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Campylobacteriosis in Poultry: A Review

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ABSTRACT

Campylobacter is common in poultry, including layer and broiler chickens, geese, ducks, and turkeys. This review aimed to emphasize the prevalence of campylobacteriosis, recent poultry diagnoses, and strict prevention measures. *Campylobacter* species colonize the intestines of poultry and waterfowl but are generally nonpathogenic in poultry. However, they are the most common bacterial cause of sporadic human enteritis in both developed and developing countries. The main species responsible for campylobacteriosis is *Campylobacter jejuni*, followed by *Campylobacter coli*. A number of other *Campylobacter* species, such as *Campylobacter lari, fetus, upsaliensis*, and *hyointestinalis* are rarely associated with campylobacteriosis. *Campylobacter hepaticus* is the species linked to spotty liver disease in layers and breeder chickens, and it may be the etiological agent of the disease previously known as avian vibrionic hepatitis. The most prevalent infection source for *Campylobacter* is environmental contamination from poultry droppings. However, some *Campylobacter* species can be transmitted vertically, either on the surface of eggs or via trans-ovarian transmission in addition to consumption of contaminated feed or water. Due to the non-specific clinical signs such as diarrhea and weight loss, diagnosing campylobacteriosis in poultry requires culture or polymerase chain reaction tests. Little is known about the available vaccine or effective antibiotic treatment due to the rapid development of antibiotic resistance. Therefore, strict biosecurity measures play a crucial role in preventing *Campylobacter* infection in commercial poultry. These measures include decontaminating housing between flocks, preventing the entry of rodents, wild birds, and animals, and eradicating insects. To control campylobacteriosis and reduce infection risks, it is important to implement efficient on-farm biosecurity measures, conduct regular inspections of workers at meat processing plants and poultry farms, and ensure thorough preparation of chicken meat and eggs before consumption. These measures are vital in minimizing the *Campylobacter* transmission from both broiler and laying chickens, thereby reducing the risk of foodborne diseases caused by contaminated food.

Keywords: Campylobacteriosis, *Campylobacter jejuni*, Control, Diagnosis, Epidemiology, Poultry

INTRODUCTION

The world faces a significant challenge in terms of inadequate nutrition, especially for individuals who rely on animal-based food sources. The poultry industry plays a crucial role in the economies of developed countries by providing meat and animal protein to meet people's dietary needs. One important strategy to tackle the protein shortage, particularly in middle-income nations, is to increase chicken production (Barakat et al., 2012).

Avian campylobacteriosis is a serious bacterial infection that affects both farmed and wild birds. This disease is primarily caused by bacteria belonging to the *Campylobacter* genus, with *Campylobacter jejuni* (*C. jejuni*) and *Campylobacter coli* (*C. coli*) being the most common species involved (Malik et al., 2021). Gram-negative slender or spirally curved rods characterize *Campylobacter* species. When two or more bacterial cells are grouped together, they resemble a seagull. Most species have a corkscrew-like motion due to the presence of a single flagellum at one or both ends of the bacterium (On et al., 2017). *Campylobacter* species can be found in the gastrointestinal and/or genital tracts of various animal species, either as harmless commensals or as pathogens (Tshipamba et al., 2021; Hafez, 2022). The clinical effects of *Campylobacter* infection can vary significantly in humans and animals (Ranjbar and Babazadeh, 2017; Wu et al., 2022).

The prevalence of *Campylobacter* species in poultry, particularly in broiler flocks close to slaughter age, could be as high as 100% (Asmai et al., 2020). Despite being widely colonized, *Campylobacter* is largely commensal in

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birds, meaning it exists without causing harm to its host. However, it plays a major role in causing foodborne gastroenteritis in humans, with contaminated poultry meat being the primary source of exposure (Sahin et al., 2015). Studies have shown that *Campylobacter* can quickly spread from one bird to an entire flock within a week through the fecal-oral route (Stern et al., 2001). Once inside the birds, it primarily colonizes the ceca, which has the highest concentration of the bacterium, and to a lesser extent, the liver, spleen, deep muscles, thymus, and bursa of Fabricius (Awad et al., 2015). Therefore, the idea behind the prevention methods used on the farms is to reduce the likelihood that the bacteria will ever enter the flock. However, these preventive measures have largely been unsuccessful (Hermans et al., 2011), leading to a call for further research into the ecology of *Campylobacter* and methods to control its spread (Kretzschmar, 2020). Understanding the epidemiology and diagnostics of *Campylobacter* infections is crucial for implementing effective control measures. Consequently, this review aimed to highlight the campylobacteriosis epidemiology, recent diagnosis in poultry, natural and chemical treatment, and strict preventive measures and infection control in humans.

