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# Systematic Review and Meta-Analysis of *Campylobacter* Species Contamination in Poultry, Meat, and Processing Environments in South Korea

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**Abstract:** *Campylobacter* spp. constitute a significant global threat as a leading cause of foodborne illnesses, with poultry meat as a prominent reservoir for these pathogens. South Korea is known for its diverse poultry consumption habits, and continuous outbreaks make it a matter of concern to perform a meta-analysis to identify the primary source of contamination. This systematic review and meta-analysis aimed to assess and compare the prevalence of *Campylobacter* in various poultry and meat types while also considering the importance of environmental factors in South Korea. The meta-analysis revealed that duck meat exhibited the highest prevalence of *Campylobacter*, with a pooled estimate of 70.46% (95% CI: 42.80% to 88.38%), followed by chicken meat at a pooled prevalence of 36.17% (95% CI: 26.44% to 47.91%). Additionally, our analysis highlighted the predominance of *C. jejuni* and *C. coli* in South Korea. These findings underscore the importance of implementing rigorous food safety measures and establishing robust surveillance programs in the poultry industry to mitigate the risk of *Campylobacter*-related foodborne illnesses associated with meat consumption in South Korea.

**Keywords:** *Campylobacter jejuni*; *Campylobacter coli*; prevalence; cross-contamination; foodborne-pathogens

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## 1. Introduction

*Campylobacter* is a Gram-negative, spiral-shaped, and microaerophilic pathogen commonly associated with foodborne illnesses. The optimal growth temperature range for *Campylobacter* spp. is 37–42 °C, which is close to the body temperature of warm-blooded animals [1]. The *Campylobacter* genus comprises 15 known species, and 12 have been linked to causing diseases in humans [2]. Notably, *C. jejuni* and *C. coli* account for over 95% of human *Campylobacter infections* [3]. *Campylobacter* infection can lead to long-term complications such as irritable bowel syndrome (IBS), arthritis, and Guillain–Barré Syndrome (GBS). It is estimated that 0.2 to 1.7 per 1000 individuals with diagnosed or undiagnosed *Campylobacter* infections ultimately develop GBS, accounting for 5–41% of total GBS cases [4].

*C. jejuni* contamination has emerged as a global concern, as evidenced by a comprehensive epidemiological study conducted by Kaakoush et al., 2015 [5]. The study revealed a concerning increase in cases in North America, Europe, and Australia. Furthermore, data from Africa, Asia, and the Middle East indicated a particularly high prevalence among children [6]. In the United States, the Foodborne Disease Active Surveillance Network (FoodNet) reported an annual incidence of approximately 20 cases per 100,000 individuals [7]. An outbreak of *C. jejuni* foodborne infection in 2017 in Seoul, South Korea, was associated with cross-contamination through sharing cutting boards and knives with various food items. Notably, chicken was identified as the primary source, and the bacterium was subsequently transferred to other foods, leading to a widespread outbreak [8]. Another study by Yu et al., 2010, indicated an outbreak in a middle school linked to undercooked chicken as the primary source and subsequently transferred to other foods, leading to a widespread outbreak. [9].

The upswing in foodborne *Campylobacter* infections can be attributed to various intertwined factors. Changes in food production and consumption patterns, including a surge in demand for convenience foods like poultry products, particularly chicken, and a growing tendency to eat out have bolstered *Campylobacter* infections [10]. This bacterium often contaminates chicken products and can spread through cross-contamination in both domestic and commercial kitchens [11]. The emergence of antibiotic-resistant *Campylobacter* strains further complicates treatment and prolongs illness [12]. The global movement of food and people facilitates the spread of *Campylobacter*, leading to sporadic outbreaks and widespread infections [13]. Environmental influences, such as climate change and weather conditions, also affect the prevalence of *Campylobacter* in the environment, adding to the complexity of addressing this public health challenge [14].

Analyzing the historical data allows health authorities and researchers to gain insights into the epidemiology of the disease, such as identifying high-risk areas, vulnerable populations, and seasonal variations [15]. *Campylobacter* outbreaks, despite frequent occurrences, have historically been underreported. However, an observable upward trend in their prevalence has become evident. According to the CDC, from 2004 to 2009, an average of 22 outbreaks were officially reported annually. This figure slightly increased to 31 outbreaks from 2010 to 2012 before declining to 29 from 2013 to 2017 [16]. One of the most significant case studies of Campylobacteriosis was in June 2019, when Askøy in Norway was struck by a significant waterborne outbreak, resulting in over 1500 cases of Campylobacteriosis [17]. Another large-scale outbreak was in New Zealand in 2020, stemming from a contaminated water supply, which led to an estimated 8320 cases [18], underscoring the urgency of addressing this issue globally. According to data published by the Ministry of Food and Drug Safety in South Korea, *Campylobacter* ranks as the third most prevalent food pathogen, following pathogenic *E. coli* and *Salmonella* in this decade [19]. Thus, by examining the patterns and trends of past cases, we can identify common factors, potential sources, and contamination pathways associated with Campylobacteriosis. This analysis offers crucial insights into the causes of contamination and transmission pathways, facilitating evidence-based interventions and strategies to control the disease and protect public health.

Meta-analysis with systematic reviews can offer a comprehensive perspective by amalgamating data from numerous studies and identifying knowledge gaps [20]. Systematic review employs a comprehensive and structured approach to synthesize existing research, while meta-analysis employs statistical methods to combine the outcomes of multiple studies, yielding an overall estimate of the effect of an intervention [21]. These methodologies are crucial for conducting a thorough and exhaustive evaluation of the available research on a specific topic by facilitating the consolidation and synthesis of evidence from diverse studies to enhance the statistical power and generalizability of the findings. By providing a robust summary of the available evidence, they support evidence-based decision-making processes and inform policy formulation and implementation [22]. Ultimately, these approaches benefit researchers, policymakers, clinicians, and other stakeholders by offering a reliable and evidence-based foundation for decision making and further investigation. Therefore, investigating these methodologies would be valuable in guiding future research and informing public health policies and interventions to mitigate the burden of *Campylobacter*-related illness in Korea.

Several studies have been conducted in South Korea to investigate the prevalence of *Campylobacter* contamination in various poultry and meat products. However, these studies have been limited in scope and have reported conflicting results, potentially because of differences in study design, sampling methods, or laboratory testing procedures. Despite efforts to mitigate *Campylobacter* infection in meat products by implementing food safety regulations and guidelines for handling and processing, concerns regarding the prevalence of contamination persist [23]. Therefore, gathering and analyzing all available data from previous studies becomes imperative to facilitate further research in this area. This study aims to determine the prevalence of *Campylobacter* spp. in poultry and meat products in South Korea. This study also aims to consider the environmental conditions under which the products were processed, as these factors may also play a significant role in meat contamination. By conducting a comprehensive analysis of existing studies, this research endeavors to provide a consolidated and robust assessment of the prevalence of *Campylobacter* contamination in poultry and meat products in South Korea, accounting for relevant environmental factors.

## 2. Materials and Methods

### *2.1. Search Strategy*

This systematic review strictly adhered to the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analysis, http://www.prisma-statement.org/, accessed on 14 March 2023). PRISMA 2020 guidelines were specifically employed for "new systematic reviews which included searches of databases and registers only." The implementation of PRISMA 2020 aimed to uphold high reporting standards and minimize bias in the review's findings [24]. Thus, we meticulously followed the PRISMA 2020 guidelines to ensure the transparency, reliability, and rigor of our methodology.

In order to compile a comprehensive body of literature, an exhaustive search was conducted across multiple databases. The search encompassed two widely recognized English databases, Web of Science and PubMed. Additionally, to include relevant studies in South Korea, three Korean-language-based databases were explored: DBpia (https://www.dbpia.co.kr/, accessed on 7 March 2023), RISS (http://www.riss.kr/index.do, accessed on 7 March 2023) and ScienceON (https://scienceon.kisti.re.kr/, accessed on 7 March 2023).

The search algorithm used was "*Campylobacter*" and "Korea". After retrieving research from each database, the reference management software EndNote 20 (Clarivate Analytics, Boston, MA, USA) was employed to facilitate the de-duplication and screening processes in March 2023.

### *2.2. Eligibility Criteria*

A two-level screening procedure was conducted from March to April 2023: title comprisal and abstract screening (Level 1), followed by full-text screening (Level 2). Various criteria aligned with the study's specific objectives were carefully considered during the data screening and selection process at the searching stage. The authors (HJ Je, DW Kim, HS Hur, AL Kim, and EJ Seo) independently conducted the selection process, rigorously applying the predetermined criteria to each retrieved article. The data were assembled in a Microsoft Excel sheet, and screening was performed according to the parameters set for exclusion and inclusion criteria. In cases where discrepancies in the selection arose, all authors engaged in constructive discussions to reach a consensus, ensuring a meticulous and unbiased assessment of the data.

### *2.3. Inclusion Criteria*

The inclusion criteria encompassed studies investigating the presence and contamination of *Campylobacter* in poultry and meat products (chicken, duck, beef, and pork), and contamination by environmental sources (feces, washing water, and equipment). Additionally, articles unrelated to the prevalence, including those centered on antimicrobial research, detection methods, risk analysis, pathogenesis, and other microbiological studies, were excluded. No restrictions were set on the year of publication or the study period; however, articles not in Korean or English were excluded during the initial screening phase.

Meticulously and independently, the authors cross-checked each article's eligibility based on the predefined criteria, ensuring consistency in the selection process. Ultimately, only articles meeting the specific inclusion criteria were considered for this study, and their relevant details were diligently recorded systematically.

### *2.4. Exclusion Criteria*

Exclusion criteria in this study were research articles that did not demonstrate the prevalence of *Campylobacter*. Additionally, studies focusing on other bacterial contaminations such as other food products, detection methods different from standard methods, antimicrobial research, and abstract-only papers were excluded. The detection methods excluded from this study were detection via PCR and metagenome analysis without any enrichment process. Furthermore, sampling sites outside South Korea and studies published in languages other than Korean or English were also excluded, but no limitation was made regarding publication years.

