Journal of Current Science and Technology, September-December 2021 Vol. 11 No. 3, 457-467

ISSN 2630-0656 (Online)

Cite this article: Tenorio, J. C. B., & Flores, V (II). D. (2021, September). *Campylobacter jejuni* from farm to fork: Campylobacteriosis and chicken meat. *Journal of Current Science and Technology, 11*(3), 457-467.
DOI: 10.14456/jcst.2021.45

Journal of Current Science and Technology

Journal homepage: https://jcst.rsu.ac.th

Campylobacter jejuni from farm to fork: Campylobacteriosis and chicken meat

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Received 15 June 2021; Revised 13 July 2021; Accepted 3 August 2021;
Published online 28 September 2021

Abstract

Campylobacteriosis is one of the four primary etiologies of foodborne diarrheal illnesses globally. The disease affects 1 out of 10 individuals worldwide, with 33 million life years lost annually. There is evidence that campylobacteriosis is increasing in its occurrence in developed countries, but research is lacking in those with developing economies such as the Philippines. Of the 34 *Campylobacter* species known to date, *C. jejuni* subsp. *jejuni* and *C. coli* are the most common case isolates. These bacteria are commensals of the intestinal tract of animals, among which, chickens and their meats have been implicated as the primary source of human campylobacteriosis. All the components of the poultry production chain contribute to the zoonotic transmission of the foodborne pathogen. Inadequate farm biosecurity measures and unsanitary dressing procedures bleed into high contamination loads of chicken meats at the market and consumer levels. Attempts to decrease *C. jejuni* in poultry include rearing and management modifications, alterations in slaughter and dressing procedures, novel packaging technologies, and hygienic practices in food preparation. Antimicrobial resistance of *C. jejuni* has been increasingly reported globally. On the veterinary public health front, studies are needed to continuously assess *C. jejuni* as a pathogen in the poultry production line and the consumer level. This paper reviewed *C. jejuni* as a foodborne pathogen and its close association with chicken meat as its food vehicle of infection.

Keywords: *Campylobacter jejuni; Campylobacteriosis; foodborne pathogen; food safety; from farm to fork; veterinary public health*

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1. Introduction

Campylobacteriosis is one of the four primary etiologies of foodborne diarrheal illnesses globally, and it affects 1 out of 10 individuals, with 33 million life years lost annually (World Health Organization (WHO), 2020). In Europe, campylobacteriosis is the most reported enteric bacterial infection, affecting more than 245,000 individuals yearly (European Food Safety Authority (EFSA), 2010; European Food Safety Authority (EFSA) & European Centre for Disease Prevention and Control (ECDC), 2017; Truccollo, Whyte, Burgess, & Bolton, 2021). In the United States, it was reported that campylobacteriosis had an incidence of 19.5 cases per 100,000 persons (Tack et al., 2019). The illness accounted for 22, 500 disabilities adjusted life years (DALYs) lost in the country (Scallan, Hoekstra, Mahon, Jones, & Griffin, 2015). Of the 34 *Campylobacter* species known to date, *C. jejuni* subsp. *jejuni* (*C. jejuni* hereafter) and *C. coli* are the most common isolates from patients (Skarp, Hänninen, & Rautelin, 2016;

EFSA & ECDC, 2017; WHO, 2020). Aside from causing severe bacterial enteritis and diarrhea, campylobacteriosis has also been linked to an important demyelinating neuropathic sequela – the Guillain-Barr*é* syndrome (Ramos et al., 2021).

Campylobacter spp. are commensals of the intestinal tract of livestock, pets, and birds (World Organization for Animal Health (OIE), 2017; Soro, Whyte, Bolton, & Tiwari, 2020). Of these, chickens and their meats have been implicated as the primary source of human campylobacteriosis (Shane, 2000; Domingues, Pires, Halasa, & Hald, 2012; OIE, 2017). However, transmissions via drinking of contaminated water, direct contact with infected humans and other animals, and consumption of unpasteurized dairy products have also been documented (Jaakkonen, Kivistö, Aarnio, Kalekivi, & Hakkinen, 2020; Hagos et al., 2021). Acute bloody diarrhea caused by campylobacteriosis is considered as a notifiable vehicle-borne illness in the Philippines (Department of Health Philippines (DOH), 2020).