ETIOLOGY

Campylobacteriosis is a bacterial infection caused by species within the *Campylobacter* genus. These bacteria belong to the kingdom of bacteria, Phylum Proteobacteria, class Epsilonproteobacteria, order Campylobacterales, and family *Campylobacteraceae*. Recent studies have identified four main genera within this family, which include *Campylobacter*, *Arcobacter*, *Sulfurospirillum*, and *Dehalospirilum*. This family is made up of motile Gram-negative, microaerophilic or microaerobic, and non-saccharolytic bacteria (On et al., 2017). Individual species may be free-living, commensal, pathogenic, motile, or aflagellate and capable of colonizing the mouth, intestinal, stomach, or reproductive tracts of people, large production animals, such as sheep, cattle, and deer, birds, and reptiles with the temperature of 25-42°C (Lastovica, 2016). The genus *Campylobacter* was initially known to have 16 species (Foster et al., 2004) although some researchers have identified 20 species and subspecies in this genus (Fernández et al., 2008). Several studies recently claimed that the genus *Campylobacter* contains 23 species along with 6 subspecies (García-Sánchez et al., 2018**)** or even 39 species (Parte, 2018). *Campylobacter* is a group of bacteria that belong to the Gram-negative category and have a distinctive shape resembling small spirally curved rods (0.2-0.8 µm × 0.5-5 µm). When two or more bacterial cells are grouped together, they form an S or V shape that resembles a seagull (Ngulukun, 2017). The majority of the species move in a corkscrew pattern owing to a single polar flagellum at one or both ends of the bacterium (Figures 1a and b). *Campylobacter gracilis, hominis, ureolyticus,* and *blaseri* which are non-motile, and *Campylobacter showae*, which has multiple flagella, are the exceptions (Gilbert et al., 2018). *Campylobacter jejuni is* the most commonly isolated species from the confirmed cases of poultry or avian campylobacteriosis, and the remaining related to the other non-*jejuni* species, mainly *C. coli* (Indykiewicz et al., 2021). There are other minor species within the genus *Campylobacter* including *Campylobacter lari, fetus,* and *upsaliensis* that have been reported to cause infection in both humans and poultry (Facciolà et al., 2017).

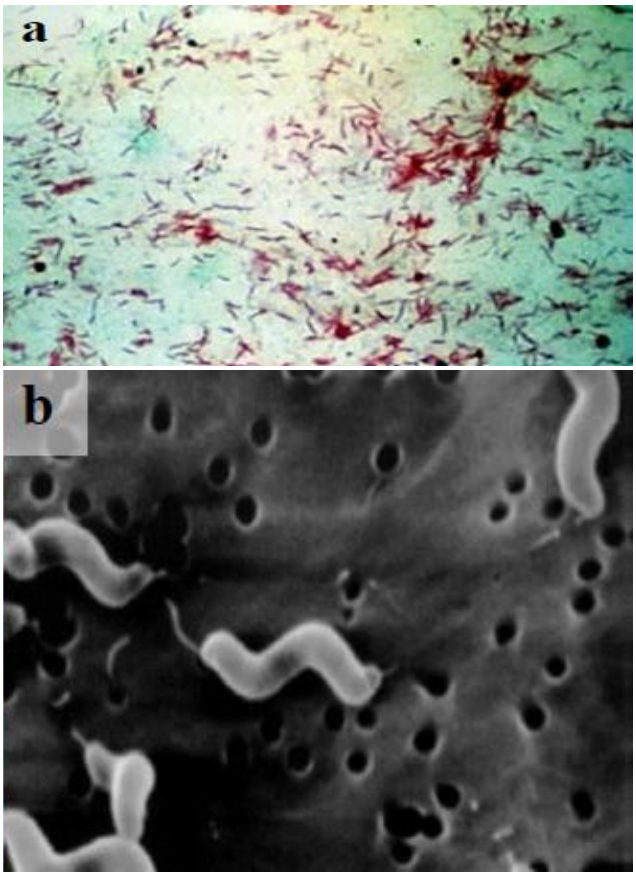

Figure 1. *Campylobacter* bacteria. **a:** Gram-negative after staining with Gram's stain, **b:** Motile flagellated under an electron microscope. Source: On et al. (2017).

HISTORY

The genus *Campylobacter* was initially proposed by Sebald and Véron (1963), which set them apart from the true *Vibrio* species. However, difficulties in the culture

and characterization of the causative organism kept it from being recognized as the major cause of disease until the 1970s. In 1906, two veterinarians in Great Britain identified large numbers of peculiar organisms in the mucus inside the uterus of pregnant sheep. These organisms were later recognized as *Campylobacter*, although their definition was not well-established at that time (Zilbauer et al., 2008). Initially, *Campylobacter* species were believed to cause diarrhea in animals and birds, and they were attributed to the Vibrio fetus, which is now known as the *Campylobacter fetus*. Veterinarians later discovered that *Campylobacter* species were responsible for many cases of septic abortion in cattle and sheep (Igwaran and Okoh, 2019). *Campylobacter* species are of great significance due to their increasing association with animal illnesses. Furthermore, the involvement of domestic and wild birds in the epidemiology of campylobacteriosis (Malik et al., 2021) contributes to its global prevalence, with sporadic occurrences reported (Upadhyay et al., 2019).