### *2.5. Data Extraction*

In order to ensure accuracy and reliability, data extraction was carried out by employing a consensus-based approach to minimize the potential for individual bias and enhance the overall quality of the systematic review. Authors (HJ Je, S Singh) extracted data including the sampling period; food type; environmental factors; and the presence of *Campylobacter* spp., *C. jejuni*, or *C. coli* and summarized them in the Microsoft Office Excel software 365, version 2016 (Microsoft Corporation, Redmond, WA, USA). Samples were classified into two groups: food (raw chicken, duck, beef, pork, ham, and meat products) and environmental factors (feces, washing water, and equipment) for meta-analysis.

### *2.6. Risk of Bias for Quality Assessment*

A risk of bias assessment was conducted using a questionnaire approach, with scores calculated based on the answers. Each selected study was evaluated based on specific questions, and scores were assigned accordingly (2 points for "YES," 0 points for "NO," and 1 point for "UNSURE") [25]. The total scores ranged from 0 to 12, with scores $\geq 9$ considered high quality, scores $\geq 6$ considered moderate quality, and less than 6 considered low-quality studies [26,27]. The questions were as follows:

Q1. Was the research question/objective clearly described and stated?
Q2. Was the period of study clearly stated?
Q3. Was the sample population clearly specified?
Q4. Was the sampling method described in detail?
Q5. Was the same laboratory method used for all samples in the study?
Q6. Was the isolation method tested based on a standard bacteriological and/or molecular procedure?

### *2.7. Data Analysis*

Statistical analysis was performed using the Comprehensive Meta-Analysis Software program version 4 (Biostat Inc., Englewood, NJ, USA). The prevalence of *Campylobacter* and corresponding 95% confidence intervals (CIs) were calculated based on the total number of tested and positive samples. A forest plot was generated to visualize the estimated prevalence and distribution for individual studies and the pooled study estimate within the 95% confidence interval. A random effects model was employed for the meta-analysis, which accounts for expected heterogeneity among the included studies. Heterogeneity levels were assessed using Cochran's Q statistic and the I-squared ($I^2$) inconsistency index. Heterogeneity levels of $I^2$ were categorized as low (less than 40%), moderate (between 25% and 50%), substantial (between 50% and 90%), and considerable (greater than 75%) heterogeneity [28].

The groups considered for the study included different types of meat, including beef, pork, chicken, and duck. Since environmental factors play an important role in contamination, various factors like feces, equipment, and washing water were also considered. Equipment includes bedding for cattle, chopping boards, drawers, and knives. The data were also divided into specific detection values for *C. jejuni* and *C. coli* to find which species had more prevalence. The study also included the detection method of using enrichment and selective media techniques.

Publication bias was evaluated using a funnel plot, which could indicate the asymmetrical distribution of effect sizes and standard errors, suggesting the presence of publication bias. Statistical significance for publication bias was determined using a threshold of $p < 0.05$ [29,30].

## 3. Results

### 3.1. Search Results and Risk of Bias

In this study, a total of 1045 studies were considered from the databases RISS, DBpia, and Science ON in Korean search engines and Web of Science and PubMed in international search engines after duplicate removal (Figure 1). Title and abstract screening was performed thereafter, resulting in 70 full-text articles. After the full-text screening, 31 studies between 1985 to 2020 were considered for further systematic review and meta-analysis (Table 1). The studies considered in the meta-analysis were confirmed as high (22/32) to moderate (10/32) quality studies, with no low (0/32) quality studies using risk of bias assessment (Figure S1).

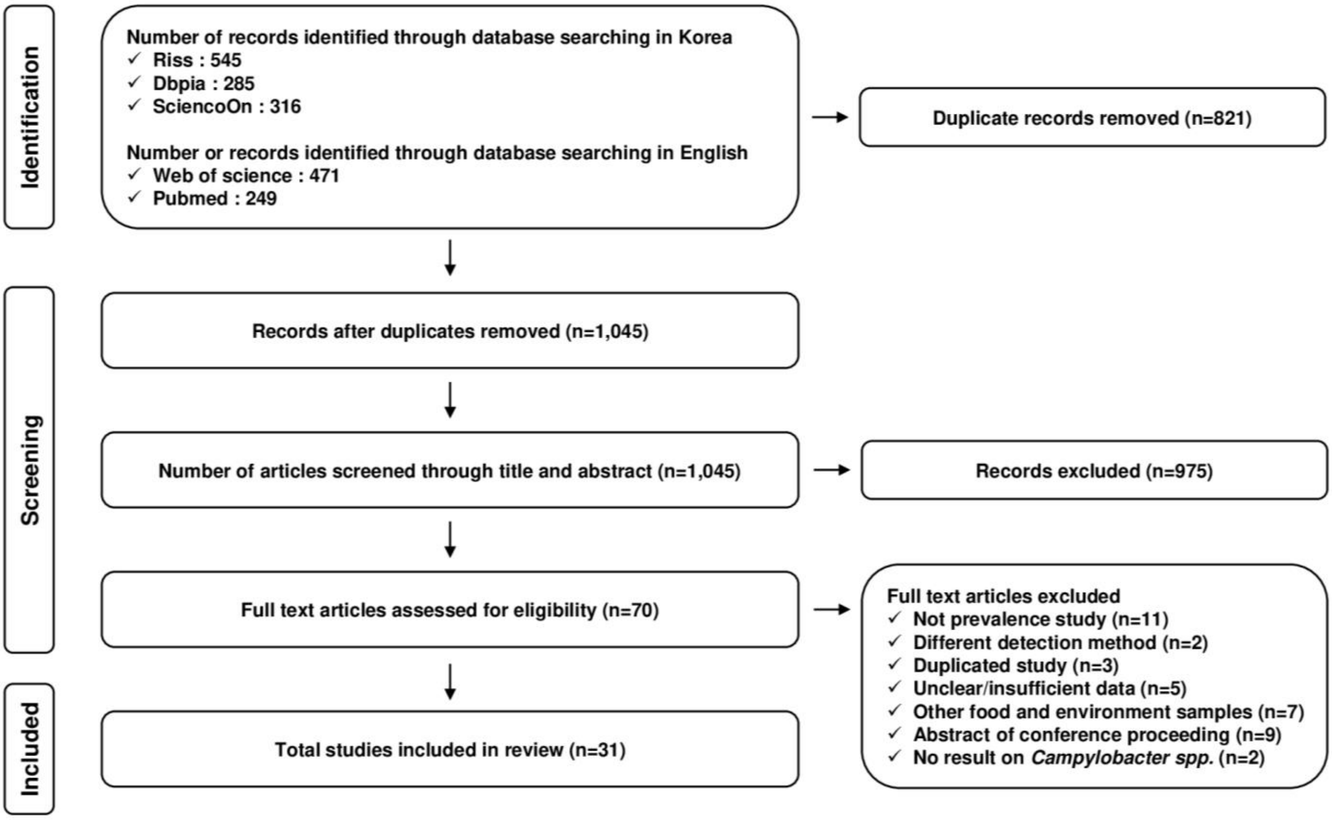


**Figure 1.** Flowchart of the study selection process followed by a PRISMA 2020 flow diagram for systematic reviews.

**Table 1.** Characteristics of studies with the prevalence of *Campylobacter* spp. in South Korea.

| Reference | Sampling Period (YYYY. MM) | Sample Group | Sample | Total Sample Size | *Campylobacter* spp. (No. of Positive Samples) | *C. jejuni* (No. of Positive Samples) | *C. coli* (No. of Positive Samples) | Detection Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Enrichment Medium | Selective Medium |
| Kang et al., 1999 [31] | 1996.03–1998.10 | Food | Beef | 300 | 45 | 0 | 0 | VTP-Brucella FBP broth | Campy BAP |
| | | | Beef (frozen) | 50 | 1 | 0 | 0 | | |
| | | | Pork | 288 | 68 | 0 | 0 | | |
| | | | Pork (frozen) | 50 | 1 | 0 | 0 | | |
| | | | Chicken | 300 | 70 | 0 | 0 | | |
| | | | Chicken (frozen) | 50 | 0 | 0 | 0 | | |
| Kang et al., 1985 [32] | 1985.03–1985.05 | Food | Chicken | 449 | 79 | 79 | 0 | VTP-Brucella FBP broth | Campy BAP |
| | | Environment | Feces of chicken | 278 | 67 | 67 | 0 | | |
| Kim et al., 2013 [33] | 2010.09–2010.12 | Environment | Feces of duck | 430 | 112 | 112 | 0 | CEB | CBFA |
| Kim and Chong, 1996 [34] | 1996.01–1996.08 | Food | Chicken | 313 | 190 | 0 | 0 | - | BM |
| Kim et al., 2020 [35] | 2015 | Food | Chicken | 30 | 23 | 12 | 11 | 2 × BD | PA |
| | | | Chicken (cut) | 30 | 23 | 18 | 4 | | |
| Kim et al., 1986 [36] | - | Environment | River and lake waters | 48 | 1 | 1 | 0 | BM | BM |
| Na et al., 2007 [37] | - | Environment | Feces of chicken | 80 | 0 | 0 | 0 | HB | Modified CBFA |
| | | | Chicken wash water | 20 | 9 | 0 | 0 | | |
| Park et al., 2002 [38] | 2000.05–2000.10 | Food | Beef | 145 | 0 | 0 | 0 | SCB | CBFA |
| Lee et al., 2015 [39] | 2013.02–2014.10 | Food | Chicken | 204 | 30 | 15 | 15 | BD | *Campylobacter* agar base, blood agar |
| Yang et al., 2014 [40] | 2009.06–2010.01 | Environment | Feces of duck | 117 | 99 | 93 | 6 | BB | MCCDA-PA, blood agar |
| Oh et al., 1988 [41] | 1987.06–1987.09 | Environment | Feces of chicken | 120 | 41 | 41 | 0 | BB | Campy BAP |
| | | Food | Chicken | 20 | 9 | 9 | 0 | | |
| | | Food | Chicken (frozen) | 20 | 11 | 11 | 0 | | |
| | | Environment | Chilling water | 20 | 12 | 12 | 0 | | |
| | | Environment | Knife | 20 | 9 | 9 | 0 | | |
| Woo, 2005 [42] | 1996.03–1996.10 | Food | Chicken | 25 | 16 | 0 | 0 | - | - |
| Woo, 2007 [43] | 2007 | Food | Chicken | 115 | 43 | 43 | 0 | - | - |
| Hong et al., 2002 [44] | 1997 | Food | Pork | 296 | 24 | 0 | 0 | - | Campy brucella agar |
| An et al., 2018 [45] | 2012.08–2013.09 | Environment | Feces of cattle | 266 | 68 | 68 | 0 | - | MCCDA |
| | | | Bedding sample of cattle | 32 | 3 | 3 | 0 | | |
| Cho et al., 2012 [46] | 2011.02–2011.10 | Food | Beef | 52 | 0 | 0 | 0 | BD | CBFA |
| | | | Pork | 62 | 0 | 0 | 0 | | |
| | | | Chicken | 41 | 0 | 0 | 0 | | |