This paper will focus on *C. jejuni* as a foodborne pathogen and its close association with chicken meat as its food vehicle of infection. A discussion on the agent, its ecological considerations, routes of transmission, clinical signs, occurrence in humans, and its prevention and control, as presented in published literature, are succinctly reviewed herein.

2. The agent: *Campylobacter jejuni*

Campylobacter jejuni belongs to the bacterial family Campylobacteriaceae, with *Arcobacter* and *Sulfurospirillium* (Nachamkin, 2007). It has two subspecies: *C. jejuni* subsp. *doylei* and *C. jejuni* subsp. *jejuni*; the latter is the more frequent isolate of the two (OIE, 2017). The bacterium is Gram-negative, fastidious, non-spore-forming, non-saccharolytic, catalase, oxidase, and hippurate hydrolysis positive (Snelling, Matsuda, Moore, & Dooley, 2005; Hoepers, Medina, Rossi, & Fernandez, 2016). *Campylobacter* spp. have a characteristic cork-screw-like motility attributed to a polar flagellum at one or both ends of the spirally curved or s-shaped bacterial cell (0.2-0.8 µm wide; 0.5-5 µm long) (Gilbreath, Cody, Merrell, & Hendrixson, 2011; Umaraw, Prajapati, Verma, Pathak, & Singh, 2017). In general, pathogenic *Campylobacter* are microaerophilic (3-5% oxygen with 2-10% CO_2) and thermophilic (optimum growth temperature is between 37-42^{o}C), characteristics that enable them to preferentially colonize poultry gastrointestinal tracts (Bolton, 2015; Umaraw et al., 2017). Bacterial isolates can be serotyped using the *C. jejuni* capsular polysaccharide (CPS) through Penner passive hemagglutination serotyping (Clarke et al., 2021). The entire circular genome of *Campylobacter jejuni* is about 1.6 million base pairs long and contains numerous hyper variable sequences that have been posited to be important in the survival of the bacteria (Parkhill et al., 2000). The presence of the *CJIE1* prophage gene in the genome is linked to phenotypic differences in protein expression and virulence (Clark et al., 2016). Virulent gene markers for *C. jejuni* include *flaA, cadF, iam, cdtABC, operon, virB11*, and *wlaN* (Sierra-Arguello et al., 2021). The bacterium has extended survival in milk, feces, urine, and water held at 4^{o}C: 3 weeks in feces, 5 weeks in urine, and 4 weeks in water (Blaser, Hardesty, Powers, & Wang, 1980). Environmental conditions that affect and other environmental sensitivities of *C. jejuni* are summarized in Table 1.

3. Campylobacteriosis: from farm to fork

All poultry production chain components contribute to the zoonotic transmission of campylobacteriosis (Figure 1). In the rearing stage, infections can be contracted by chicks via the feco-oral route from contaminated water and feed supplies resulting in colonization of the jejunum, cecum, and cloaca; the minimum infective dose is said to be 40 cells per chicken (Chen, Geys, Cawthraw, Havelaar, & Teunis, 2006; Awad, Hess, & Hess, 2018; Sierra-Arguello et al., 2021). Infected rearing stock start to excrete the bacterium two weeks post-infection and from this time, rapid horizontal transmission may arise (Shane, 2000; Pielsticker, Glünder, & Rautenschlein, 2012; Mourkas et al., 2020). Relaxed biosecurity on a farm is vital in perpetuating the proliferation of *C. jejuni* in flocks; other animals, farm staff, fomites, and pests may introduce and spread the bacterium (Umaraw et al., 2017). Filthy transport crates may also significantly contribute to contamination of harvested poultry (Ridley et al., 2011; Soro et al., 2020). However, Skarp et al. (2016) argued that the most critical *Campylobacter* contamination point is the slaughter and dressing stage, with carcasses most likely to be contaminated during evisceration. In addition, the defeathering, bleeding, washing, and chilling done in slaughterhouses were also reported to be significant contributors to contamination (Seliwiorstow et al., 2016; Perez-Arnedo & Gonzales-Fandos, 2019). In the UK, partial depopulation, slaughter in the summer and autumn, increasing broiler age, and high mortality in the flock have been identified as significant risk factors to high *C. jejuni* contamination of carcasses at slaughter (Lawes et al., 2012).