TAXONOMY

The term *Campylobacter* originates from the Greek words "kampylos," meaning "curved," and "baktron," meaning "rod." This name accurately describes the genus Campylobacter, as its members are spiral or curved rods (Linden, 2022). The taxonomic structure of the genus *Campylobacter* has changed dramatically since its inception, and some aspects of the current genus taxonomy are still debatable and require further investigation (Debruyne et al., 2008).

GROWTH AND SURVIVAL CHARACTERISTICS

Campylobacter species are non-spore forming, fastidious bacteria and mostly microaerophilic. They grow best in low-oxygen environments with 5% oxygen, 10% carbon dioxide, and 85% nitrogen (Malik et al., 2014). The survival of *Campylobacter* depends on species and other environmental conditions, including temperature, humidity, light, oxygen, or nutrient (Al-Qadiri et al., 2015). *Campylobacter* species can grow best at 37°C but not below 32°C (Figure 2). The high optimum growth temperature (42°C) distinguishes the thermophilic *C. jejuni* from most other *Campylobacter* species (Hakeem and Lu, 2021). This growth temperature is due to the absence of cold shock protein genes which play a role in low-temperature adaptation (Keto-Timonen et al., 2016). *Campylobacter jejuni* can survive for up to 6 days in chicken droppings after excretion, making them a potential source of transmission to the environment, particularly when manure is used as a fertilizer (Coorey et al., 2018).

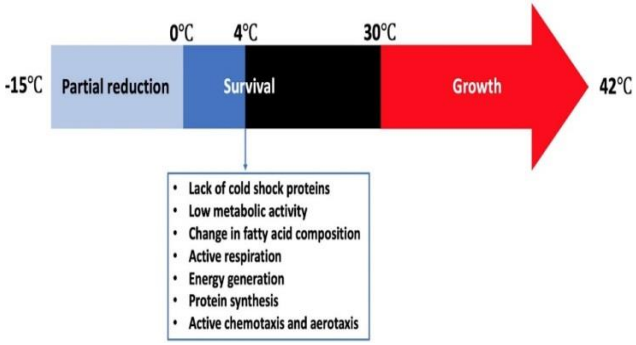

Figure 2. *Campylobacter* temperature range for survival and its reaction to stress at 4°C. Source: Hakeem and Lu (2021).

VIRULENCE FACTORS

The ability of *Campylobacter*, particularly *C. jejuni*, to adapt to unfavorable conditions and the host immune response appears to be one of the most important factors in successful gut colonization. Microorganisms go towards the intestinal environment during fecal-oral transmission under the effect of chemoattractants in order to colonize the intestinal tract of chickens (chemotaxis, Underwood et al., 2015). The proximal digestive tract also contains some proteins with antimicrobial properties, such as beta-defensin gallinacin-6 (van Dijk et al., 2007). Virulence factors determine the pathogenicity of *Campylobacter* species, and many studies have been conducted on the virulence characteristics of *C. jejuni* (Frasao et al., 2017). The virulence factors in the genus *Campylobacter*, in particular pathogenic species, such as *C. jejuni*, are multifactorial in nature, and the capacity of these bacteria to endure and withstand any physiological stress also adds to their pathogenicity (Casabonne et al., 2016).

Chemotaxis

Campylobacter jejuni adapts to various niches by using a procedure called chemotaxis, which mediates directional motility towards or away from chemical stimuli (chemo effectors/ligands that can be attractants or repellents) in the environment. The chemotaxis system comprises the methyl-accepting-domain-containing Transducer-like proteins (Tlps) and core signal transduction proteins. Chemotaxis proteins in the cytoplasm receive a signal from ligands binding to Tlps, and these proteins then start a signal transduction cascade that results in directional flagellar movement. Transducer-like

proteins make it easier for *C. jejuni* to engage in substrate-specific chemotaxis, which is crucial for the pathogen's ability to adapt, develop its pathobiology, and colonize the chicken gastrointestinal tract (Figure 3, Chandrashekhar et al., 2017).

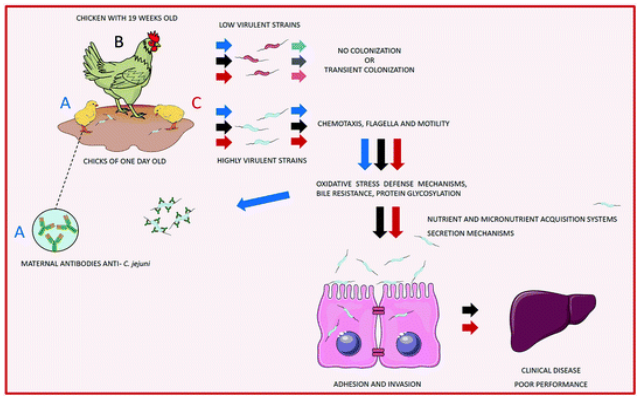

Figure 3. *Campylobacter* infection in the digestive system of early chicks can result in the destruction of bacteria (**A:** Blue arrows). Safe chickens against *Campylobacter jejuni* colonization (**B:** Black arrows). Chickens that are both unprotected (**C:** Red arrows). Source: Fonseca et al. (2016).