**Table 1.** *Cont.*

| Reference | Sampling Period (YYYY. MM) | Sample Group | Sample | Total Sample Size | *Campylobacter* spp. (No. of Positive Samples) | *C. jejuni* (No. of Positive Samples) | *C. coli* (No. of Positive Samples) | Detection Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Enrichment Medium | Selective Medium |
| Chon et al., 2018 [47] | 2014.06–08,<br>2014.12–2015.02 | Food | Chicken | 120 | 38 | 0 | 0 | 2 × blood-free BD | MCCDA |
| | | | Duck | 120 | 93 | 0 | 0 | | |
| Chon et al., 2016 [48] | 2015.01–2015.02 | Food | Pork by-product | 95 | 5 | 0 | 0 | BD | MCCDA |
| | | | Chicken by-product | 159 | 8 | 0 | 0 | | |
| Han et al., 2007 [49] | 2004.02–2004.09 | Food | Chicken | 265 | 181 | 100 | 94 | BD | Abeyta–Hunt–Bark agar |
| Hong et al., 2007 [50] | 2001.09–2006.04 | Food | Chicken | 270 | 220 | 140 | 170 | BD | CBFA |
| | | | Pork | 250 | 3 | 3 | 3 | | |
| | | | Beef | 250 | 4 | 0 | 4 | | |
| Hong and Lim, 2015 [51] | - | Environment | Dishcloth | 50 | 0 | 0 | 0 | Modified BD | MCCDA |
| | | | Chopping board | 50 | 0 | 0 | 0 | | |
| | | | Drawer of Refrigerator | 50 | 0 | 0 | 0 | | |
| Jeong et al., 2017 [52] | - | Food | Beef | 80 | 1 | 1 | 0 | - | MCCDA + Preston enrichment broth |
| Kim et al., 2019 [53] | 2016.12–2017.03<br>2017.04–06 | Food | Chicken | 133 | 67 | 51 | 29 | BD | PA |
| | | | Duck | 61 | 38 | 30 | 19 | | |
| Kim et al., 2010 [54] | 2004–2008 | Food | Poultry meat (domestic) | 475 | 375 | 219 | 156 | PB | CBFA |
| | | | Poultry meat (imported) | 867 | 217 | 173 | 44 | | |
| Kim et al., 2017 [55] | 2013.12–2014.03 | Food | Chicken | 124 | 37 | 0 | 0 | 2 × BD | PA |
| Lee et al., 2015 [56] | - | Food | Pressed ham with antimicrobials | 80 | 0 | 0 | 0 | BD | Modified CCDA-PA and MCCDA |
| | | | Pressed hams without antimicrobials | 80 | 0 | 0 | 0 | | |
| | | | Fermented–cured hams | 40 | 0 | 0 | 0 | | |
| Lee et al., 2017 [57] | 2014.06–08,<br>2014.12–2015.02 | Food | Chicken | 152 | 15 | 0 | 0 | 2 × blood-free BD | MCCDA |
| | | | Duck | 154 | 30 | 0 | 0 | | |
| Lee et al., 2019 [23] | - | Food | Patties | 96 | 0 | 0 | 0 | - | Modified CCDA-PA |
| | | | Meatballs | 73 | 0 | 0 | 0 | | |
| | | | Cutlets | 55 | 0 | 0 | 0 | | |
| Choi et al., 2012 [58] | 2010.01 | Environment | Feces of pig | 100 | 55 | 33 | 22 | - | PA |

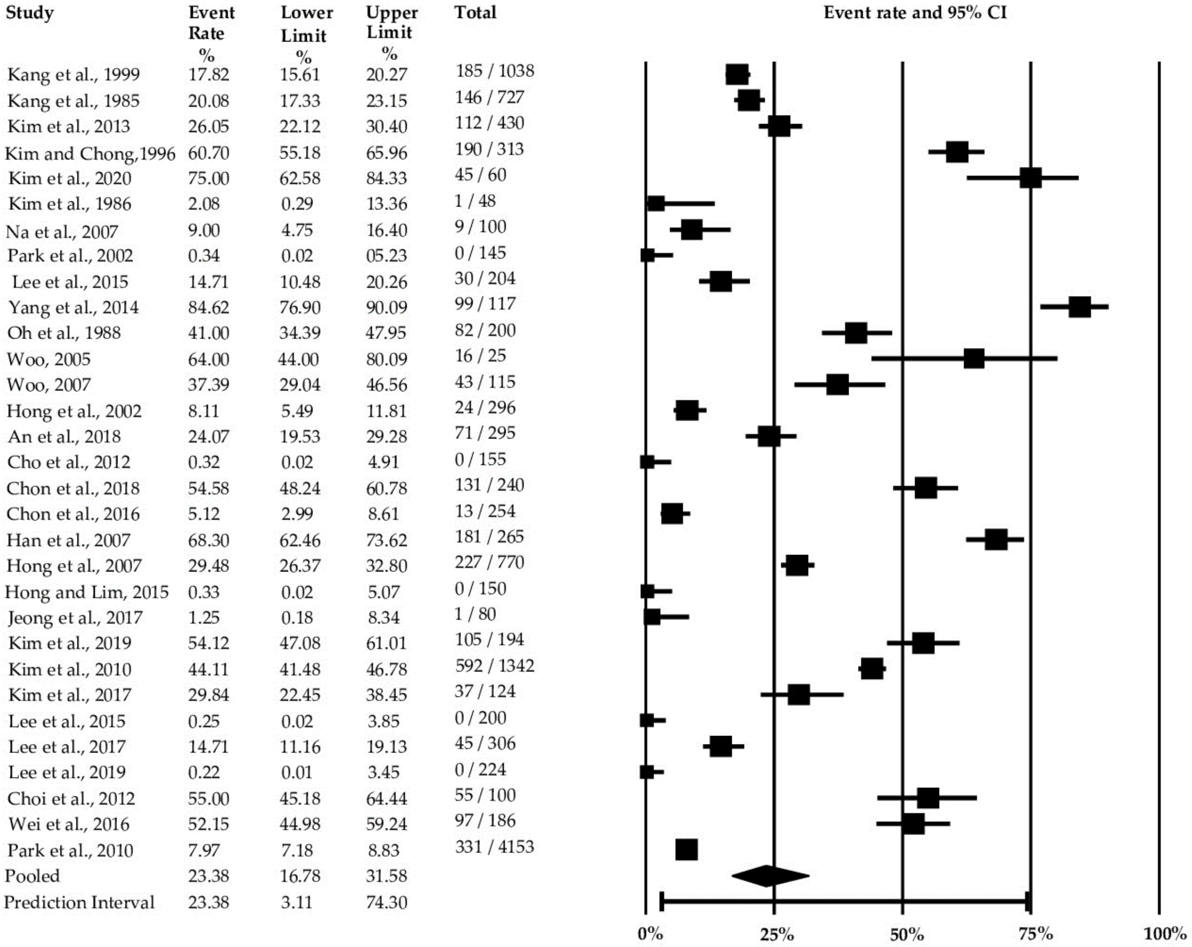
**Table 1.** *Cont.*

| Reference | Sampling Period (YYYY. MM) | Sample Group | Sample | Total Sample Size | *Campylobacter* spp. (No. of Positive Samples) | *C. jejuni* (No. of Positive Samples) | *C. coli* (No. of Positive Samples) | Detection Methods | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Enrichment Medium | Selective Medium |
| Wei et al., 2016 [59] | 2013.01–03 | Food | Chicken | 80 | 47 | 42 | 5 | 2 × BD | MCCDA |
| | | | Duck | 52 | 0 | 39 | 13 | | |
| | | | Duck (sliced) | 54 | 50 | 43 | 6 | | |
| Park et al., 2010 [60] | 2005–2009 | Food | Beef (domestic) | 630 | 1 | 1 | 0 | PB | CBFA |
| | | | Pork (domestic) | 644 | 1 | 1 | 0 | | |
| | | | Chicken (domestic) | 609 | 187 | 125 | 62 | | |
| | | | Duck (domestic) | 70 | 32 | 18 | 14 | | |
| | | | Beef (imported) | 711 | 0 | 0 | 0 | | |
| | | | Pork (imported) | 943 | 1 | 1 | 0 | | |
| | | | Chicken (imported) | 546 | 109 | 83 | 26 | | |

Abbreviations: YYYY= year, MM= month, BD = Bolton broth, MCCDA = modified charcoal cefoperazone deoxycholate agar, CEB = *Campylobacter* enrichment broth, BB = Brucella broth, PB/PA = Preston broth/Preston Agar, BM = Butzler medium, SCB = Skirrow's *Campylobacter* selective broth, HB = Hunt broth, CBFA = *Campylobacter* blood-free agar, Campy BAP = BD *Campylobacter* agar + ASB, VTP = vancomycin–trimethoprim–polymyxin B, FBP = Brucella–fructose-1,6-bisphosphate.

