Bacteriological Profile of Campylobacter SPP Isolated from Pigs in Cameroon: A Review

Serge Damase Oyong Assiene1*, Esther Ngah2 and Dieudonné Ndjonka3

1Laboratory of Microbiology of Higher Institute of Medical Technology, Douala University, Douala Cameroon.
2National Higher School of Agro-Industrial Sciences, Ngaoundere University, Ngaoundere, Cameroon.
3Faculty of Sciences, Ngaoundere University, Ngaoundere, Cameroon.

Authors’ contributions

This work was carried out in collaboration among all authors. Author SDOA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors EN and DN managed the analyses of the study. Author EN managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/MRJI/2020/v30i1230283

Received 25 October 2020
Accepted 29 December 2020
Published 31 December 2020

ABSTRACT

Campylobacter is the most frequent bacteria implicated in acute gastroenteritis in the industrialized world and is considered as a major public health problem. The aim of this review is to improve our knowledge on the bacteriological profile of Campylobacter isolated from pigs. Pork, beef also represent sources of infection with these microorganisms. Campylobacter is a bacterium comprising seventeen species, including Campylobacter jejuni, Campylobacter coli and Campylobacter fetus. C. coli is the most common Campylobacter species recovered from pigs. The prevalence (46%, 52%, 75%) varies from one country to another, from the collection site. C. jejuni and C. coli grows best in a low oxygen or microaerophilic environment. The virulence markers varies among different sources of the isolates. The majority of genes were found at high levels in Campylobacter spp. isolated from pork meat (csrA, sodB, cdtB, and racR). Moreover, this review revealed virulent properties of Campylobacter isolated from swine products and high resistance rates to Tetracycline (68%), Erythromycin (61%), which may represent difficulties in campylobacteriosis treatment.

*Corresponding author: E-mail: assieneserge@yahoo.fr
Fluoroquinolones resistance (2.2%, 7%, 11%,100%) varies according to the country and the source of the sample. It will be wise to insist on hygienic measures as a solution to limit the incidence of Campylobacter and prevent dissemination of pathogens in animals (chicken, pork and beef) within slaughter-houses/ killings Cameroon.

**Keywords:** Campylobacteriosis; pork; gastroenteritis; prevalence; resistance.

### 1. INTRODUCTION

Among food borne diseases, zoonoses takes a special place [1]. Studies indicates that a third of human infectious diseases are of zoonotic origin [2]. Indeed, these diseases are induced by pathogens of which the animal is the main carrier [3]. Zoonotic diseases are defined as diseases transmitted between animals and humans as a consequence of a direct contact, indirect environmental contact, or through food [4]. Among recognised pathogens causing human diseases, almost 60% are of animal origin [5]. *Campylobacter* spp is a typical zoonotic microorganism/ zoonotic bacteria. *Campylobacter* spp are the most common cause of acute bacterial enteritis in humans [6,7]. They are typically considered foodborne pathogens and have been identified as the leading cause of food poisoning in Europe [8], the United States [9], Canada [10] and Australia [11].

*Campylobacter* is a gram-negative, non-spore forming, curved or spiral bacilli, which are oxygen sensitive and prefer to grow under micro-aerobic conditions [12,13]. Some *Campylobacter* species are thermotolerant; for instance, *Campylobacter jejuni* (C. jejuni) and *Campylobacter coli* (C. coli), which are of critical importance to food safety, grow optimally at 42°C [14]. Meat obtained from poultry is the most common source of *Campylobacter* bacteria, but pork, beef, and unpasteurized milk also represent sources of infection with these microorganisms [15,16]. Pork and beef have long been preferred in many countries, and their level of consumption depends on the availability of the product in the market. The presence of *Campylobacter* in cattle and pig carcasses at slaughterhouses is well documented and significant [17,18]. However, the occurrence of *Campylobacter* in beef or pork is lower than that in poultry meat [19]. A lower rate of *Campylobacter* isolation from beef or pork meat can be associated with longer slaughter time, cooling of carcasses, and drying of the meat surface [20].

Resistance to antimicrobial substances among zoonotic bacteria is the current subject of research concerning the entire food chain, given the importance of this phenomenon in public health. Infections caused by drug-resistant strains requires a long term treatment, have a higher morbidity and mortality rates, and are associated with higher cost of treatment [21].

Several genes (i.e., *flaA* and *fliA*), are essential for the mobility/ passage of *Campylobacter* through the stomach and gut environment [22]. In addition, several proteins (encoded by the *cadF*, *docA*, *racR*, *virB11*, *ciaB*, and *iam* genes) on the surface of Campylobacters have been shown to promote the adherence and invasion of epithelial cells of the intestine [23,24]. *Campylobacter* has also been found to excrete several cytotoxins (encoded by the *cdtA*, *cdtB*, *cdtC*, and *wlaN* genes) that contribute to the development of human illness [25,26].