Flagellar motility

Motility is an essential factor for *Campylobacter* survival during a diversity of conditions that come along in the gastrointestinal tract. Due to flagella-driven motility, *Campylobacter* species can locate their appropriate habitat within the host. Two heavily glycosylated structural flagellins (FlaA and FlaB) are produced by the human foodborne pathogen *C. jejuni* (Radomska et al., 2017).

Oxygen tension and oxidative stress defense

Campylobacter can withstand a variety of unfavorable environmental factors in order to enter the gastrointestinal tract, including pH changes, oxygen restriction in the cecum, oxidative stress, increased osmotic pressure, and the presence of digestive fluids, including bile salts. The expression of genes involved in oxidative stress resistance is modulated by the peroxide resistance regulator and the *Campylobacter* oxidative stress regulator (Kim et al., 2015).

Bile resistance

For successful colonization, *C. jejuni* also needs to possess bile salt resistance. The detergent-like bile acids, such as cholates and bacteria, are killed by deoxycholates, which rupture the lipid bilayer of the cell membrane and cause the proteins in the bacterial cytoplasm to unfold and aggregate (Cremers et al., 2014).

Adhesion

Campylobacter jejuni has a number of adhesins, both individually and collectively, that can influence or mediate bacterial adherence to different cell structures and in different hosts. The adhesin that has received the most research is *Campylobacter* adhesion protein to fibronectin (CadF), a 37 kDa protein that binds to the ligand fibronectin found on epithelial cells and encoded by the gene CadF (Bolton, 2015).

Invasion

Campylobacter species have the ability to secret the invasion antigens (Cia), for example, CiaB, CiaC, CiaI, that are fundamental virulence factors by which the bacteria can invade the epithelial cells and colonize the host gastrointestinal tract in addition to the intracellular survival (Casabonne et al., 2016).

Cytolethal distending toxin

A toxin known as cytolethal distending toxin generates DNA damage that prevents cell division and kick-starts apoptosis because it exhibits DNase-like activity. This toxin causes diarrhea through its parasitical behavior with the destruction of the intestinal crypts (Carvalho et al., 2013).

EPIDEMIOLOGY

Prevalence

The European Food Safety Authority (EFSA) reports in 2019 confirmed 220,682 human cases in the European Union, with an average notification rate of 59.7 per 100,000 people (EFSA, 2021). Of the 429 meat samples from broiler chickens, 141 (32.9%) had *Campylobacter* species. In total, 3 (1.8%), 49 (36.6%), and 89 (66.9%) of the broiler chicken meat samples from Estonia, Latvia, and Lithuania tested positive for *Campylobacter* species (Tedersoo et al., 2022). *Campylobacter* has been isolated from various wild bird species worldwide, such as crows, pigeons, gulls, geese, and others. It has been found in different regions across the globe, including Africa, America, Europe, Australia, the Middle East, and Asia. These findings highlight the widespread distribution of the bacterium among wild bird populations (Antilles et al., 2021). The oldest common hosts for *Campylobacter* are the avian species due to their high body temperatures (Nur-Aziera-Aina et al., 2020; Babazadeh and Ranjbar, 2022).

Campylobacter jejuni bacteria are common commensals found in poultry and spread incredibly fast in avian flocks (Jokinen et al., 2011). Contact with a single *Campylobacter*-infected chicken for only three days is enough to infect the entire flock. Chickens show prolonged intestinal colonization at high levels with few or no symptoms or pathology (Singh and Mallick, 2019). The prevalence of *C. jejuni* in Egyptian farmed chicken intestine and liver was found to be 40.4% and 37.5% in the same manner (Elshraway et al., 2018). *Campylobacter jejuni* was isolated from chicken cloacal swabs at a rate of 15% and detected in the intestinal content of layers (17.5%) and broilers (20%, Ghoneim et al., 2020).

Transmission

The main methods of transmission for the infection are contaminated food and water, as well as direct contact with infected poultry or animals. Following an initial infection, campylobacteriosis can spread quickly within the flock (Facciolà et al., 2017). The young chicks did not become colonized until they were aged two-four weeks old, most likely because of maternally derived antibodies (Hermans et al., 2011). *Campylobacter* species transmission is made easier by various survival mechanisms. These include a variety of stress adaptation mechanisms, such as the ability to withstand oxygen exposure and desiccation, the development of biofilms and the enhancement of the viable but nonculturable state (Bolton, 2015).