### 3.2. Overall Meta-Analysis

The comprehensive meta-analysis considered all the relevant food and environmental factors. Among the 31 studies, the overall pooled prevalence of *Campylobacter* was 23.38% (95% CI: 16.78–31.58%) (Figures 2 and S2). The analysis showed an $I^2$ value of 98% ($p <$ 0.001), indicating significant variability among the studies (Table 2). When considering the food groups, ducks exhibited the highest prevalence of *Campylobacter* spp. at 70.46% (95% CI: 42.80–88.38%), followed by chicken with a prevalence rate of 36.17% (95% CI: 26.44–47.19%), pork at 2.10% (95% CI:0.67–6.35%), and beef at 0.99% (95% CI: 0.20–4.71%) (Figures 3 and S3 and Table 2). The analysis also included ham and meat products such as patties, meatballs, and cutlets; however, they did not yield enough studies for meta-analysis.



| Study | Event Rate % | Lower Limit % | Upper Limit % | Total |
|---|---|---|---|---|
| Kang et al., 1999 | 17.82 | 15.61 | 20.27 | 185 / 1038 |
| Kang et al., 1985 | 20.08 | 17.33 | 23.15 | 146 / 727 |
| Kim et al., 2013 | 26.05 | 22.12 | 30.40 | 112 / 430 |
| Kim and Chong,1996 | 60.70 | 55.18 | 65.96 | 190 / 313 |
| Kim et al., 2020 | 75.00 | 62.58 | 84.33 | 45 / 60 |
| Kim et al., 1986 | 2.08 | 0.29 | 13.36 | 1 / 48 |
| Na et al., 2007 | 9.00 | 4.75 | 16.40 | 9 / 100 |
| Park et al., 2002 | 0.34 | 0.02 | 05.23 | 0 / 145 |
| Lee et al., 2015 | 14.71 | 10.48 | 20.26 | 30 / 204 |
| Yang et al., 2014 | 84.62 | 76.90 | 90.09 | 99 / 117 |
| Oh et al., 1988 | 41.00 | 34.39 | 47.95 | 82 / 200 |
| Woo, 2005 | 64.00 | 44.00 | 80.09 | 16 / 25 |
| Woo, 2007 | 37.39 | 29.04 | 46.56 | 43 / 115 |
| Hong et al., 2002 | 8.11 | 5.49 | 11.81 | 24 / 296 |
| An et al., 2018 | 24.07 | 19.53 | 29.28 | 71 / 295 |
| Cho et al., 2012 | 0.32 | 0.02 | 4.91 | 0 / 155 |
| Chon et al., 2018 | 54.58 | 48.24 | 60.78 | 131 / 240 |
| Chon et al., 2016 | 5.12 | 2.99 | 8.61 | 13 / 254 |
| Han et al., 2007 | 68.30 | 62.46 | 73.62 | 181 / 265 |
| Hong et al., 2007 | 29.48 | 26.37 | 32.80 | 227 / 770 |
| Hong and Lim, 2015 | 0.33 | 0.02 | 5.07 | 0 / 150 |
| Jeong et al., 2017 | 1.25 | 0.18 | 8.34 | 1 / 80 |
| Kim et al., 2019 | 54.12 | 47.08 | 61.01 | 105 / 194 |
| Kim et al., 2010 | 44.11 | 41.48 | 46.78 | 592 / 1342 |
| Kim et al., 2017 | 29.84 | 22.45 | 38.45 | 37 / 124 |
| Lee et al., 2015 | 0.25 | 0.02 | 3.85 | 0 / 200 |
| Lee et al., 2017 | 14.71 | 11.16 | 19.13 | 45 / 306 |
| Lee et al., 2019 | 0.22 | 0.01 | 3.45 | 0 / 224 |
| Choi et al., 2012 | 55.00 | 45.18 | 64.44 | 55 / 100 |
| Wei et al., 2016 | 52.15 | 44.98 | 59.24 | 97 / 186 |
| Park et al., 2010 | 7.97 | 7.18 | 8.83 | 331 / 4153 |
| Pooled | 23.38 | 16.78 | 31.58 | |
| Prediction Interval | 23.38 | 3.11 | 74.30 | |

**Figure 2.** Forest plot of the overall study for the prevalence of *Campylobacter* in South Korea [23,31–60].

**Table 2.** Meta-analysis results for the overall study and each food type and environment.

| Sample Type | | No. of Studies | Pooled Prevalence and 95% Interval | | | $I^2$ (%) | *p*-Value |
|---|---|---|---|---|---|---|---|
| | | | Pooled Prevalence (%) | Lower Limit (%) | Upper Limit (%) | | |
| Overall | | 31 | 23.38 | 16.78 | 31.58 | 98% | <0.001 |
| Food | Chicken | 22 | 36.17 | 26.44 | 47.19 | 97% | <0.001 |
| | Duck | 6 | 70.46 | 42.80 | 88.38 | 96% | <0.001 |
| | Beef | 8 | 0.99 | 0.20 | 4.71 | 90% | <0.001 |
| | Pork | 8 | 2.10 | 0.67 | 6.35 | 94% | <0.001 |
| Environment | Feces | 7 | 36.33 | 22.62 | 52.68 | 96% | <0.001 |
| | Washing water | 3 | 27.69 | 6.05 | 69.47 | 86% | 0.001 |
| | Equipment | 5 | 4.99 | 0.76 | 26.41 | 84% | <0.001 |

### 3.3. *Campylobacter* Prevalence in Food

Studies examining the prevalence of *Campylobacter* species in food sources, particularly poultry products, have consistently found *C. jejuni* to be more prevalent than *C. coli* [61]. Our study verified these findings, as *C. jejuni* exhibited higher prevalence rates than *C. coli* across all samples (Tables 3 and 4).

**Table 3.** Prevalence of *C. jejuni* and *C. coli* in duck.

| Author | Total Sample Size | Total Positive Samples (%) | *C. jejuni* (%) | *C. coli* (%) |
|---|---|---|---|---|
| Wei et al., 2016 [59] | 52 | 52 (100) | 39 (75.0) | 13 (25.0) |
| Wei et al., 2016 [59] | 54 | 50 (92.6) | 43 (79.6) | 6 (11.1) |
| Park et al., 2010 [60] | 70 | 32 (45.7) | 18 (25.7) | 14 (20.0) |

**Table 4.** Prevalence of *C. jejuni* and *C. coli* in chicken.

| Author | Total Sample Size | Total Positive Sample (%) | *C. jejuni* (%) | *C. coli* (%) |
|---|---|---|---|---|
| Kim et al., 2019 [53] | 67 | 67 (100) | 51 (76.1) | 29 (43.3) |
| Wei et al., 2016 [59] | 80 | 47 (58.8) | 42 (52.5) | 5 (6.3) |
| Park et al., 2010 [60] | 609 | 187 (30.7) | 125(20.5) | 62 (10.2) |
| Park et al., 2010 [60] | 546 | 109 (20.0) | 83 (15.2) | 26 (4.8) |
| Kang et al., 1985 [32] | 449 | 79 (17.6) | 79 (17.6) | 0 (0.0) |
| Kim et al., 2020 [35] | 30 | 23 (76.7) | 12 (40.0) | 11 (36.7) |
| Kim et al., 2020 [35] | 30 | 22 (73.3) | 18 (60.0) | 4 (13.3) |
| Lee et al., 2015 [56] | 204 | 30 (14.7) | 15 (7.4) | 15 (7.4) |
| Oh et al., 1988 [41] | 20 | 9 (45.0) | 9 (45.0) | 0 (0.0) |
| Oh et al., 1988 [41] | 20 | 11 (55.0) | 11 (55.0) | 0 (0.0) |
| Woo, 2007 [43] | 115 | 43 (37.4) | 43 (37.4) | 0 (0.0) |