The aim of this study is to improve our knowledge of the bacteriological profile of *Campylobacter* isolated from pigs. This will help in understanding whether it is possible to eliminate *Campylobacter* from the pigs population, to produce *Campylobacter*-free pigs (meat) and to prevent the spread of *Campylobacter* from pigs to the environment, particularly in Cameroon.

### 2. CAMPYLOBACTER SPP

*Campylobacter* are small, curved-to-spiral shaped, flagellated Gram-negative rods, ranging from 0.5 to 8 mm in length and from 0.2 to 0.5 mm wide [27]. *Campylobacter* is a bacterium comprising seventeen species, including *Campylobacter jejuni*, *Campylobacter coli* and *Campylobacter fetus*. *Campylobacter* is an intestinal infection almost always caused by *Campylobacter jejuni* or *Campylobacter coli*, in the form of diarrhea. *Campylobacter fetus* can cause neonatal infection [27].

#### 2.1 Survival in the Environment

Survival of *C. jejuni* and *C. coli* outside the gut is poor, and replication does not occur readily [28].
C. jejuni and C. coli grows best at 37°C to 42°C [29], the approximate body temperature of the pork (41°C to 42°C), such as an atmosphere of 5%O₂, 10%CO₂, and 85%N. The organism is sensitive to freezing, drying, acidic conditions (pH 5.0), and salinity.

Campylobacter survives in water thanks to the multilayer bag. The protozoan tetrahymania, is a unicellular organism living in fresh water. This feeds on bacteria. However, some bacteria, such as Campylobacter, which survive digestion, can become trapped there. Once evacuated, the multi-layered bag will offer them good protection against the vagaries of a decidedly hostile environment. Researchers have shown that the drinking water of farms and pigsties contained the bacteria, but also protozoa. Interestingly, some bacteria are able to survive in protozoa and therefore use them as a host [30]. This is the case with Campylobacter.

2.2 Pigs

Unlike poultry and cattle, C. coli is the more common Campylobacter species recovered from pigs [13]. In some studies, for instance, C. coli has been recovered from pigs fecal samples at greater than 99% [30,31]. Jensen et al. [32] studied the establishment of C. coli and C. jejuni in outdoor organically-reared pigs to monitor potential shifts from C. coli to C. jejuni in intestinal colonization. Their results demonstrated excessive fluctuations in numbers of swine colonized by C. jejuni, with recoveries ranging from 18.8 and 78.6% among the three trials, but C. jejuni was never more prevalent than C. coli [32]. Despite being recognized as the minor Campylobacter species in swine, high prevalence of C. jejuni has been observed in fecal or rectal contents of guilts, sows, and weaned piglets (76, 89, and 82%, respectively) [33]. In their report, C. coli (68%) was only more prevalent than C. jejuni (31.7%) in neonates when isolated within 24 h of birth [33].

3. GENUS OF CAMPYLOBACTER

The sequence of the genome of Campylobacter jejuni NCTC11168 was originally published in 2000. There is a considerable variation between strains and reannotation of the C. jejuni genome published in 2006 revealed that the complete sequence is 1,641,481 bp in length with 25 polymorphic regions [34]. Moreover, new information for 1,450 of the original 1,654 coding sequences revealed changes corresponding to over 300 product functions [34]. The infectious diseases caused by members of the bacterial genus Campylobacter are called campylobacteriosis [35]. Currently Campylobacter jejuni and Campylobacter coli are considered to be the most important enteropathogens among Campylobacter spp. The rate of Campylobacter infections are increasing worldwide, exceeding shigellosis [35,36]. Sequencing of the C. jejuni NCTC 11168 genome demonstrated the existence of genes that code some proteins with infectious potential. Despite numerous studies on the molecular genetics of Campylobacter spp., their mechanisms of pathogenicity and virulence remain poorly understood [37]. Although the bacteria are considered to be susceptible to stress associated with environmental conditions, in the course of evolution, they were able to develop some complex mechanisms of survival and virulence [38].

The occurrence of virulence markers various among different sources of the isolates. On the other hand depending on the species (C. jejuni, C. coli...etc.) some virulence markers are different. Malgorzata et al. [39] in his study stated that the majority of genes were found at high levels in Campylobacter spp. isolated from pork meat ( csrA, sodB, cdtB, and racR). Low levels of the pathogenic markers virB11 and iam were noted in Campylobacter isolates from pork and beef meat. Also that significant differences in the occurrence of iam, wlaN, and virB11 genes were detected between C. jejuni and C. coli isolates.