Pathogenesis

Campylobacter infections are frequently linked to oral infections. The bacteria typically grow in abundance in the final third of the jejunum, ceca, and cloacae (Bolton, 2015). The first step in the pathogenesis of a *Campylobacter* infection is intestinal mucosa colonization, which is followed by adherence. The *Campylobacters* adhere, invade the epithelial cells, and then pass through the lamina propria to eventually reach the connective tissue beneath. Although the precise mechanism is unknown, it is possible that both paracellular and transcellular pathways are taken by the bacterial cells (Bolton, 2015). Cytolethal distending toxin is primarily responsible for cellular damage and death through cell cycle arrest (Facciolà et al., 2017).

CLINICAL SIGNS

The primary clinical symptoms of campylobacteriosis in chickens are diarrhoea and mucous-tinted droppings, which typically appear after 6 hours of infection. These clinical symptoms are typically exacerbated when other immunosuppressive agents are present. Infected poultry with *Campylobacter* species has also indicated a significant decrease in body weight and production (Umaraw et al., 2017).

Gross lesions

The principal symptoms of *C. jejuni* infection in chickens include considerable expansion of the distal intestine loops, a buildup of mucus and water in the intestinal lumen, as well as reddish or yellowish mottling of the liver parenchyma (Figure 4, Awad et al., 2015).

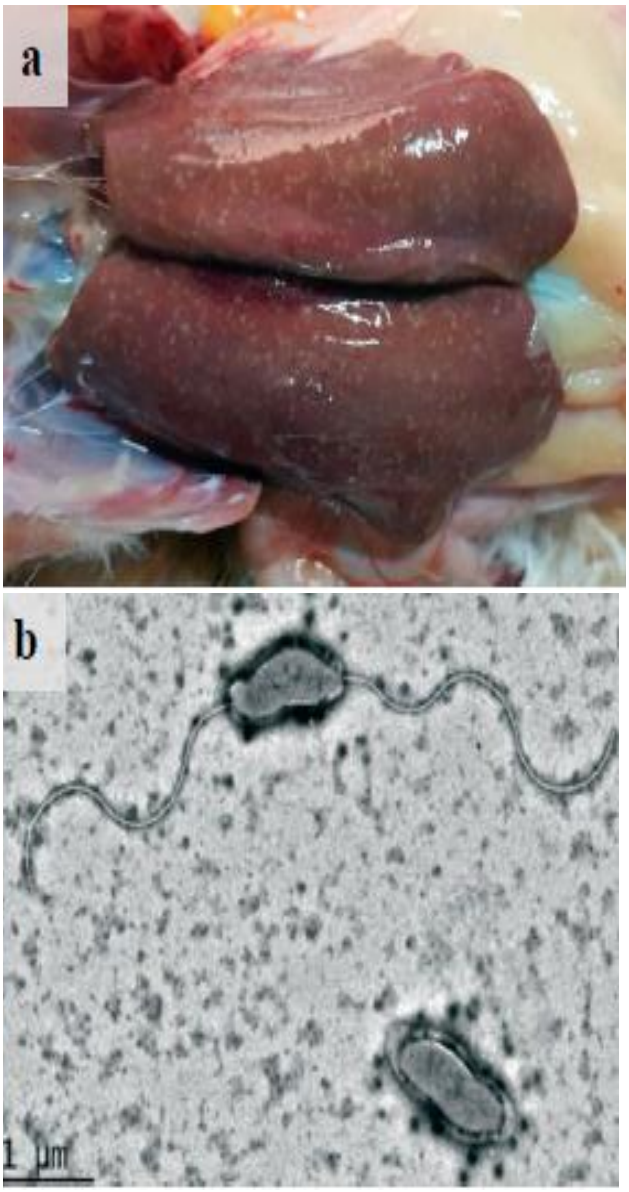

Figure 4. Liver of a chicken affected by spotty liver disease. **a:** Typical 1-2 mm lesions, transmission electron micrograph of *Campylobacter Hepaticus*, **b:** Bipolar flagella present on the top cell. Source: Moore et al. (2019).

DIAGNOSIS

Effective and quick diagnosis of *Campylobacter* species infection in avian hosts is essential for both individual care and farm-level disease management. Additionally, effective detection aids in the appropriate monitoring and surveillance of *Campylobacter* infection, which may present a risk to human health due to zoonotic transmission (Hassanain et al., 2018).

Isolation and identification

Enriching the sample in the proper broth, such as Bolton broth, followed by isolation by plating on niche medium, such as modified charcoal cefoperazone deoxycholate media, are the traditional steps in *campylobacter* species identification (mCCDA), for which a variety of commercial media are available (Figure 5a, Bolton, 2015). Bacterial isolation is usually followed by a variety of biochemical tests in the research lab, including oxidase and catalase production, urease expression, nitrate and nitrite reduction, H_2S production, and indoxyl acetate and hippurate hydrolysis (Figure 5b, Gharst et al., 2013).