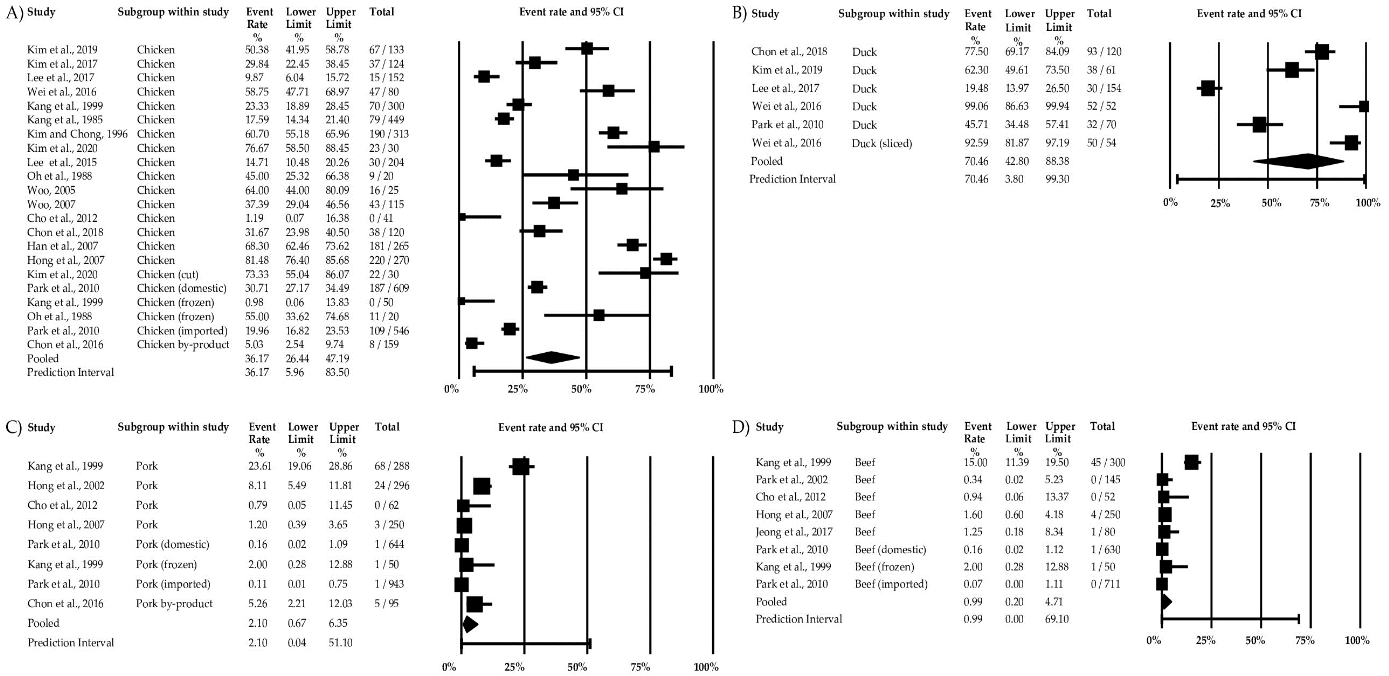
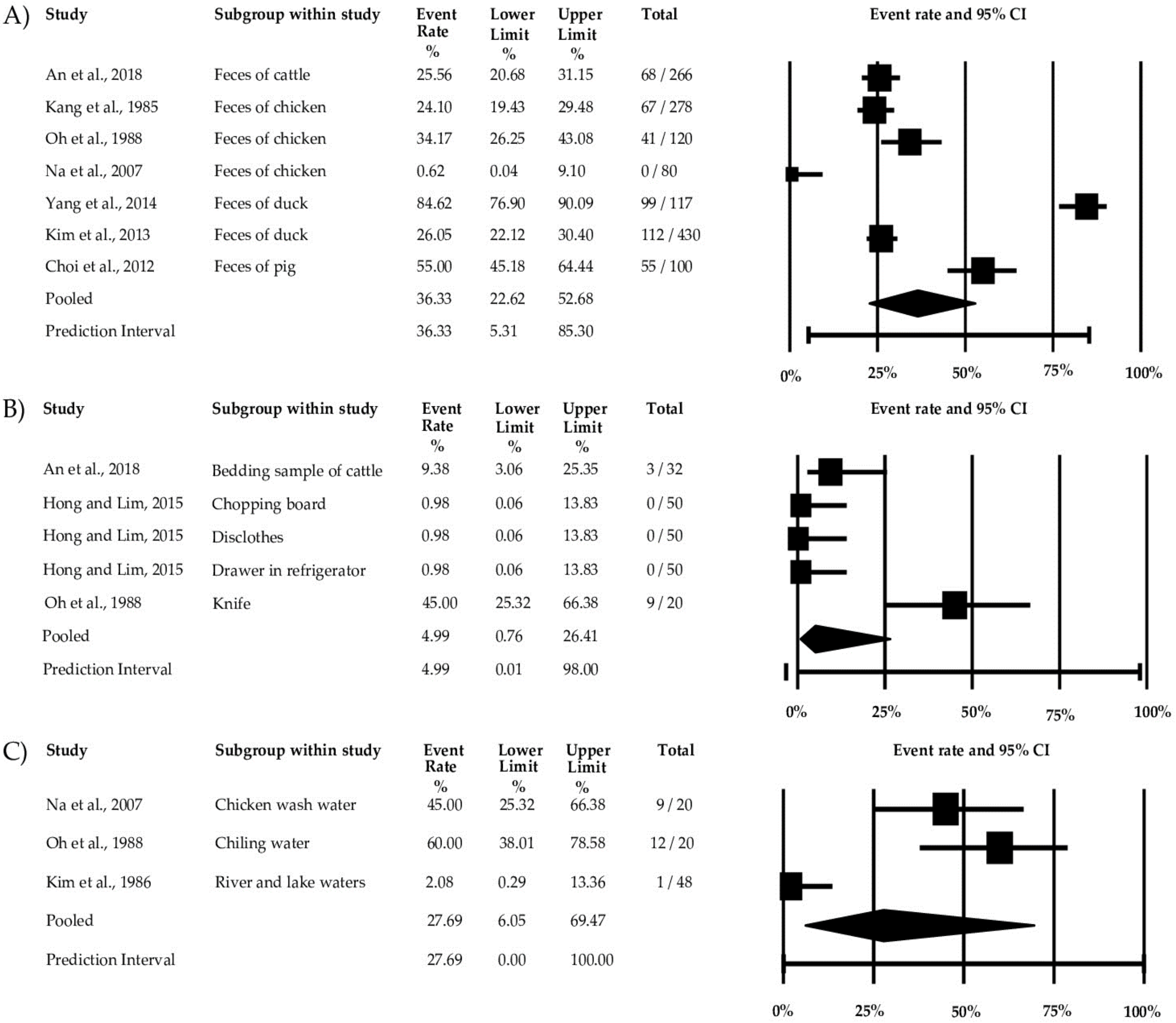


**Figure 3.** Forest plot of each food type for the prevalence of *Campylobacter* in South Korea: (**A**) chicken, (**B**) duck, (**C**) pork, and (**D**) beef [3,31,32,34,35,39,41–43,46–50,52–54,57,59,60].

### 3.4. Environmental Factors Play a Major Role in Contamination

Among the environmental factors considered in this study, feces showed the highest prevalence at 36.33% (95% CI: 22.62–52.68%), followed by wash water at 27.69%

(95% CI: 6.0.5–69.47%) and equipment at 4.99% (95% CI: 0.76–26.41%). Duck feces exhibited the highest prevalence of *Campylobacter* spp., followed by pig and chicken feces. Chilling and chicken wash water also showed high prevalence rates of 60% and 45%, respectively. Among the equipment commonly used, knives showed the highest prevalence at 45% (95% CI: 25.32–63.38%) (Figure 4).



A)

| Study | Subgroup within study | Event Rate % | Lower Limit % | Upper Limit % | Total |
|---|---|---|---|---|---|
| An et al., 2018 | Feces of cattle | 25.56 | 20.68 | 31.15 | 68 / 266 |
| Kang et al., 1985 | Feces of chicken | 24.10 | 19.43 | 29.48 | 67 / 278 |
| Oh et al., 1988 | Feces of chicken | 34.17 | 26.25 | 43.08 | 41 / 120 |
| Na et al., 2007 | Feces of chicken | 0.62 | 0.04 | 9.10 | 0 / 80 |
| Yang et al., 2014 | Feces of duck | 84.62 | 76.90 | 90.09 | 99 / 117 |
| Kim et al., 2013 | Feces of duck | 26.05 | 22.12 | 30.40 | 112 / 430 |
| Choi et al., 2012 | Feces of pig | 55.00 | 45.18 | 64.44 | 55 / 100 |
| Pooled | | 36.33 | 22.62 | 52.68 | |
| Prediction Interval | | 36.33 | 5.31 | 85.30 | |

B)

| Study | Subgroup within study | Event Rate % | Lower Limit % | Upper Limit % | Total |
|---|---|---|---|---|---|
| An et al., 2018 | Bedding sample of cattle | 9.38 | 3.06 | 25.35 | 3 / 32 |
| Hong and Lim, 2015 | Chopping board | 0.98 | 0.06 | 13.83 | 0 / 50 |
| Hong and Lim, 2015 | Disclothes | 0.98 | 0.06 | 13.83 | 0 / 50 |
| Hong and Lim, 2015 | Drawer in refrigerator | 0.98 | 0.06 | 13.83 | 0 / 50 |
| Oh et al., 1988 | Knife | 45.00 | 25.32 | 66.38 | 9 / 20 |
| Pooled | | 4.99 | 0.76 | 26.41 | |
| Prediction Interval | | 4.99 | 0.01 | 98.00 | |

C)

| Study | Subgroup within study | Event Rate % | Lower Limit % | Upper Limit % | Total |
|---|---|---|---|---|---|
| Na et al., 2007 | Chicken wash water | 45.00 | 25.32 | 66.38 | 9 / 20 |
| Oh et al., 1988 | Chiling water | 60.00 | 38.01 | 78.58 | 12 / 20 |
| Kim et al., 1986 | River and lake waters | 2.08 | 0.29 | 13.36 | 1 / 48 |
| Pooled | | 27.69 | 6.05 | 69.47 | |
| Prediction Interval | | 27.69 | 0.00 | 100.00 | |

**Figure 4.** Forest plot of prevalence of *Campylobacter* considering environmental factors and processing environments in South Korea: (**A**) feces, (**B**) equipment, (**C**) wash water [32,33,36,37,40,41,45,51,58].

## 4. Discussion

A World Health Organization (WHO) report states that poultry, including chicken and turkey, is a common source of foodborne pathogens such as *Salmonella* and *Campylobacter* [62]. Meat products such as beef and pork are potential sources of *Campylobacter* contamination [63]. Taremi et al. (2006) found the highest prevalence of *Campylobacter* in chicken (63%) and beef (10%) [64]. Given that chicken is the most consumed meat worldwide [65], addressing the prevalence and consequences of *Campylobacter* infections in poultry becomes paramount. Furthermore, *Campylobacter* prevalence is not confined to poultry and meat; it has been found in vegetables, fruits, and fresh produce at an estimated prevalence of approximately 0.53% [66].

During the screening process, the detection method for *Campylobacter* was also considered (Table 1). Although specific differences exist in overall protocols for detecting *Campylobacter*, the methodology was similar in media composition and temperature, which can be excluded from the potential cause of heterogeneity and bias. Components such as amphotericin, sodium bisulfite, sodium pyruvate, and sodium chloride were prevalent across most compositions, with pH levels ranging from 7.2 to 7.4. Additionally, we conducted a risk of bias assessment to determine the quality of the studies considered. Overall, 22 out of 32 studies were classified as high quality, and the remaining nine were moderate quality, without any studies considered low quality (Figure S1).

It is noteworthy that our findings showed a higher prevalence of duck, in contrast to studies conducted in the US (12.5%), UK (50.7%), and Ireland (45.8%) [59]. There could be several factors contributing to a high prevalence of duck, including contamination in duck farms [67], high intestinal concentration, or the protective effects of thicker skin layers [68]. Another explanation is that chicken has recently been the focus of contamination prevention efforts, which may not be the case for ducks [59]. Nevertheless, chicken is still more prevalent than other meat, such as beef and pork. It is important to note the limitations in conducting subgroup analysis due to insufficient study information. For instance, the condition of the meat (sliced or whole) was not consistently specified in the studies, limiting our ability to perform subgroup analysis (Figure 3). The considerable variation in the sample sizes and event rates also posed challenges in conducting subgroup analysis and identifying the sources of high heterogeneity (Figures S2 and S3). Nevertheless, the results provide valuable insights into the prevalence of *Campylobacter* in poultry and meat, aiding in understanding the trends and high-risk foods.