4. PREVALENCE OF CAMPYLOBACTER IN PIGS

Pigs are well-recognized carriers of Campylobacter spp., particularly C. coli [40]. However, these agents are not commonly associated with enterocolitis in swine and a diagnosis of campylobacteriosis in pigs has historically been based upon the exclusion of other diseases [41]. As such, Campylobacter culture is not typically included in routine diagnostic testing for enteric disease in grow-fin ish pigs and thus the role of Campylobacter spp. infection is pigs with diarrhea is poorly characterized. A study detecting the prevalence of Campylobacter in swine through the different processing stations and comparing carcasses, colon and rectal samples throughout a slaughter operation was conducted by Pearce et al. [42]. When results from four different recovery methods were compared, C. coli was found in 151 of 202 isolates with recovery of C. jejuni...
accounting for only 1% of the samples tested. Malakauskas et al. [43] reported that C. coli was prevalent in 92 of 120 isolates obtained from fecal, carcasses and slaughter line surfaces combined, while C. jejuni isolates accounted for 28 of 120 of positive samples recovered from carcasses and slaughter line surfaces.

All pigs excreted Campylobacter 10^3 - 10^7 CFU g^-1 faeces from the age of 8 – 13 weeks old. Pigs seem to be a natural reservoir of Campylobacter spp. with prevalence between 50% and 100% and excretion levels ranging from 10^2 to 10^7 CFU/g, but opposite to most animals, pigs show a dominance of C. coli [31,44]. Table 2 shows that the prevalence of Campylobacter spp varies from one country to another, from the site of collection. C. coli in pigs still remains the most common despite cohabitation with C. jejuni. In Africa few studies have had a work on pigs, particularly in Cameroon where there is none, the few studies are more interested in poultry. This observation led us to present the data already known in pigs and subsequently to carry out this study in Yaoundé, Cameroon in order to describe the situation of Campylobacter in pigs in Cameroon.

5. IDENTIFICATION AND ANTIBIOTICS RESISTANCE PROFILE

Characterization methods make it possible to determine the genus and the bacterial species (biochemical identification and Polymerase Chain Reaction); other methods discriminate against strains within each species (serological methods or genotypic). Further to the limited technical platforms in Cameroon, identification is more focused on biochemical techniques.

5.1 Identification of Species by Biochemical Characterization

Biochemical tests performed on strains including morphological characters are suggestive of gender Campylobacter make it possible to identify the 4 major species of thermotolerant Campylobacter. These tests are carried out in conjunction with the assessment of sensitivity to two antibiotics, nalidixic acid and cephalotin. These tests are recommended in the ISO 10272 standard for the detection of Campylobacter in food. However, the emergence of resistance to nalidixic acid can pose problem for the use of this criterion for discrimination between C. jejuni and C. upsaliensis on the one hand and C. coli and C. lari on the other. A Campylobacter identification kit is also available (API Campy; API Biomerieux). However, difficulties in identifying certain strains of C. coli and C. lari have been reported [45].

5.2 Antimicrobial Resistance

According to the World Health Organisation [46], surveillance of AMR in Campylobacter has identified important levels of resistance to erythromycin and fluoroquinolones in many studies of the world, which appears to be associated with the use of these drugs in pork production systems. [47,48]. Fluoroquinolones and macrolides such as ciprofloxacin and erythromycin, respectively, are recommended for the treatment of Campylobacter infections in humans [36,49]. However, given their abuse and misuse, resistance to these drugs has emerged [46].

Table 4 shows some studies carried out on the resistance of Campylobacter isolates from pigs in different countries. These different studies confirm the high resistance of Campylobacter to tetracycline the percentages of which are substantially the same. On the other hand fluoroquinolones (Ciprofloxacin) resistance varies according to the country and the source of sample. This reveals that despite the already known resistance to fluoroquinolones, it may happen that this resistance is not identical on all Campylobacter strains. The study that we will be carrying out in the coming days will enable us to obtain a percentage of resistance to ciprofloxacin in Campylobacter strains isolated from pigs in slaughterhouses in the city of Yaoundé. Resistance to Erythromycin remains substantially the same in all studies. According to Jonker and Picard [50], in intensive poultry and pig rearing systems the use of oral antibiotics is essential to maintain health; hence there is a high risk for the Campylobacter in the intestinal tract of food animals to develop resistance to commonly used antibiotics. The increased resistance of bacteria to antibiotics has been associated with the continuous use of antibiotics either therapeutically, prophylactically, or as growth-promoting agents to maintain animal welfare in swine production systems. This practice creates a potential risk for human health care based on the present knowledge of gene transfer and co-resistance [51].
Table 1. Factors of *Campylobacter* genus bacteria allowing them to infect and survive in a host organism