Inadequate farm biosecurity measures and unsanitary dressing procedures bleed into high contamination loads in poultry meats at the market and consumer household levels. In Europe, *Campylobacter* prevalences of >75% in broiler carcasses were found; *C. jejuni* was the most prevalent pathogenic contaminant (EFSA, 2010). In the Philippines, *C. jejuni* has been isolated in chicken meat sold at dressing plants, public markets, and grocery establishments (Baldrias & Reymundo, 2009; Sison et al., 2014; Lim et al., 2017). In the nation's capital, 78.1% of commercially available chicken samples were found to harbor *C. jejuni* and *C. coli;* chicken skins and livers were the most frequently contaminated carcass parts (Lim et al., 2017). In Thailand, a 57% *Campylobacter* prevalence among retail chicken was recently reported (Wangroongsarb et al., 2021). Unsurprisingly, this high level of contamination at the market level is further exacerbated by unhygienic food preparation practices within households. It has been noted that dirty and improperly washed kitchen utensils and eating cutlery vector the bacteria across meals and food preparations (Wassenaar, 2011). Thus, cross-contamination of other otherwise clean food articles occur frequently. The use of the same set of utensils for preparing raw food and cooked meat was noted to pose a higher risk of causing campylobacteriosis than eating undercooked chicken meat (Luber, 2009; Khalid et al., 2020).

4. Campylobacteriosis: clinical manifestations, epidemiology, and antimicrobial resistance

Campylobacteriosis generally manifests as gastroenteritis, resulting to hemorrhagic diarrhea in humans (Kaakoush, Castaño-Rodríguez, Mitchell, & Man, 2015; Truccollo et al., 2021). It has been found that an infective dose of 360-800 CFU is enough to cause illness (Black, Levine, Clements, Hughes, & Blaser, 1988). Upon ingestion of contaminated food vehicles, symptoms usually arise 24 to 72 hours post-exposure (Kaakoush et al., 2015; WHO, 2020). Infections may range from asymptomatic to mild to severe cases, with symptoms of fever, diarrhea (may or may not be hemorrhagic), abdominal cramps (mimicking appendicitis), nausea, and vomiting that last for about a week (Nachamkin, 2007). These signs are usually self-limiting in healthy individuals, but infections may have dire consequences in those with compromised immunity (i.e., school-aged children, pregnant women, the elderly, and people living with HIV) (Umaraw et al., 2017; WHO, 2020). Most infections have been observed to occur during summer, when environmental conditions are conducive to the maintenance of *C. jejuni* in food (Spickler & Leedom-Larson, 2013).

Campylobacteriosis has also been linked to increased risk of developing Crohn's Disease, ulcerative colitis and other inflammatory bowel diseases (Gradel et al., 2009). Aside from these, esophageal diseases (e.g., Barrett's esophagus), periodontal diseases, colorectal cancer, functional gastrointestinal disorders, cholecystitis, and celiac disease have also been associated with campylobacteriosis (Kaakoush et al., 2015). An extra gastrointestinal sequela known to be triggered by the infection is Guillain-Barré syndrome – an autoimmune neuromotor degenerative illness characterized by hyporeflexia and weakness of the limbs (van Doorn, Ruts, & Jacobs, 2008; Scallan et al., 2015). In Thailand, Guillain-Barré syndrome has increased in its incidence and was noted to be more deleterious among the elderly and young (Kasemsap et al., 2021).