A study conducted in Brazil also showed that *C. jejuni* was more prevalent in poultry (28.8%) compared with *C. coli* (15.6%) [69]. In a Netherlands case study, consuming poultry and undercooked meat was associated with more *C. jejuni* infections than *C. coli* infections [69]. Usually, there are more cases found related to *C. jejuni*, but cases also exist where *C. coli* surpasses *C. jejuni*, as a study in Argentina showed that *C. coli* (59%) was more prevalent than *C. jejuni* (41%) in slaughterhouse samples [70]. The variation in prevalence between two species could be due to factors such as seasons, geography, and the evolutionary forces of recombination [71,72].

Studying food, its environment, and processing units is crucial for comprehensively understanding pathogen contamination risks. It allows for identifying contamination sources, assessing transmission pathways, evaluating overall risk, and developing effective intervention strategies [73]. A notable example is the 2017 outbreak of *C. jejuni* in Seoul, Korea, where environmental factors and improper handling were implicated as potential causes [8]. Chai et al., (2008) showed that up to 38.2% of *C. jejuni* was transferred from vegetables to wash water, up to 47.2% from wash water to cucumbers, and up to 73.3% from cutting boards to cucumbers, highlighting the importance of environmental factors [74]. In Figure 4, the forest plot shows the high prevalence of *C. jejuni* through handling and equipment sources and contamination through feces. The data in this study (Figure 4) suggest that, given the high prevalence of *Campylobacter* in environmental sources, there could be high contamination in final food products, which, upon consumption, may pose a threat to public health. Although these results show the high contamination risks, a lack of enough studies puts a limitation on finding the ultimate source.

*Campylobacter* contamination sources have been the subject of extensive research because of the prevalence of *Campylobacter* infections worldwide. Poultry, especially chicken and turkey, is a well-documented reservoir of *Campylobacter* species, with high prevalence rates reported in many countries [75]. *Campylobacter* colonization in poultry can be attributed to the gut microflora of these birds, which serves as a natural reservoir. Additionally, improper handling, cross-contamination during processing, and the consumption of undercooked poultry products have all been implicated in *Campylobacter* infections [10].

Moreover, *Campylobacter* can also contaminate water sources, posing a risk to individuals who consume untreated or contaminated water [76]. The primary sources of *Campylobacter* contamination in surface water have been identified as wild birds and poultry, although their influence varies based on factors such as the type of water body, the time of year, and the concentrations of local poultry and ruminant populations [77]. Research has revealed that isolates from poultry exhibit a prolonged survival period compared with other sources, suggesting a critical role in the transmission of *Campylobacter* through water sources [78]. Even in our meta-analysis, river and lake water, chicken wash water, and others revealed a significant amount of positive *Campylobacter* cases, with *C. jejuni* being the predominant species. Notably, a study on waterborne-outbreak-associated *C. jejuni* provided insight into how bacteria originating from cattle manure can infiltrate groundwater, leading to the contamination of water supplies [79]. Understanding these diverse contamination sources is crucial for the prevention and control of *Campylobacter* infections, and ongoing research seeks to elucidate the complex dynamics involved in *Campylobacter* transmission.

## 5. Conclusions

This review comprehensively examined the prevalence of *Campylobacter in* South Korea in poultry, meat, and environmental contexts. The results highlighted ducks as a high-risk food source, corroborating previous research showing higher antibiotic resistance than chickens. The widespread presence of *Campylobacter* species across various meat types and processing settings indicates the urgent need for stringent hygiene measures throughout the production chain. The diverse findings emphasize the significance of tailored control strategies in mitigating the risk of *Campylobacter* contamination in meat products, thereby safeguarding public health and emphasizing the importance of continuous monitoring and intervention efforts in the meat industry. The insights derived from this analysis can serve as a foundation for shaping future strategies in food safety management. By understanding the prevalence and distribution of *Campylobacter* in meat and processing environments, regulatory bodies and industry stakeholders can design interventions to target specific sources of contamination. This knowledge can guide the development of more effective hygiene protocols, surveillance programs, and risk assessment models, reducing the incidence of foodborne illnesses associated with *Campylobacter.*

**Supplementary Materials:** The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/microorganisms11112722/s1: Figure S1: Risk of bias assessment for all included studies presented as the percentage of bias risk for each question. Figure S2: Funnel plot of the overall study for the prevalence of *Campylobacter* in South Korea. Figure S3: Funnel plot of each food type for the prevalence of *Campylobacter* in South Korea: (a) chicken, (b) duck, (c) pork, (d) beef.

**Author Contributions:** H.J.J. and S.S. contributed equally to the systematic review and meta-analysis. H.J.J. contributed to the overall processes and suggested the direction of the meta-analysis. S.S. contributed to data extraction; meta-analysis; and, especially, research writing. The other authors (D.W.K., H.S.H., A.L.K. and E.J.S.) participated in the entire systematic review. O.K.K. contributed to supervising the entire process of this research. All authors have read and agreed to the published version of the manuscript.

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## References

1. Young, K.T.; Davis, L.M.; DiRita, V.J. *Campylobacter jejuni*: Molecular Biology and Pathogenesis. *Nat. Rev. Microbiol.* **2007**, *5*, 665–679. [CrossRef] [PubMed]
2. Lastovica, A.J.; Allos, B.M. Clinical significance of *Campylobacter* and related species other than *Campylobacter jejuni* and *C. coli*. In *Campylobacter*; Nachamkin, I., Szymanski, C.M., Blaser, M.J., Eds.; ASM Press: Washington, DC, USA, 2008; Volume 3, pp. 89–120.

3. Park, S.F. The physiology of *Campylobacter* species and its relevance to their role as foodborne pathogens. *Int. J. Food Microbiol.* **2002**, *74*, 177–188. [CrossRef]
4. Campylobacter (Campylobacteriosis): Information for Health Professionals. Available online: https://www.cdc.gov/Campylobacter/technical.html (accessed on 30 August 2023).
5. Kaakoush, N.O.; Castaño-Rodríguez, N.; Mitchell, H.M.; Man, S.M. Global epidemiology of *Campylobacter infection*. *Clin. Microbiol. Rev.* **2015**, *28*, 687–720. [CrossRef]
6. Mukherjee, P.; Ramamurthy, T.; Bhattacharya, M.K.; Rajendran, K.; Mukhopadhyay, A.K. *Campylobacter jejuni* in hospitalized patients with diarrhea, Kolkata, India. *Emerg. Infect. Dis.* **2013**, *19*, 1155. [CrossRef] [PubMed]
7. Campylobacter (Campylobacteriosis): Reports of Selected Campylobacter Outbreak Investigation. Available online: https://www.cdc.gov/Campylobacter/outbreaks/outbreaks.html (accessed on 2 July 2023).
8. Kang, C.R.; Bang, J.H.; Cho, S.I. *Campylobacter jejuni* foodborne infection associated with cross-contamination: Outbreak in Seoul in 2017. *Infect. Chemother.* **2019**, *51*, 21–27. [CrossRef] [PubMed]
9. Yu, J.H.; Kim, N.Y.; Cho, N.G.; Kim, J.H.; Kang, Y.A.; Lee, H.G. Epidemiology of *Campylobacter jejuni* outbreak in a middle school in Incheon, Korea. *J. Korean Med. Sci.* **2010**, *25*, 1595–1600. [CrossRef]
10. Silva, J.; Leite, D.; Fernandes, M.; Mena, C.; Gibbs, P.A.; Teixeira, P. *Campylobacter* spp. as a foodborne pathogen: A review. *Front. Microbiol.* **2011**, *2*, 200. [CrossRef]
11. Luangtongkum, T.; Morishita, T.Y.; Ison, A.J.; Huang, S.; McDermott, P.F.; Zhang, Q. Effect of conventional and organic production practices on the prevalence and antimicrobial resistance of *Campylobacter* spp. in poultry. *Appl. Environ. Microbiol.* **2006**, *72*, 3600–3607. [CrossRef]
12. Hoelzer, K.; Wong, N.; Thomas, J.; Talkington, K.; Jungman, E.; Coukell, A. Antimicrobial drug use in food-producing animals and associated human health risks: What, and how strong, is the evidence? *BMC Vet. Res.* **2017**, *13*, 211. [CrossRef]
13. Strachan, N.J.; Gormley, F.J.; Rotariu, O.; Ogden, I.D.; Miller, G.; Dunn, G.M.; Sheppard, K.S.; Dallas, F.J.; Reid, T.S.; Howie, H.; et al. Attribution of *Campylobacter* infections in northeast Scotland to specific sources by use of multilocus sequence typing. *J. Infect. Dis.* **2009**, *199*, 1205–1208. [CrossRef]
14. Lake, I.R.; Colon-Gonzalez, F.J.; Takkinen, J.; Rossi, M.; Sudre, B.; Dias, J.G.; Tavoschi, L.; Joshi, A.; Semenza, J.C.; Nichols, G. Exploring *Campylobacter* seasonality across Europe using the European surveillance system (TESSy), 2008 to 2016. *Eurosurveillance* **2019**, *24*, 1800028. [CrossRef] [PubMed]
15. Cassidy, A.; Myles, J.P.; Liloglou, T.; Duffy, S.W.; Field, J.K. Defining high-risk individuals in a population-based molecular-epidemiological study of lung cancer. *Int. J. Oncol.* **2006**, *28*, 1295–1301. [CrossRef]
16. Tack, D.M.; Marder, E.; Griffin, P.M.; Cieslak, P.R.; Dunn, J.; Hurd, S.; Scallan, E.; Lathrop, S.; Muse, A.; Ryan, P.; et al. Preliminary incidence and trends of infections with pathogens transmitted commonly through food—Foodborne Diseases Active Surveillance Network, 10 US sites, 2015–2018. *Am. J. Transplant.* **2019**, *19*, 1859–1863. [CrossRef]
17. Hyllestad, S.; Iversen, A.; MacDonald, E.; Amato, E.; Borge, B.Å.; Bøe, A.; Sandvin, A.; Brandal, L.T.; Lyngstad, T.M.; Naseer, U.; et al. Large waterborne *Campylobacter* outbreak: Use of multiple approaches to investigate contamination of the drinking water supply system, Norway, June 2019. *Eurosurveillance* **2020**, *25*, 2000011. [CrossRef] [PubMed]
18. Gilpin, B.J.; Walker, T.; Paine, S.; Sherwood, J.; Mackereth, G.; Wood, T.; Hambling, T.; Hewison, C.; Brounts, A.; Wilson, M.; et al. A large scale waterborne Campylobacteriosis outbreak, Havelock North, New Zealand. *J. Infect.* **2020**, *81*, 390–395. [CrossRef]
19. Ministry of Food and Drug Safety: Food and Food Additives Codex, Food Code: Article 8: 4.19: Campylobacter jejuni/coli. Available online: https://www.foodsafetykorea.go.kr/foodcode/01_03.jsp?idx=392 (accessed on 25 July 2023).
20. Muka, T.; Glisic, M.; Milic, J.; Verhoog, S.; Bohlius, J.; Bramer, W.; Chowdhury, R.; Franco, O.H. A 24-step guide on how to design, conduct, and successfully publish a systematic review and meta-analysis in medical research. *Eur. J. Epidemiol.* **2020**, *35*, 49–60. [CrossRef] [PubMed]
21. Delgado-Rodríguez, M.; Sillero-Arenas, M. Systematic review and meta-analysis. *Med. Intensiv.* **2018**, *42*, 444–453. [CrossRef]
22. Siddaway, A.P.; Wood, A.M.; Hedges, L.V. How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annu. Rev. Psychol.* **2019**, *70*, 747–770. [CrossRef]
23. Lee, J.; Lee, H.; Lee, S.; Kim, S.; Ha, J.; Choi, Y.; Oh, H.; Kim, Y.; Lee, Y.; Yoon, K.S.; et al. Quantitative microbial risk assessment for *Campylobacter jejuni* in ground meat products in Korea. *Food Sci. Anim. Resour.* **2019**, *39*, 565–575. [CrossRef]
24. Rethlefsen, M.L.; Kirtley, S.; Waffenschmidt, S.; Ayala, A.P.; Moher, D.; Page, M.J.; Koffel, J.B. PRISMA-S: An extension to the PRISMA statement for reporting literature searches in systematic reviews. *Sys. Rev.* **2021**, *10*, 39. [CrossRef]
25. Armijo-Olivo, S.; Stiles, C.R.; Hagen, N.A.; Biondo, P.D.; Cummings, G.G. Assessment of study quality for systematic reviews: A comparison of the Cochrane Collaboration Risk of Bias Tool and the Effective Public Health Practice Project Quality Assessment Tool: Methodological research. *J. Eval. Clin. Pract.* **2012**, *18*, 12–18. [CrossRef] [PubMed]
26. Grooten, W.J.; Tseli, E.; Äng, B.O.; Boersma, K.; Stålnacke, B.M.; Gerdle, B.; Enthoven, P. Elaborating on the assessment of the risk of bias in prognostic studies in pain rehabilitation using QUIPS—Aspects of interrater agreement. *Diagn. Progn. Res.* **2019**, *3*, 5. [CrossRef]
27. Rubinstein, S.M.; van Eekelen, R.; Oosterhuis, T.; de Boer, M.R.; Ostelo, R.W.; van Tulder, M.W. The risk of bias and sample size of trials of spinal manipulative therapy for low back and neck pain: Analysis and recommendations. *J. Manip. Physiol. Ther.* **2014**, *37*, 523–541. [CrossRef] [PubMed]