| The mechanism of survival/virulence | Description                                                                 | References |
|------------------------------------|-----------------------------------------------------------------------------|------------|
| Adherence to host’s epithelial cells | Initial colonisation of intestinal epithelium  
Mediation of the adhesins on the surface of bacterial cells, including: CadF (an external membrane protein), PEB1 (periplasmatic binding protein), JlpA (lipoproteins engaged in adhesion to Hep-2 cells), and CapA (Camplyobacter A adhesion protein) | [52-54] |
| Invasion of host’s cells           | Avoiding immunological response  
Significant role played by the external lipopolysaccharide bacterial core | [38,53] |
| Mobility                           | Moving against the peristalsis, reaching target sites in the intestine  
adhesion to host’s cells, formation of a biofilm, secretion of invasive proteins  
Required flagella and a chemosensory system (regulation of the flagellar movement depending on environmental conditions) | [52–55] |
| Production of Toxins-cytolethal distending toxin (CDT) | A protein composed of the subunits coded by genes cdtA, cdtB, and cdtC  
*Cdt* B encodes the enzymatic part of the toxin  
*cdtA* and *cdtC* encode subunits responsible for binding the toxin to the membrane of an eukaryotic cell  
Subunits CdtA, CdtB, and CdtC necessary for correct function of the toxin | [56,52,57] |

[a] for *C. jejuni;* [b] for *Campylobacter* genus
Table 2. Prevalence of *Campylobacter* isolates from Pigs in few countries

| Country         | Samples types     | Samples tested | Prevalence% | % of genes/species | Detection procedure | References |
|-----------------|-------------------|----------------|-------------|--------------------|---------------------|------------|
| Poland          | Pork chops        | 151            | 19 (12.6)   | (47.4) *C. jejuni* | PCR                 | [39]       |
|                 |                   |                |             | 10 (52.6) *C. Coli*|                     |            |
| Ghana (Kumasi)  | Pigs Carcass      | 102            | (36.3)      | *Campylobacter* spp| Cultural            | [58]       |
| Ivory Coast     | Pigs faeces       | 270            | 3 (1.1)     | 1 (0.37) *C. jejuni*| Cultural            | [59]       |
|                 |                   |                |             | 2 (0.74) *C. coli* |                     |            |
| Brittany, France| Pigs caeca        | 582            | 86 (14.8)   | *C. coli*          | Multiplex PCR       | [60]       |
| Dannemark       | Pigs rectal faecal| 47             | /           | 29 *C. jejuni*      | PCR                 | [61]       |
|                 |                   |                |             | 0.3 – 46 *C. coli* |                     |            |
| 10 U.S states   | Pigs faecal       | 838            | 472 (56.3)  | *Campylobacter* spp| Cultural            | [62]       |
| USA             | Pigs feces with diarrhea | 155          | 128 (82.6) | 75 *C. coli*        | PCR                 | [63]       |
|                 |                   |                |             | 25 *C. jejuni*      |                     |            |
Table 3. Biochemical tests used for identification of the 4 thermotolerant *Campylobacter* species

|                          | *C. jejuni* | *C. coli* | *C. lari* | *C. upsaliensis* |
|--------------------------|-------------|-----------|-----------|------------------|
| Culture à 42°C           | +           | +         | +         | +                |
| Oxydase                  | +           | +         | +         | +                |
| Catalase                 | +           | +         | +         | - or low         |
| Hydrolysis of hippurate  | +           | -         | -         | -                |
| nalidixic Acid (disc 32µg) | S     | R         | R         | S                |
| Cephalotine (disc 32µg)  | R           | R         | R         | S                |

Table 4. Antimicrobial resistances of *Campylobacter* isolated from pigs in few studies

| Country     | Sources                        | Species       | Antibiotics       | % Resistance | References |
|-------------|--------------------------------|---------------|-------------------|--------------|------------|
| Poland      | Pork (chops, meat)             | *C. coli*     | Ciprofloxacin     | 100          | [39]       |
|             |                                |               | Tetracycline      | 64.3         |            |
|             |                                |               | Gentamycin        | 10.7         |            |
|             |                                |               | Erythromycin      | 3.6          |            |
|             |                                |               | Azythromycin      | 7.2          |            |
| U.S Regions | Pork (pré, post evisceration)  | *Campylobacter* spp | Ciprofloxacin | 2.2          | [62]       |
|             |                                |               | Tetracycline      | 64.5         |            |
|             |                                |               | Erythromycin      | 47.9         |            |
|             |                                |               | Nalidixic acid    | 23.5         |            |
|             |                                |               | Chloramphenicol   | 11.5         |            |
|             |                                |               | Gentamycin        | 0.6          |            |
| Canada      | Pork (feces, meat)             | *C. coli*     | Clindamycine      | 59           | [64]       |
| Quebec      |                                |               | Erythromycin      | 61           |            |
|             |                                |               | Streptomycin      | 67           |            |
|             |                                |               | Gentamycin        | 5            |            |
|             |                                |               | Tetracycline      | 68           |            |
|             |                                |               | Ciprofloxacin     | 11           |            |