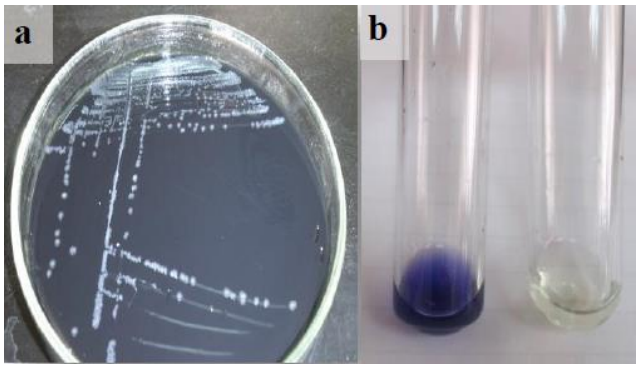

Figure 5. Isolation of *Campylobacter* on mCCDA medium showing trailing along the streak lines (**a**) and identification by hippurate hydrolysis (**b**), positive (purple), and negative (colorless). Source: Bolton (2015)

Immunological tests

Enzyme-linked immunosorbent assays (ELISA), quantitative immunofluorescence, and flow cytometry are among the enzyme immunoassays used for the diagnosis of *Campylobacter*, but ELISA dominates these immunological methods for targeting multiple specific antigens on the surface of microorganisms (Hassanain et al., 2013; Ricke et al., 2019). To identify pathogen-specific epitopes, both monoclonal and polyclonal antibodies can be produced. Additionally, antibodies can be altered, which frequently entails conjugating different detection systems, such as horseradish peroxidase, to increase the sensitivity and specificity of various target epitopes' detection (Shaapan et al., 2021). It is important to note that although immune-based detection techniques have some sensitivity with *Campylobacter* species (Figure 6), they produce false positive results. This has been observed in comparisons of commercial kits with conventional microbiological and molecular techniques (Gharst et al., 2013; Perdoncini et al., 2022).

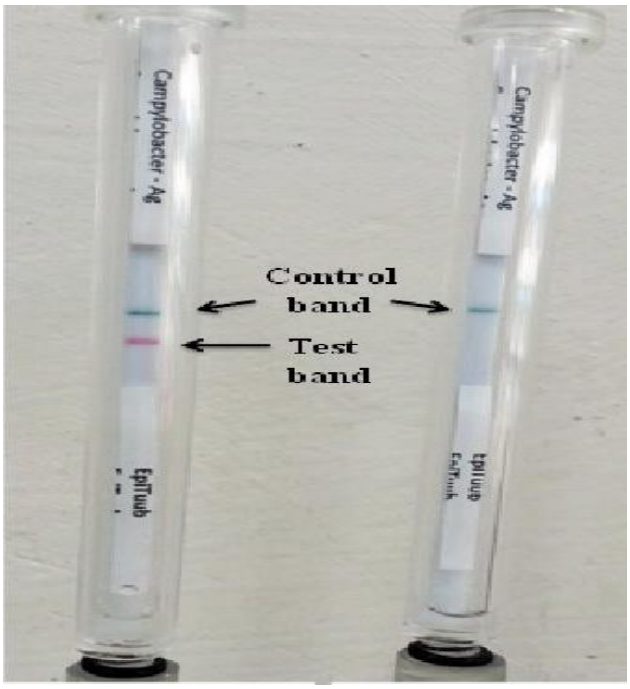

Figure 6. *Campylobacter* positive (colored test band) and negative samples by rapid immunochromatography test. Source: Gharst et al. (2013)

Molecular diagnosis

By using nucleic acid-based technologies, different and highly specific DNA or RNA sequences are discovered. These sequences can then be sequenced, amplified, and seen on a gel or else distinguished for identification, quantitative determination, and molecular typing (Ghatak et al., 2020). Polymerase chain reaction (PCR) and DNA sequencing can allow for the simple, quick, and precise identification of *Campylobacter* species while also revealing its epidemiological characteristics (Figure 7). Also, they allow researchers to generate data that can be communicated via web-based databases and used for phylogenetic studies (Negahdari et al., 2016). Quantitative PCR or real-time PCR are the two names for this technology, which are both referred to as qPCR (Ghoneim et al., 2020).

Differential diagnosis

The clinical signs of avian campylobacteriosis are similar to those of other enteric pathogens like *Salmonella*, *Shigella*, *Escherichia coli* (*E. coli*) 0157:H7, *Shiga* toxin-produced by *E. coli*, *Clostridium difficile*, *Yersinia*, *Entamoeba histolytica*, *coccidia*, and *Rota virus* (Nieder et al., 2018).