28. Bashiry, M.; Javanmardi, F.; Sadeghi, E.; Shokri, S.; Hossieni, H.; Oliveira, C.A.; Khaneghah, A.M. The prevalence of aflatoxins in commercial baby food products: A global systematic review, meta-analysis, and risk assessment study. *Trends Food Sci. Technol.* **2021**, *114*, 100–115. [CrossRef]
29. Lohmueller, K.E.; Pearce, C.L.; Pike, M.; Lander, E.S.; Hirschhorn, J.N. Meta-analysis of genetic association studies supports a contribution of common variants to susceptibility to common disease. *Nat. Genet.* **2003**, *33*, 177–182. [CrossRef]
30. Ranjbar, R.; Halaji, M. Epidemiology of *Listeria monocytogenes* prevalence in foods, animals and human origin from Iran: A systematic review and meta-analysis. *BMC Public Health* **2018**, *18*, 1057. [CrossRef] [PubMed]
31. Kang, H.J.; Kim, Y.H.; Suk, J.M.; Lee, S.M.; Kim, J.Y.; Jung, S.C. Prevalence and serovar of food poisoning bacteria in retail fresh, frozen and packed meats. *J. Food Hyg. Saf.* **1999**, *14*, 327–332.
32. Kang, H.J.; Kim, Y.H.; Cho, H.H. Isolation of *Campylobacter jejuni* from chicken. *Korean J. Vet. Public Health* **1985**, *9*, 43–47.
33. Kim, N.H.; Chae, H.S.; Kang, Y.I.; Shin, B.W.; Choi, N.H.; Kim, H.B. Prevalence and antimicrobial resistance patterns of *Campylobacter jejuni* from duck feces. *Korean J. Vet. Serv.* **2013**, *36*, 57–60. [CrossRef]
34. Kim, S.M.; Chong, S.J. Prevalence and in vitro antimicrobial activity against *Campylobacter jejuni/coli* from chickens. *Korean J. Clin Lab. Sci.* **1996**, *28*, 20–28.
35. Kim, J.S.; Jeong, N.B.; Kim, B.Y.; Mun, S.; Lim, E.S.; Koo, O.K. Prevalence of *Campylobacter* in retail raw chickens and their motility phenotypes in South Korea. *J. Agri. Life Environ. Sci.* **2020**, *32*, 345–352.
36. Kim, C.K.; Oh, H.S.; Ryeom, K.; Cho, M.K. Contamination and survival of *Campylobacter jejuni* in river water. *Korean J. Limnol.* **1986**, *19*, 39–48.
37. Na, H.; Koh, B.; Park, S.; Kim, Y. Studies on *Campylobacter jejuni* and *Campylobacter coli* contamination on broiler carcasses in slaughterhouse. *Korean J. Vet. Serv.* **2007**, *30*, 77–84.
38. Park, S.D.; Kim, Y.H.; Koh, B.R.; Kim, C.H.; Yoon, B.C.; Kim, C.K. A study on the contamination level of pathogenic microorganisms in beef distribution stages. *Korean J. Vet. Serv.* **2002**, *25*, 117–126.
39. Lee, E.M.; Shin, D.S.; Kwon, M.S.; Lee, S.J. Survey of pathogenic microorganisms contamination of chicken carcasses. *Korean J. Vet. Serv.* **2015**, *38*, 167–171. [CrossRef]
40. Yang, J.W.; Kim, S.H.; Lee, W.W.; Kim, Y.H. Prevalence of virulence-associated genes and antimicrobial resistance of *Campylobacter jejuni* from ducks in Gyeongnam Province, Korea. *Korean J. Vet. Serv.* **2014**, *37*, 85–96. [CrossRef]
41. Oh, J.S.; Shin, K.S.; Yoon, Y.D.; Park, J.M. Prevalence of *Campylobacter jejuni* in broilers and chicken processing plants. *Korean J. Food Hyg.* **1988**, *3*, 27–36.
42. Woo, Y.K. Microbial hygienic status of poultry meats and eggs collected at the public markets in Seoul and Kyung-gi regions in 1996. *Korean J. Microbiol.* **2005**, *41*, 38–46.
43. Woo, Y.K. Survey on the status of microbial contamination of chicken meats collected from poultry processing plants in nationwide. *Korean J. Microbiol.* **2007**, *43*, 186–192.
44. Hong, C.H.; Lee, K.H.; Lee, S.M. Microbial change of pork carcass during processing in small size slaughterhouse. *Korean J. Vet. Serv.* **2002**, *25*, 31–37.
45. An, J.U.; Ho, H.; Kim, J.; Kim, W.H.; Kim, J.; Lee, S.; Mun, S.H.; Guk, J.H.; Hong, S.; Cho, S. Dairy cattle, a potential reservoir of human Campylobacteriosis: Epidemiological and molecular characterization of *Campylobacter jejuni* from cattle farms. *Front. Microbiol.* **2018**, *18*, 3136. [CrossRef] [PubMed]
46. Cho, J.I.; Joo, I.S.; Choi, J.H.; Jung, K.H.; Choi, E.J.; Lee, S.H.; Hwang, I.G. Prevalence and characterization of foodborne bacteria from meat products in Korea. *Food Sci. Biotechnol.* **2012**, *21*, 1257–1261. [CrossRef]
47. Chon, J.W.; Lee, S.K.; Yoon, Y.; Yoon, K.S.; Kwak, H.S.; Joo, I.S.; Seo, K.H. Quantitative prevalence and characterization of *Campylobacter* from chicken and duck carcasses from poultry slaughterhouses in South Korea. *Poult. Sci.* **2018**, *97*, 2909–2916. [CrossRef]
48. Chon, J.W.; Jung, H.I.; Kuk, M.; Lim, J.S.; Seo, K.H.; Kim, S.K. Microbiological evaluation of pork and chicken by-products in South Korea. *J. Food Protect.* **2016**, *79*, 715–722. [CrossRef] [PubMed]
49. Han, K.; Jang, S.S.; Choo, E.; Heu, S.; Ryu, S. Prevalence, genetic diversity, and antibiotic resistance patterns of *Campylobacter jejuni* from retail raw chickens in Korea. *Int. J. Food Microbiol.* **2007**, *114*, 50–59. [CrossRef]
50. Hong, J.; Kim, J.M.; Jung, W.K.; Kim, S.H.; Bae, W.; Koo, H.C.; Gil, J.; Kim, M.; Ser, J.; Park, Y.H. Prevalence and antibiotic resistance of *Campylobacter* spp. isolated from chicken meat, pork, and beef in Korea, from 2001 to 2006. *J. Food Protect.* **2007**, *70*, 860–866. [CrossRef]
51. Hong, J.; Lim, S.Y. Microbial contamination in kitchens and refrigerators of Korea households. *J. Food Hyg. Saf.* **2015**, *30*, 303–308. [CrossRef]
52. Jeong, J.; Lee, J.; Lee, H.; Lee, S.; Kim, S.; Ha, J.; Yoon, K.S.; Yoon, Y. Quantitative microbial risk assessment for *Campylobacter* foodborne illness in raw beef offal consumption in South Korea. *J. Food Protect.* **2017**, *80*, 609–618. [CrossRef]
53. Kim, J.; Park, H.; Kim, J.; Kim, J.H.; Jung, J.I.; Cho, S.; Ryu, S.; Jeon, B. Comparative analysis of aerotolerance, antibiotic resistance, and virulence gene prevalence in *Campylobacter jejuni* isolates from retail raw chicken and duck meat in South Korea. *Microorganisms* **2019**, *7*, 433. [CrossRef]
54. Kim, H.J.; Kim, J.H.; Kim, Y.I.; Choi, J.S.; Park, M.Y.; Nam, H.M.; Jung, S.C.; Kwon, J.W.; Lee, C.H.; Kim, Y.H.; et al. Prevalence and characterization of *Campylobacter* spp. isolated from domestic and imported poultry meat in Korea, 2004–2008. *Foodborne Pathog. Dis.* **2010**, *7*, 1203–1209. [CrossRef]