Fig. 1. Scanning electron microscope image of *Campylobacter jejuni*, illustrating its corkscrew appearance and bipolar flagella

Source: VirginiaMaryland Regional College of Veterinary Medicine, Blacksburg, Virginia
6. APPROACH TO PREVENT THE SPREAD OF CAMPYLOBACTER FROM PIGS TO THE ENVIRONMENT

Animal production and management systems plays an important part in Campylobacter control and must be carefully considered. Cameroon has no national surveillance programs on Campylobacter. Cameroon does not have slaughterhouses meeting international standards. According to SODEPA, Yaounde only has 02 slaughterhouses and several killings. To better control and limit the spread of Campylobacter, it would be wise to insist on hygiene measures. Butchers must wear personal protective equipment (PPE). Despite the lack of slaughterhouses, the killings should improve their work surfaces to limit the contamination of meat. Applying biosecurity interventions at swine production sites has resulted in different levels of success in different countries [65-67]. In Cameroon it would be important to minimise human-animal contact, practice personal and environmental hygiene, and seek proper medical care for sick persons in households in order to minimise risks of transmission. To reduce the risk of campylobacteriosis, careful management practices focus on innovative methods to avoid cross-contamination from raw meat products. Predominantly, the reduction of contamination of raw meats is handled at the processing plants through a post-harvest cleaning process. Pre-chilled carcasses that harbor Campylobacter may lead to contamination of retail consumer products [68,69].