There is sufficient evidence globally that campylobacteriosis is increasing in its incidence (Kaakoush et al., 2015; WHO, 2020). Data from developed countries indicate a rising trend, yet data from developing countries in the Asia-Pacific region and Africa remain wanting (Skarp et al., 2016). In 2018, campylobacteriosis had an incidence of 19.5 cases per 100, 000 population in the United States, and it was the highest of any foodborne pathogen (Tack et al., 2019). In Europe, the infection is also ranked first among enteric bacterial pathogens in terms of number of cases reported; affecting more than 245,000 individuals yearly (EFSA & ECDC, 2017; Truccollo et al., 2021). Risk factors for acquiring the disease vary in different parts of the world. However, international travel, consumption of contaminated insufficiently cooked poultry meat, drinking of unsafe water and unpasteurized milk, contact with domestic (i.e., livestock and pets) and wild animals, and rare person-to-person contact are consistent findings in epidemiologic studies (Little, Gormley, Rawal, &

Richardson, 2010; Domingues et al., 2012; Mulder et al., 2020).

Aside from the rising number of *C. jejuni* cases worldwide, the increasing number of published studies reporting antimicrobial resistance (AMR) of isolates is also worrisome. A recent review of Southeast Asian campylobacteriosis studies revealed that isolates of human and animal origins were becoming increasingly resistant to quinolones and tetracyclines (Jafari, Ebrahimi, & Luangtongkum, 2020). A recent report in Belgium revealed that a few isolates from diarrheal patients were resistant to nalidixic acid, ciprofloxacin, and tetracycline (Elhadidy et al., 2020). In the Philippines, isolates from chicken meats in Nueva Ecija had been found to be resistant to ampicillin, ciprofloxacin, tetracycline, erythromycin, and gentamycin (Sison et al., 2014). Several isolates from chicken carcasses from Metro Manila, Philippines also had resistance to clindamycin, erythromycin, nalidixic acid, tetracycline, gentamycin, and chloramphenicol (Lim et al., 2017). In China, isolates from diarrheal patients were also found to be resistant to some of the previously mentioned antimicrobials (Zhang et al., 2020). Interestingly, in Australia, fluoroquinolone-resistant *Campylobacter* isolates were detected in broiler chickens that had not received such antimicrobial medication or supplement; the authors noted that humans, pests, and wild birds may have been sources of infection (Abraham et al., 2020). Despite these recent reports, much is still unknown regarding AMR among *C. jejuni.* The wide AMR knowledge gap should be addressed by future research.

5. Campylobacteriosis: prevention and control

Several efforts to prevent and control campylobacteriosis in poultry production, in slaughter and dressing, and in food preparation have been described. Attempts to decrease *C. jejuni* in the production stages have included stringent biosecurity measures, probiotics, bacteriocins, vaccinations, feed and water additives, and pre- and post-harvest measures (Saint-Cyr et al., 2017; Sibanda et al., 2018; Vandeputte et al., 2019; Soro et al., 2020). Biosecurity measures such as physical step over barriers, footwear that is only worn within specific houses, elimination of bodies of water near houses, and having two or more broiler houses on a farm have been found to reduce the odds of campylobacteriosis in broiler flocks (Smith et al., 2016). However, a high number of broiler houses (i.e., three or more) have also been found to increase the odds of campylobacteriosis among broiler flocks (McDowell et al., 2008). Moreover, the relative risks of *Campylobacter* flock infections have been found to decrease through vaccinations, addition of feed and water supplements, discontinued thinning, employing few well-trained personnel, hygienic anterooms, avoiding drinkers that allow water standing, using house-specific tools, and the addition of disinfectants to drinking water (BIOHAZ et al., 2020). The judicious use of antimicrobial agents must be practiced to limit the development of antimicrobial resistance that has been well researched in *C. jejuni* (Abraham et al., 2020; Hull, Harrell, van Vliet, Correa, & Thakur, 2021).