55. Kim, S.H.; Park, C.; Lee, E.J.; Bang, W.S.; Kim, Y.J.; Kim, J.S. Biofilm formation of *Campylobacter strains* isolated from raw chickens and its reduction with DNase I treatment. *Food Control* **2017**, *71*, 94–100. [CrossRef]
56. Lee, J.; Ha, J.; Kim, S.; Lee, H.; Lee, S.; Yoon, Y. Quantitative microbial risk assessment for *Campylobacter* spp. on ham in Korea. *Korean J. Food Sci. Anim. Resour.* **2015**, *35*, 674–682. [CrossRef]
57. Lee, J.; Jeong, J.; Lee, H.; Ha, J.; Kim, S.; Choi, Y.; Oh, H.; Seo, K.; Yoon, Y.; Lee, S. Antibiotic susceptibility, genetic diversity, and the presence of toxin producing genes in *Campylobacter* isolates from poultry. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1400. [CrossRef] [PubMed]
58. Choi, M.R.; Kim, S.M.; Kim, S.H.; Choi, W.S.; Kim, Y.K. Prevalence and antimicrobial susceptibility of erythromycin-resistant *Campylobacter jejuni* and *Campylobacter coli* isolated from swine. *Biomed. Sci. Lett.* **2012**, *18*, 152–159.
59. Wei, B.; Cha, S.Y.; Yoon, R.H.; Kang, M.; Roh, J.H.; Seo, H.S.; Lee, J.A.; Jang, H.K. Prevalence and antimicrobial resistance of *Campylobacter* spp. isolated from retail chicken and duck meat in South Korea. *Food Control* **2016**, *62*, 63–68. [CrossRef]
60. Park, H.J.; Kim, Y.J.; Kim, J.H.; Song, S.W.; Heo, E.J.; Kim, H.J.; Ku, B.K.; Lee, S.W.; Lee, J.Y.; Moon, J.S.; et al. Prevalence of *Campylobacter jejuni* and *Campylobacter coli* isolated from domestic and imported meats in Korea, 2005~2009. *Korean J. Vet. Public Health* **2010**, *34*, 181–187.
61. Carter, P.E.; McTavish, S.M.; Brooks, H.J.; Campbell, D.; Collins-Emerson, J.M.; Midwinter, A.C.; French, N.P. Novel clonal complexes with an unknown animal reservoir dominate *Campylobacter jejuni* isolates from river water in New Zealand. *Appl. Environ. Microbiol.* **2000**, *275*, 6038–6046. [CrossRef]
62. World Health Organization. *Foodborne Disease Outbreaks: Guidelines for Investigation and Control*; World Health Organization: Geneva, Switzerland, 2008.
63. European Food Safety Authority. The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2017. *EFSA J.* **2018**, *16*, 5500.
64. Taremi, M.; Dallal, M.M.; Gachkar, L.; MoezArdalan, S.; Zolfagharian, K.; Zali, M.R. Prevalence and antimicrobial resistance of *Campylobacter* isolated from retail raw chicken and beef meat, Tehran, Iran. *Int. J. Food Microbiol.* **2006**, *108*, 401–403. [CrossRef]
65. Chowdhury, M.A.; Ashrafudoulla, M.; Mevo, S.I.; Mizan, M.F.; Park, S.H.; Ha, S.D. Current and future interventions for improving poultry health and poultry food safety and security: A comprehensive review. *Compr. Rev. Food Sci. Food Saf.* **2023**, *22*, 1555–1596. [CrossRef]
66. Mohammadpour, H.; Berizi, E.; Hosseinzadeh, S.; Majlesi, M.; Zare, M. The prevalence of *Campylobacter* spp. in vegetables, fruits, and fresh produce: A systematic review and meta-analysis. *Gut Pathog.* **2018**, *10*, 41. [CrossRef] [PubMed]
67. Wei, B.M.; Cha, S.Y.; Kang, M.; Roh, J.H.; Seo, H.S.; Yoon, R.H.; Jang, H.K. Antimicrobial susceptibility profiles and molecular typing of *Campylobacter jejuni* and *Campylobacter coli* isolates from ducks in South Korea. *Appl. Environ. Microbiol.* **2014**, *80*, 7604–7610. [CrossRef] [PubMed]
68. Rosenquist, H.; Sommer, H.M.; Nielsen, N.L.; Christensen, B.B. The effect of slaughter operations on the contamination of chicken carcasses with thermotolerant *Campylobacter*. *Int. J. Food Microbiol.* **2006**, *108*, 226–232. [CrossRef]
69. Doorduyn, Y.; Van Den Brandhof, W.E.; Van Duynhoven, Y.T.; Breukink, B.J.; Wagenaar, J.A.; Van Pelt, W. Risk factors for indigenous *Campylobacter jejuni* and *Campylobacter coli* infections in The Netherlands: A case-control study. *Epidemiol. Infect.* **2010**, *138*, 1391–1404. [CrossRef] [PubMed]
70. Schreyer, M.E.; Olivero, C.R.; Rossler, E.; Soto, L.P.; Frizzo, L.S.; Zimmermann, J.A.; Signorini, M.L.; Virginia, Z.M. Prevalence and antimicrobial resistance of *Campylobacter jejuni* and *C. coli* identified in a slaughterhouse in Argentina. *Curr. Res. Food Sci.* **2022**, *5*, 590–597. [CrossRef] [PubMed]
71. Jorgensen, F.; Ellis-Iversen, J.; Rushton, S.; Bull, S.A.; Harris, S.A.; Bryan, S.J.; Gonzalez, A.; Humphrey, T.J. Influence of season and geography on *Campylobacter jejuni* and *C. coli* subtypes in housed broiler flocks reared in Great Britain. *Appl. Environ. Microbiol.* **2021**, *77*, 3741–3748. [CrossRef]
72. Sheppard, S.K.; Maiden, M.C. The evolution of *Campylobacter jejuni* and *Campylobacter coli*. *Cold Spring Harb. Perspect. Biol.* **2015**, *7*, a018119. [CrossRef]
73. Li, A.M. Ecological determinants of health: Food and environment on human health. *Environ. Sci. Pollut. Res.* **2017**, *24*, 9002–9015. [CrossRef]
74. Chai, L.C.; Lee, H.Y.; Ghazali, F.M.; Bakar, F.A.; Malakar, P.K.; Nishibuchi, M.; Nakaguchi, Y.; Radu, S. Simulation of cross-contamination and decontamination of *Campylobacter jejuni* during handling of contaminated raw vegetables in a domestic kitchen. *J. Food Protect.* **2008**, *71*, 2448–2452. [CrossRef]
75. Acheson, D.; Hohmann, E.L. Nontyphoidal salmonellosis. *Clin. Infect. Dis.* **2001**, *32*, 263–269. [CrossRef]
76. Vally, H.; Glass, K.; Ford, L.; Hall, G.; Kirk, M.D.; Shadbolt, C.; Veitch, M.; Fullerton, K.E.; Musto, J.; Becker, N. Proportion of illness acquired by foodborne transmission for nine enteric pathogens in Australia: An expert elicitation. *Foodborne Pathog. Dis.* **2014**, *11*, 727–733. [CrossRef] [PubMed]
77. Ottesen, A.; Ramachandran, P.; Reed, E.; White, J.R.; Hasan, N.; Subramanian, P.; Ryan, G.; Jarvis, K.; Grim, C.; Daquiqan, N.; et al. Enrichment dynamics of Listeria monocytogenes and the associated microbiome from naturally contaminated ice cream linked to a listeriosis outbreak. *BMC Microbiol.* **2016**, *16*, 275. [CrossRef] [PubMed]

78. Whiley, H.; Van den Akker, B.; Giglio, S.; Bentham, R. The role of environmental reservoirs in human campylobacteriosis. *Int. J. Environ. Res. Public Health* **2013**, *10*, 5886–5907. [CrossRef] [PubMed]
79. Clark, C.G.; Price, L.; Ahmed, R.; Woodward, D.L.; Melito, P.L.; Rodgers, F.G.; Jamieson, F.; Ciebin, B.; Li, A.; Ellis, A. Characterization of waterborne outbreak–associated *Campylobacter jejuni*, Walkerton, Ontario. *Emerg. Infect. Dis.* **2023**, *9*, 1232. [CrossRef]