7. CONCLUSION

To the best of our knowledge, this is the first review of bacteriological profile of Campylobacter spp isolated from pigs, in Yaounde Cameroon. Campylobacter coli is the more common Campylobacter species recovered from pigs. High resistance rates for tetracycline, fluoroquinolones, and emergence of MDR isolates from pork sample are reported. Moreover, a high level of resistance to ciprofloxacin and tetracycline among C. jejuni and C. coli species indicate the reduced clinical utility of these antibiotics for the treatment of patients. Pigs are also well-recognized as potential carriers of Campylobacter spp, particularly Campylobacter coli, yet enteric disease in swine associated with infection by these bacteria is considered uncommon and diagnosis has historically been based upon exclusion of other causes. It is crucial that education in areas such as microbiology, sanitation, hygiene, food science, good agricultural and good manufacturing practices should be considered as necessary in slaughterhouses/killings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. AFSSA (Agence Française De Sécurité Sanitaire Des Aliments), Inventaire du réseau Salmonella, Sérotypage et sensibilité aux antibiotiques 2004, Maison-Alfort : Edition AFSSA : 2006 ;113.
2. EFSA, Zoonose d’origine alimentaire. 2014,4(1): DOI:10.2805/50820, ISBN : 978-92-9199-562-2
3. Fosse J, Laroche M, Rossero A, Seeger H, Magras C et al. Suivi de la contamination de lots de porcs par Staphylococcus aureus et Yersinia enterocolitica de l’élevage à l’abattoir: une étude exploratrice, Revue Méd. Vét. 2010;161(1):20–29
4. European Food Safety Authority (EFSA), European Centre for Disease Prevention and Control (ECDC). The European union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2015. EFSA J. 2016;14:04634.
5. Karesh WB, Dobson A, Lloyd Smith JO, Lubroth J, Dixon MA, Bennett M, et al. Ecology of zoonoses: Natural and unnatu ral histories. Lancet. 2012;380:1936–1945.
6. Wilson DJ, Gabriel E, Leatherbarrow AJH, Cheesbrough J, Gee S, Bolton E, et al. Tracing the source of campylobacteriosis. PLoS Genet. 2008;4:1–9.
7. Sheppard SK, Dallas JF, Strachan NJC, Mac Rae M, Mc Carthy ND, Wilson DJ, et al. Campylobacter genotyping to determine the source of human infection. Clin. Infect. Dis. 2009;48:1072–1078.
8. European Food Safety Authority. The community summary report on trends and sources of zoonoses, zoonotic agents, antimicrobial resistance and foodborne outbreaks in the European Union in 2005. EFSA J. 2006;9:4:288.
9. Altekruse SF, Stern NJ, Fields PI, Swerdlow DL. Campylobacter jejuni—An
emerging foodborne pathogen. Emerg. Infect. Dis. 1999;5:28–35.
10. Nguyen, H. Acanthamoeba-campylobacter interactions; University of Ottawa: Ottawa, ON, Canada; 2001.
11. Australian national notifiable diseases surveillance system; number of notifications for all diseases by year, Australia, 1991 to 2009 and Year-to-Date Notifications: for; Australian Department of Health and Aging: Adelaide, Australia; 2010.
12. Gharst G, Oyarzabal OA, Hussain SK. Review of current methodologies to isolate and identify Campylobacter spp. from foods. J. Microbiol. Methods 2013;95:84–92.
13. Padungton P, Kaneene JB. Campylobacter spp. in humans, chickens, pigs and their antimicrobial resistance. J. Vet. Med. Sci. 2003;65:161–170.
14. Adams MR, Moss MO. Food microbiology; The Royal Society of Chemistry: Cambridge, UK; 2008.
15. EFSA. The European Union summary report on trends and sources of zoonoses, zoonotic agents and food—borne outbreaks in 2017. EFSA J. 2018;16:5500.
16. Kashoma IP, Kassem II, John J, Kessy BM, Gebreyes W, Kazwala RR, et al. Prevalence and antimicrobial resistance of campylobacter isolated from dressed beef carcasses and raw milk in Tanzania. Microb. Drug. Resist. 2016;22:40–52.
17. Wieczorek K, Osek J. Antimicrobial resistance and genotypes of Campylobacter jejuni from pig and cattle carcasses isolated in Poland during 2009–2016. Microb. Drug. Resist. 2018;24:680–684.
18. Wysok B, Wojtacka J. Detection of virulence genes determining the ability to adhere and invade in campylobacter spp. from cattle and swine in Poland. Microb. Pathog. 2018;115:257–263.
19. Korsak D, Ma’ckiw E, Ro’zynek E, Zylowska M. Prevalence of campylobacter spp. in retail chicken, Turkey, Pork, and beef meat in Poland between 2009 and 2013. J. Food Prot. 2018;78:1024–1028.
20. Narvaez Bravo C, Taboada EN, Mutschall SK, Aslam M. Epidemiology of antimicrobial resistant Campylobacter spp. isolated from retail meats in Canada. Int. J. Food Microbiol. 2017;17:43–47.
21. EFSA. The European Union summary report on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food in 2017. EFSA J. 2019;17:5598.
22. Park SF. The physiology of Campylobacter species and its relevance to their role as foodborne pathogens. Int J Food Microbiol. 2000;74:177–188.
23. Dasti JI, Taren AM, Lugert R, Zautner AE, Gross U. Campylobacter jejuni: A brief overview on pathogenicity-associated factors and disease-mediating mechanisms. Int. J. Med. Microbiol. 2010;300: 205–211.
24. Carvalho AC, Ruiz Palacios GM, Ramos Cervantes P, Cervantes LE, Jiang X, Pickering LK. Molecular characterization of invasive and noninvasive Campylobacter jejuni and Campylobacter coli isolates. J. Clin. Microbiol. 2001;39:1353–1359.
25. Hickey TE, Mcveigh AL, Scott DA, Michielutti RE, Bixby A, Carroll SA et al. Campylobacter jejuni Cytolethal distending toxin mediates release of interleukin-8 from intestinal epithelial cells. Infect. Immun. 2000;68:6535–6541.
26. Tresse O, Alvarez Ordonez A, Connerton IF. Editorial: About the Food borne Pathogen Campylobacter. Front Microbiol. 2017; 8:1908.
27. Penner JL. The genus Campylobacter: A decade of progress. Clin Microbiol Rev 1988;1:157–72.
28. Ketyley JM. Pathogenesis of enteric infection by Campylobacter. Microbiology 1997; 143:5–21.
29. Nachamkin I. Campylobacter and Arcobacter. In: Manual of clinical microbiology. 6th ed. Washington: ASM Press. 1995;483–91.
30. Hana Trigui, Valeria E Paquet, Steve J Charrette and Sébatiens P. Faucher. Packaging of campylobacter jejuni into multilamellar bodies by the ciliate 2 tetrahya mena pyriformis. Appl. Environ. Microbiol ; 2016. DOI:10.1128/AEM.03921-15.
31. Alger T, Gaul F, Kasimt S, Gurtler M, Mielke H, Linnebur M, et al. Prevalences and transmission routes of Campylobacter spp. strains within multiple pig farms. Vet Microbiol. 2005;108:251–61.
32. Jensen AN, Dalsgaard A, Baggesen DL, Nielsen EM. The occurrence and characterization of Campylobacter jejuni and C. coli in organic pigs and their outdoor environment. Vet Microbiol. 2006;116:96–105.
33. Young CR, Harvey R, Anderson R, Nisbet D, Stanker LH. Enteric colonization
following natural exposure to Campylobacter in pigs. Res Vet Sci. 2000;68:75–8.