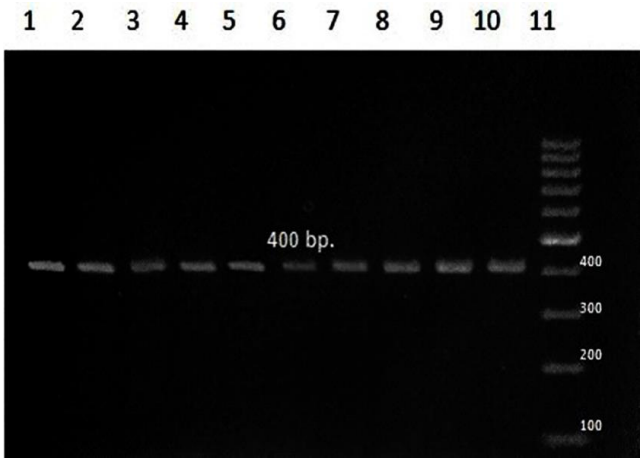

Figure 7. DNA ladder (100 bp.); Lanes (1-10): positive *Campylobacter jejuni* isolates showing specific bands at 400 bp. and *cadF* gene in *Campylobacter jejuni* isolates: Lane (11). Source: Ghoneim et al. (2020).

TREATMENT

Chemical additives, both natural and synthetic, have been tested *in vitro* and *in vivo* to verify their anti-*Campylobacter* effects. In such a study, caprylic acid at a dose of 0.175% (v/v) was administrated in the drinking water of one-day-old chicks for 6 days. The results indicated that the concentration of a mixture containing 5 strains of *C. jejuni* decreased by 3 log CFU/g by day 6 (Gracia et al., 2016). The administration of a ferric tyrosine complex at a concentration of 0.05 g/kg in broiler feed for 42 days indicated a 2-log CFU/g reduction in chickens naturally colonized with *Campylobacter* (Khattak et al., 2018). Cold plasma, ultraviolet light irradiation, high-intensity light pulses, pulsed electric fields, and ultrasound are examples of a number of novel technologies that have been investigated for their ability to inactivate Campylobacter on chicken meat (Soro et al., 2020). Many recent laboratory-scale experiments showed that the approved antimicrobials, such as acidified sodium, chlorite, cetylpyridinium, chlorine, chlorine dioxide, peroxyacetic acid, and trisodium phosphate, could reduce Campylobacter in chicken meat up to 5 log (Hakeem and Lu, 2021).

Potential pre- and postharvest interventions

Preharvest strategies include the successful oral application of phages to reduce *C. jejuni* colonization in birds and phages against *C. jejuni* as an alternative feed additive. Thus, the majority of preharvest intervention strategies of *Campylobacter* are focused on the reduction or removal of the microorganism from the ceca (Deng et al., 2020). Postharvest application of lytic phages could selectively target *Campylobacter* populations without interfering with the remaining microbiota. Phage treatment can be used to inactivate *Campylobacter* attached to food contact surfaces or grown as biofilms. *Campylobacter* bacteriophages isolated from retail poultry have been used in some post-slaughter experiments (Olson et al., 2022).

Biosecurity measures

Poultry are reservoirs of *Campylobacter* species although the birds are generally asymptomatic. *Campylobacter* is an important zoonotic pathogen, underscoring the importance of implementing suitable food safety practices and disease management methods among small flock keepers. These measures are crucial for preventing and controlling the transmission of *Campylobacter* species to humans, which can occur through direct contact with infected poultry or by consuming contaminated poultry meat (Schweitzer et al., 2021). Contaminated feed, water, and fomites, as well as wild birds, rodents, and insects, are sources of *Campylobacter* species in poultry and improper handling of contaminated food and consumption of undercooked food, in particular poultry products, and direct contact with livestock and pets, are major risk factors for *C. jejuni* and *C. coli* infections in humans (Abd El-Hack et al., 2021).

PREVENTION AND CONTROL

Strict hygiene routines and sanitary management of farm facilities and husbandry operations are the first steps in controlling infection in birds, especially poultry. Farm machinery needs to be cleaned up, especially hatcheries. An efficient method to stop the spread of infection also involves chemically treating litter. Incorporating fatty acids and bacteriocins, plant-derived substances, and the use of bacteriophage are some of the more recent methods being used to reduce colonization although further research is necessary before deciding whether they will be

effective (Facciolà et al., 2017). Some cutting-edge methods for preventing campylobacteriosis in poultry include a DNA prime/protein boost protocol for *C. jejuni* vaccination, an inventive *in ovo* vaccination in broilers using bacterin and subunit vaccine, and the use of reverse vaccinology to find potential novel targets for vaccination (Figure 8, Hassanain et al., 2018). Early colonization of the gastrointestinal tract (GIT) by probiotics may serve as an inhibitor to the growth of foodborne pathogens. Probiotics are thus a promising feed additive for lowering and eradicating Campylobacter colonization in the GIT of chicken (Deng et al., 2020).