At the poultry meat processing stage, alterations in traditional slaughter and dressing processes have had good impacts on lowering the levels of contamination (Bungay, de los Reyes, & Estacio, 2005; Umaraw et al., 2017). As an example, adjusting the scalding and chilling temperatures reduced bacterial loads on chicken carcasses. Scalding at 85ºC for 20 seconds and chilling at 4ºC for 20 seconds plus 0.1% plus immersion in a post-chill dip tank containing peracetic acid have lessened *C. jejuni* contamination loads (Whyte, Collins, & McGill, 2003; Nagel, Bauermeister, Bratcher, Singh, & McKee, 2013). Recently, ultraviolet light irradiation, cold plasma, high-intensity light pulse, ultrasound, and pulsed electric field treatments have successfully reduced bacterial contamination in chicken carcasses and cut-ups during the dressing and packaging stages (Zhuang et al., 2019; Soro et al., 2020; Soro, Whyte, Bolton, & Tiwari, 2021). Food packaging that renders the immediate environment unfavorable to the bacteria (e.g., modified atmospheric packaging and packaging with immobilized Zinc oxide nanoparticles) has been shown to be effective in maintaining low-level contamination at the market level (Meredith et al., 2014; Hakeem et al., 2020).

At the consumer homes or food preparation levels, prevention has been related to hygienic food preparation. Frequent washing of hands, keeping the preparation of raw and cooked foods separate, cooking at the correct temperature and time, avoiding unpasteurized dairy, avoiding drinking of unsafe water from unknown sources, and hygienic management of pets and backyard livestock have been advocated to prevent campylobacteriosis at home (Subejano & Peniular, 2018; Ghatak, He, Reed, & Irwin, 2020; Khalid et al., 2020).

6. Future perspectives and conclusion

Since there is no single vector nor source of *C. jejuni* infections and contamination, control measures should be developed and geared towards all the parts of the poultry production line. Moreover, the recent technological advancements to maintain the microbiological quality of chicken meat are promising and thus must be considered. Anti-*Campylobacter* strategies should be included in the integrated food safety prevention and control programs on farms, in food processing facilities, and in supermarkets, especially in developing countries. Additionally, households should also be aware of measures that keep foods safe from *C. jejuni* exposure to consumers and cross-contamination of other foods. Health education on the risk factors and proper food preparation practices should be conducted in communities – not only for campylobacteriosis but also for other foodborne pathogens.

Research has indicated that there is a gap in the campylobacteriosis data in some parts of Asia and Africa. This knowledge gap might have been the reason why the disease in these parts of world is currently out of the medical and veterinary zeitgeist. Similarly, its relatively manageable clinical signs as well as the aversion of Filipinos to raw, insufficiently cooked meat may have contributed to the sparse, close to none, published reports of human campylobacteriosis in that country. The possible severe clinical manifestations and the awful sequela of Guillain-Barré syndrome should prompt studies that will evaluate the status of this often-overlooked foodborne infection in regions where data is lacking. The occurrence of AMR among *Campylobacter* isolates from human cases, and from broiler chickens and their meats should also be continually evaluated due to the risks it posed to human health. Efforts to reduce AMR on all fronts of poultry production should likewise be considered.

On the veterinary public health front, studies that will assess the quality of poultry meats available in the market and preventive strategies along the entire production line must be enacted to ensure the safety and quality of these food articles. Results can be used to guide policy and operational interventions throughout the poultry production chain. The ultimate goal of producing high quality yet safe food products of animal origin is a serious endeavor that should be of great public health concern to all veterinarians and producers.

Table 1. Environmental conditions and disinfectants that adversely affects *Campylobacter jejuni*

Category	Agent and effect	References
Temperature	Temperatures below 30°C inhibit bacterial reproduction	Nachamkin (2007)
Temperature	Inactivated at 70°C for 1 minute; Sensitive to desiccation	Nachamkin (2007); Sprickler and Leedom-Larson (2013)
Temperature	Freezing reduces bacterial cell numbers; Low numbers can still be recovered after freezing at -20°C	Jacobs-Reitsma (2000)
Radiation	Sensitive to gamma radiation (1 kGy[1]); Refrigerated and room temperature foods are more susceptible to radiation than frozen foods	Patterson (1995)
pH	Sensitive to low pH (≤ pH 4.9); Inactivated at pH 2.3	Blaser et al. (1980)
Hydrostatic Pressure	450 MPa at 15°C for 30 seconds inactivate the bacteria	Sprickler and Leedom-Larson (2013)
Water Activity	Food with a_w below 0.987 inhibits growth	Soro et al. (2020)
Disinfectants	Iodophors, quaternary ammonium compounds, phenolic compounds, 70% ethanol, glutaradehyde, >1.5% brine solution, and hypochlorite at 5 mg/L inactivate the bacteria	Sprickler and Leedom-Larson (2013)