34. Gundogdu O, Bently SD, Holden MT, Parkhill J, Dorrell N, Wren BW. Reannotation and re-analysis of the Campylobacter jejuni NCTC11168 genome sequence. BMC Genomics 2007;8:471–472.

35. Altekruse SF, Stern NJ, Fields PI, Swerdlow DL. Campylobacter jejuni and emerging foodborne pathogen. Emerg. Infect. Dis. 1999;5:28–35.

36. Coker O, Akitoye I, Raphael D, Thomas N, Bolaji A, Kehinde O, et al. Human campylobacteriosis in developing countries. Emerg. Infect. Dis. 2002;8:237–243.

37. Laprade N, Cloutier M, Lapen DR, Topp E, Wilkes G, Villemur R, et al. Detection of virulence, antibiotic resistance and toxin (VAT) genes in Campylobacter species using newly developed multiplex PCR assays. J Microbiol. Methods. 2016;124:41–47.

38. Klanˇcnik A, Vu´ckovi´c d, Jamnik P, Abram M, Možina SS. Stress Response and Virulence of Heat Stressed Campylobacter bacter jejuni. Microbes Environ. 2014;29:338–345.

39. Malgorzata Andrzejewska, Bernadeta Szczepa´nska, Dorota Spica and Jacek J Klawe. Prevalence, virulence and antimicrobial resistance of campylobacter spp. in raw milk, beef and porkmeat in Northern Poland. Foods. 2019;8:420. DOI:10.3390/foods8090420

40. Harvey RB, Young CR, Ziprin RL, Hume ME, Genovese KJ, Anderson RC, et al. Prevalence of campylobacter spp isolated from the intestinal tract of pigs raised in an integrated swine production system. J Am Vet Med Assoc. 1999;215:16014.

41. Taylor DJ. Miscellaneous bacterial infections: Campylobacter. In: Zimmerman JJ, Karriker LA, Ramirez A, Schwartz KJ, Stevenson GW, editors. Diseases of swine. 10th ed. Ames, IA: Wiley Blackwell. 2012:8724.

42. Pearce RA, Wallace FM, Call JE, Dudley RL, Oser A, Yoder L, et al. Prevalence of Campylobacter within a swine slaughter and processing facility. J Food Prot 2003;66:1550–6.

43. Malakauskas M, Jorgensen K, Nielsen EM, Ojeniyi B, Olsen JE. Isolation of campylobacter spp. from a pig slaughterhouse and analysis of cross contamination. Int J Food Microbiol. 2006;108:295–300.

44. Niesen EM, Engberg J., Madsen M. Distribution of serotypes of Campylobacter jejuni and C.coli from Danish patients, poultry, cattle and swine. FEMS Immunol. Med.Microbiol. 1997;19:47–56.

45. Reina J, Munoz C, Serra A. Acta Gastro enterol belgi Suppl. 1993;56:22.

46. WHO. The Global View of Campylobacteriosis; World Health Organization: Geneva, Switzerland, 2013;69.

47. Moore JE, Barton MD, Blair IS, Corcoran D, Dooley JS, Fanning S, et al. The epidemiology of antibiotic resistance in Campylobacter. Microbes Infect. 2006 ;8:1955–1966.

48. Jonker A, Picard JA. Antimicrobial susceptibility in thermophilic Campylobacter species isolated from pigs and chickens in South Africa. J. S. Afr. Vet. Assoc. 2010;81:228–236.

49. Ghunaim H, Behnke JM, Aigha I, Sharma A, Doiphode SH. Analysis of resistance to antimicrobials and presence of virulence/stress response genes in Campylobacter isolates from patients with severe diarrhoea. PLoS ONE. 2015;10: 0119268.

50. Jonker A, Picard JA. Antimicrobial susceptibility in thermophilic Campylobacter species isolated from pigs and chickens in South Africa. J S Afr Vet. Assoc. 2010;81:228–236.

51. Reddy S, Zishiri OT. Detection and prevalence of antimicrobial resistance genes in campylobacter spp. Isolated from chickens and humans. Onderstepoort J Vet Res. 2017;84:1–6.