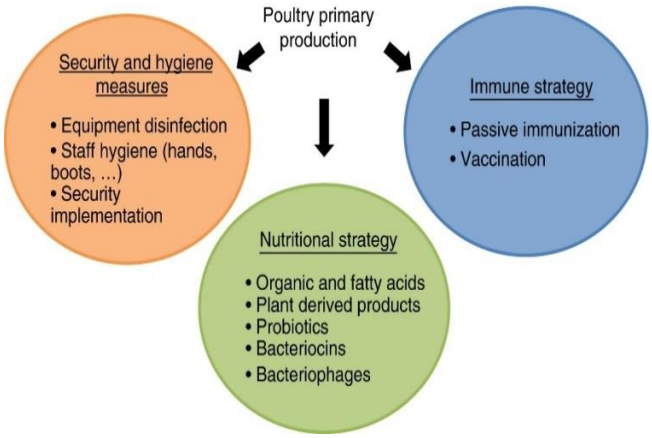

Figure 8. Control measures performed at the primary production stage to prevent human campylobacteriosis infections and the intestinal colonization of broiler chickens with *Campylobacter* (Source: Meunier et al., 2016).

PUBLIC HEALTH SIGNIFICANCE

Chickens pose the largest reservoir and the highest risk for human diseases caused by *Campylobacter* (Hermans et al., 2012). While the primary route of human infection is through oral ingestion, there is also evidence of occupational transmission of the disease. In terms of poultry meat serving as a source of human campylobacteriosis, reported rates of occupational infection by *Campylobacter* species among employees can range from 57% to 83% (Skarp et al., 2016). Genetic analysis of *Campylobacter* isolates from both humans and wild poultry has revealed frequent overlaps in clonal complexes (Sequence 5 Types, ST), indicating a potential risk of human infection from wild fowl (Wei et al., 2019). This highlights the importance of considering wild fowl as a possible source of Campylobacter transmission to humans.

ANTIMICROBIAL RESISTANCE

Antimicrobials are used for prophylaxis, treatment, or as growth promoters in food animals, and antimicrobial resistance (AMR) is a major public health threat worldwide. *Campylobacter* isolates were more resistant to tetracyclines, macrolides, ketolides, and lincosamides (Dramé et al., 2020). Among the high contamination levels of broilers (71.4%) in Morocco, five *Campylobacter* strains were analyzed, namely erythromycin (92.8%), ampicillin (95.2%), ciprofloxacin (85.7%), tetracycline (92.8%), and gentamycin (7.1%). This finding raises concerns about the effectiveness of such antibiotics for the treatment of animal diseases (Asmai et al., 2020).

VACCINATION

Vaccination is considered a promising intervention measure for reducing Campylobacter in poultry. As part of this approach, two vaccine candidates have been extensively studied and evaluated. These candidates involve a novel vaccination strategy that combines the *in ovo* vaccination route with a newly formulated DNA vaccine. The aim was to control *Campylobacter* in broiler chickens effectively. This innovative approach holds the potential to enhance the efficacy of Campylobacter vaccines in poultry (Liu et al., 2019). *Campylobacter jejuni* vaccination trials may reflect the antigen, challenge strain, vaccine administration, and adjuvant. Refinement of glycoconjugate vaccines by increasing glycosylation levels or using highly immunogenic protein carriers could improve their efficacy (Vohra et al., 2020). In a proof-of-concept study aiming to develop live-attenuated *C. jejuni* vaccines, researchers focused on oxidative stress defense mutants. They found that pre-colonizing chickens with a mutant lacking the *ahpC* gene resulted in a significant reduction in the level of *C. jejuni* and an increase in body weights among the chickens. This discovery highlights the potential of targeting the *ahpC* gene for constructing live-attenuated *C. jejuni* vaccines specifically designed for chickens (Jeon et al., 2022).

CONCLUSION

The most common manifestation of campylobacteriosis in poultry is a digestive disease, leading to diarrhea and weight loss. The rapid diagnosis is made based on the observation of symptoms or the gross lesions after

slaughter, but it can also be supported by causative agent isolation and culture. Treatment is difficult to apply in poultry. The strict hygiene and sanitary management of farm facilities and husbandry operations are the first steps in controlling infection in poultry, especially poultry. Feeding and watering equipment must be thoroughly cleaned and disinfected. Prevent crowding in the poultry house, and chemical treatment of the litter. Incorporating fatty acids and bacteriocins, plant-derived substances, and the use of bacteriophage are some of the more recent methods being used to reduce colonization. Thus, to prevent foodborne illness from contaminated food, it is advised to boil chicken meat and eggs thoroughly before consumption, implement effective on-farm biosecurity measures, and conduct routine employee checks at meat processing facilities and on chicken farms.

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Authors' contributions

Sabry A. S. Sadek conceptualized this study, surveyed the literature, drafted, and revised the manuscript. Ashraf M. Barakat was responsible for data acquisition and manuscript revision, while Raafat M. Shaapan revised, edited, and suggested changes to the manuscript. All authors have read and approved the final version of the manuscript for publication in the present journal.

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The authors have declared that no competing interest exists.

Ethical consideration

Plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been checked by the author.

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