[1]kGy = kiloGray; MPa = Megapascals; a_w = water activity value

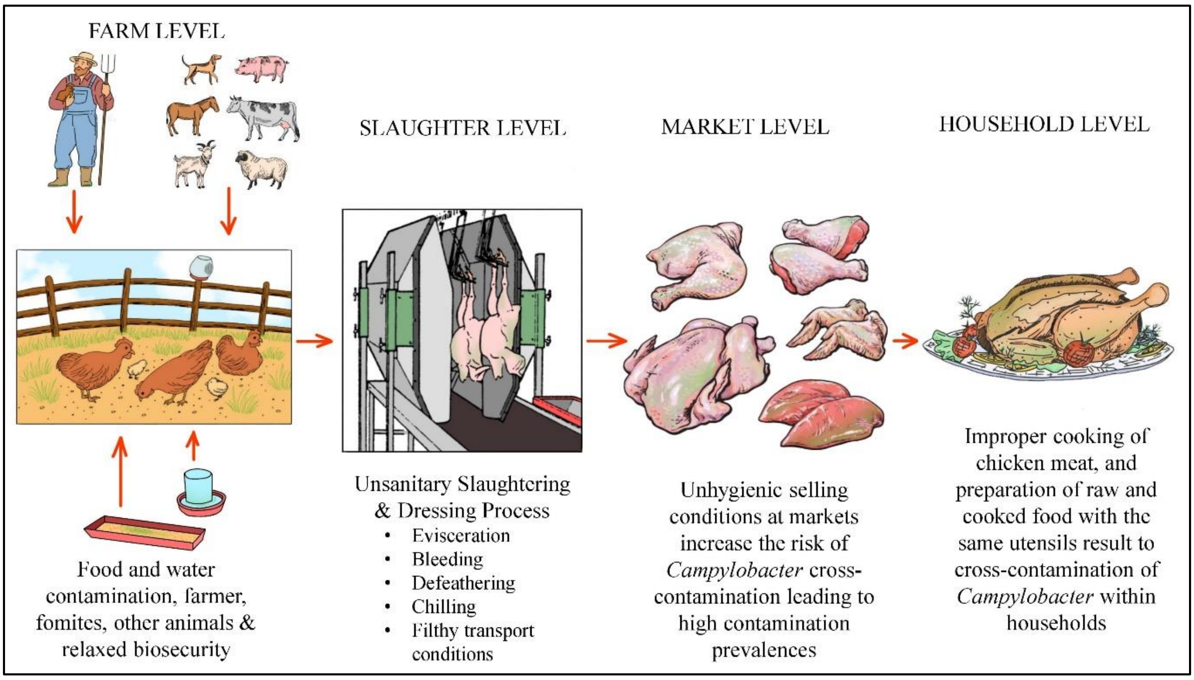

Figure 1 A farm to fork diagram of *Campylobacter jejuni* contamination sources within the poultry production chain

7. Acknowledgements

This research did not receive any funding from any institution. The first author would like to acknowledge the Philippine Department of Science and Technology- Accelerated Science and Technology Human Resource Development Program- National Science Consortium (DOST-ASTHRDP-NSC) Scholarship for funding his graduate studies. Both authors would like to thank Ms. Julia Mae Natasha Toong for rendering the figure in this review article.

8. Authors' contributions

JCBT conceptualized, researched, and wrote the manuscript. VDF critically reviewed and revised the manuscript. Both authors read and approved the manuscript for publication

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