52. Bolton, D.J. Campylobacter virulence and survival factors. Food Microbiol. 2016;48: 99–108.

53. Epps SVR, Harvey RB, Hume ME, Phillips TD, Anderson RC, Niset DJ. Foodborne campylobacter: Infections, metabolism, pathogenesis and reservoirs. Int. J. Environ. Res. Public Health. 2013;10: 6292–6304.

54. Kawai F, Paek S, Choi KJ, Prouty M, Kanipes MI, Guerry P, et al. Crystal structure of JlpA, a surface-exposed lipoprotein adhesin of Campylobacter jejuni. J. Struct. Biol. 2012;177:583–588.

55. Koolman L, Whyte P, Burgess C, Bolton D. Virulence gene expression, adhesion and invasion of Campylobacter jejuni exposed to oxidative stress (H2O). Int J Food. Microbiol. 2016;220:33–38.

56. Silva J, Leite D, Fernandes M, Mena C, Gibbs PA, Teixeira P. Campylobacter spp.
as a Foodborne Pathogen: A Review. Front. Microbiol. 2011;2:200.

57. Rokosz Chudziak N, Rastawicki W. Wybrane mechanizmy chorobotwórczości powłok Campylobacter jejuni. Med. Dosw. Mikrobiol. 2014;66:47–58. (In Polish)

58. Kariuki AB, Obiri Danso K, Frimpong EH, Krogfelt KA. Antibiotic resistance of campylobacter recovered from faeces and carcasses of healthy livestock. BioMed Res. 2017;409:1856.

59. Kouassi Eugène Koffi, Kalpy Julien Coulibaly, Nguessan Daniel Saraka, Claire Brice Valéry Senin, Haussain boka et mireille dosso. Évaluation de la qualité microbiologique des carcasses de porcs abattus à la SIVAC: Recherche de Salmonella, Yersinia et Campylobacter. Afrique science. 2020;16(1):30–38. ISSN:1813-548X, Available :http://www.afriquescience.net

60. Denis M, Chidaine B, Laisney MJ, Kempf I, Rivoal K, Mégraud F, et al. Comparison of genetic profiles of campylobacter strains isolated from poultry, pig and campylobacter human infections in Brittany, France. DOI:10.1016/j.patbio.2008.04.007

61. Jensen AN, Adalsgaard DL, Baggesen EM Nielsen. The occurrence and characterization of Campylobacter jejuni and C.coli in organic pigs and their outdoor environment. Veterinary microbiology. 2006;116:96-105. DOI : 10.1016/j.vetmic.2006.03.006

62. Daniel A Tadesse, Thomas Wittum, Peter B Bahnson, Fred DeGraves, Julie A Funk, Thakur Siddhartha, et al. Prevalence and antimicrobial resistance profile of campylo bacter spp. Isolated from conventional and antimicrobial-free swine production systems from different U.S. Regions. Food borne pathogens and disease; 2011;8:3. DOI: 10.1089/fpd.2010.0665

63. Eric Burrough, Samantha Terhorst, Orhan Sahin, Qijing Zhang. Prevalence of campylobacter spp. relative to other enteric pathogens in grow-finish pigs with diarrhea. Available:http://dx.doi.org/10.1016/j.anaerobe.2013.06.004

64. Evelyne Guévremont, Éric Nadeau, Marc Siros, Sylvain Quessy. Antimicrobial susceptibilities of thermophilic Campylobacter from humans, swine and chicken broilers. The Canadian Journal of Veterinary Research. 2006;70:81–86.

65. Goualie GB, Essoh EA, Elise Solange KN, Natalie G, Souleymane B, Lamine Sebas tien N, et al. Prevalence and antimicrobial resistance of thermophilic campylobacter isolated from chicken in Cote d’Ivoire. Int J Microbiol. 2012;150612.

66. Humphrey T, O’Brien S, Madsen M. Campylobacters as zoonotic pathogens: A food production perspective. Int J Food Microbiol. 2007;117:237–257.

67. Pieracci EG, Hall AJ, Gharpure R, Haile A, Walelign E, Deressa A et al. Prioritizing zoonotic diseases in Ethiopia using a one health approach. One Health. 2016;2:131–135.

68. Stern NJ, Robach MC. Enumeration of Campylobacter spp. in broiler feces and in corresponding processed carcasses. J Food Prot. 2003;66:1557–63.

69. Izat AL, Gardner FA, Denton JH, Golan FA. Incidence and level of Campylobacter jejuni in broiler processing. Poult Sci. 1988; 67:1568–72.

© 2020 Oyong et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history: The peer review history for this paper can be accessed here: http://www.sdiarticle4.com/review-history/65169