Campylobacter* spp. in Polish poultry meat indicated that most ducks were colonized with *Campylobacter* spp, mostly *C. jejuni* (Szosland-Fałtyn et al., 2018). The highest prevalence of *Campylobacter* was detected in duck (80%) versus chicken (70%), goose (60%), and turkey (38%) which was contrary to some studies in which other poultries especially chicken showed higher prevalence of *Campylobacter*. However, the higher prevalence of *C. jejuni* versus *C. coli* in this study was consistent with others in the literature. In South Korea (2013), a high prevalence (96.2%) of *Campylobacter* and a high prevalence of antimicrobial resistance (47.4%) in *Campylobacter* isolates from retail duck meat was reported (Wei et al., 2014). *Campylobacter* isolates from ducks had higher resistance rates as compared with chickens to AMP (69.3%), CIP (90.1%), GEN (14.9%), NAL (94.1%) and TET (98%) as determined by the agar dilution method. Wei et al. (2014) also mentioned duck meat as a potential campylobacteriosis risk for humans living in South Korea. In Egypt (2014), the higher prevalence of *Campylobacter* spp. was found in duckling (27%), compared with chicks (3%) and turkey (0%) (Shawky et al., 2015). The higher *Campylobacter* infection rate in ducks was attributed to the poor hygienic measures and sanitation in duck farms compared to chicken and turkey farms. When the prevalence of *Campylobacter* in different sample types obtained from duck farm (feather, feed, and feces) and slaughterhouse (intestine, anus, liver, skin, nail, and beak) in India (2014) was compared, the study revealed that faeces had the highest prevalence of *Campylobacter* (63.6%), followed by feed (62.5%) and intestine (61.5%) (Sivasankari et al., 2015). In addition, the study also showed that 100% of *C. jejuni* isolates were resistant to AMX, followed by ERY (85%), NAL (68%), and Norfloxacin (NOR, 63%) as determined by the disk diffusion assay.

In Iran (2014-2015), the prevalence of *Campylobacter* spp. isolated from eggs of different avian species (n = 440) showed that eggshell of duck (5%) had lower prevalence rate than that of chicken (7%) but equal to quail (5%) and higher than goose (3.3%), ostrich (2.5%), partridge (4.2%), and turkey (3.8%) (Jonaidi-Jafari et al., 2016). The prevalence of *Campylobacter* was also higher in summer than in autumn. Primary disinfection of poultry egg samples especially their surface with disinfectants and separation of contaminated eggs from the clean ones was recommended to reduce the risk of human campylobacteriosi.

In Korea (2014-2015) , a higher prevalence of *Campylobacter* was reported from duck carcass (77%) than chicken carcass (31.7%) (Chon et al., 2018). The study also found that *Campylobacter* in ducks was more prevalent in summer (91.7%) than in winter (61.7%), which was different from that reported by Lee et al. (2017). For the results of antimicrobial susceptibility test determined by the agar dilution method, most of *Campylobacter* isolates from ducks in Korea were resistant to CIP, Enrofloxacin (ENR), NAL, and TET with less resistance to ERY (3.1%) and CHL (0.8%). This finding was consistent with what reported by Lee et al. (2017) . In addition, most of the tested strains were also classified into diverse pulsotypes , indicating the diversity of *Campylobacter* isolates in duck samples collected from slaughterhouses in Korea. In Cambodia, the prevalence of *Campylobacter* in duck fecal samples (24%) was higher than that in human fecal samples (19%), but lower than the prevalence of this organism in feces of chickens (56%) and pigs (72%) (Osbjer et al., 2016). It was also suggested that PCR should be the preferred diagnostic method for detection of *Campylobacter* in humans and livestock where timely culture is not feasible. In Nigeria, the isolation rate of *Campylobacter* from cloacal swab samples of duck (56%) was higher than that of chicken (30%), guinea fowl (30%), pigeon (14%), and turkey (50%) (Nwankwo et al., 2016). The higher prevalence of *Campylobacter* in ducks compared with other poultries was likely attributed to the way ducks searching for food on the surface of shallow water which exposed the animal to be contaminated with *Campylobacter* spp. Consistently, another study on the prevalence of *Campylobacter* in different poultry species in Nigeria also revealed that the highest prevalence was found in duck (53%), followed by turkey (50%), chicken (46%), guinea fowl (38%), and pigeon (28%) (Abba Maiha et al., 2017). Surprisingly, *C. coli* was reported to be more prevalent than *C. jejuni*. In a recent study in Thailand, the presence of *Campylobacter* spp. in duck slaughtering process was reported as 25.3% with the higher frequency of *C. jejuni* than *C. coli* (68.4% vs. 18.4%) (Chanawanit et al., 2018). It was concluded that cross-contamination could result in higher prevalence of *Campylobacter* during duck slaughtering process.

In South Korea (2019), *C. jejuni* populations with antibiotic resistance phenotypes (mostly to fluoroquinolones and TET) were highly prevalent on retail duck meat (Kim et al., 2019). The prevalence of *Campylobacter* from raw duck meat was higher in summer (63.6%) than in winter (60.7%). Moreover, CC-45 was the most common clonal complex found among *C. jejuni* isolates from duck meat . Kim et al. (2019) suggested that the genetic background of certain *C. jejuni* isolates from duck meat may be different from that of chicken isolates.

In 2019, a high prevalence (33.5%) of *Campylobacter* contamination in slaughtering process (e.g., after defeathering, after evisceration, etc.) was demonstrated in China (Han et al., 2019). Forty-seven antimicrobial resistance profiles were also found, and 75.9% of the *Campylobacter* isolates were multidrug resistant strains.

Furthermore, 48 virulence gene profiles were observed among *Campylobacter* isolates. Kovanen et al. (2019) demonstrated that *C. jejuni* ST-2314 isolated from mallard duck represented bacterial clones that were genetically highly similar to human isolates detected previously in Finland. Moreover, most of the mallard duck *C. jejuni* isolates represented sequence types that diverged from those previously isolated from human patients and various animal species. The hygienic measures during slaughter and meat handling were also suggested.

CONCLUSIONS AND FUTURE DIRECTIONS

This review has highlighted a large variation in data available for prevalence rate and phenotypic antimicrobial resistance testing worldwide. The worldwide prevalence of *Campylobacter* spp. in the duck and duck related samples are mostly influenced by the isolation method, type and time of sampling. *Campylobacter* spp. were also more frequently isolated in summer than in winter. Based on the published data, antimicrobial resistance of *Campylobacter* isolates from ducks which varies among studies is becoming increasingly common worldwide, especially for fluoroquinolones and tetracycline. Some studies revealed that duck isolates represented bacterial clones that were genetically highly similar to human isolates. Therefore, hygienic measures warrant special attention. The different results reported in terms of the distribution and prevalence of antimicrobial resistance in *Campylobacter* isolates could probably be due to the variety of methods use, therefore, to support evidence-based decision−making, there is a demand for an integrated understanding of the epidemiology of antimicrobial resistance, so it would be desirable to move towards the harmonization of surveillance systems to monitor antimicrobial resistance in animal production. Monitoring and development of appropriate control strategies in poultry reared outdoors were also recommended. In the meanwhile, the genotypic antimicrobial resistance of *Campylobacter* spp. from duck isolates should be further investigated.

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DISCLOSURES

All authors declare no conflicts of interest.

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