2006

Effect of conventional and organic production practices on the prevalence and antimicrobial resistance of Campylobacter spp. in poultry

Taradon Luangtongkum  
Ohio State University - Main Campus

Teresa Y. Morishita  
Ohio State University - Main Campus

Aaron J. Ison  
Ohio State University - Main Campus

Shouxiong Huang  
Washington University School of Medicine in St. Louis

Patrick F. McDermott  
United States Food and Drug Administration

See next page for additional authors

Follow this and additional works at: https://digitalcommons.wustl.edu/open_access_pubs

Recommended Citation
Luangtongkum, Taradon; Morishita, Teresa Y.; Ison, Aaron J.; Huang, Shouxiong; McDermott, Patrick F.; and Zhang, Qijing, "Effect of conventional and organic production practices on the prevalence and antimicrobial resistance of Campylobacter spp. in poultry." Applied and Environmental Microbiology, 72, 5, 3600-3607. (2006).  
https://digitalcommons.wustl.edu/open_access_pubs/2023

This Open Access Publication is brought to you for free and open access by Digital Commons@Becker. It has been accepted for inclusion in Open Access Publications by an authorized administrator of Digital Commons@Becker. For more information, please contact engeszer@wustl.edu.
Authors
Taradon Luangtongkum, Teresa Y. Morishita, Aaron J. Ison, Shouxiong Huang, Patrick F. McDermott, and Qi Jing Zhang

This open access publication is available at Digital Commons@Becker: https://digitalcommons.wustl.edu/open_access_pubs/2023
Effect of Conventional and Organic Production Practices on the Prevalence and Antimicrobial Resistance of Campylobacter spp. in Poultry

Taradon Luangtongkum, Teresa Y. Morishita, Aaron J. Ison, Shouxiong Huang, Patrick F. McDermott and Qijing Zhang


Updated information and services can be found at: http://aem.asm.org/content/72/5/3600

**REFERENCES**

This article cites 38 articles, 12 of which can be accessed free at: http://aem.asm.org/content/72/5/3600#ref-list-1

**CONTENT ALERTS**

Receive: RSS Feeds, eTOCs, free email alerts (when new articles cite this article), more»

Information about commercial reprint orders: http://journals.asm.org/site/misc/reprints.xhtml
To subscribe to another ASM Journal go to: http://journals.asm.org/site/subscriptions/
Food-borne campylobacteriosis, a major public health concern in the United States and many countries worldwide, is caused mainly by Campylobacter jejuni (23). It is estimated that more than 2 million cases of food-borne bacterial diarrhea that occur each year in the United States are caused by Campylobacter (3). In other industrialized countries, the numbers of Campylobacter infections exceeded those of Salmonella, Shigella, and Escherichia coli O157:H7 infections combined (2). Campylobacter jejuni not only is an important cause of bacterial gastroenteritis in humans but also has been associated with Guillain–Barré syndrome, an acute immune-mediated demyelinating disorder of the peripheral nervous system (7, 24). Although most Campylobacter infections in humans are associated with ingestion of contaminated or improperly handled cooked foods as well as milk or dairy products, consumption of undercooked poultry and/or other foods that are cross-contaminated with raw poultry meat during food preparation is considered a major risk factor for food-borne campylobacteriosis (4, 7). Since thermophilic Campylobacter spp., including C. jejuni and Campylobacter coli, are highly prevalent in chickens and turkeys (29, 34), contamination of poultry carcasses by Campylobacter during processing in slaughterhouses occurs frequently, resulting in the potential transmission of Campylobacter from contaminated poultry meats to consumers.

Over the last decade, the emergence of antimicrobial resistance in Campylobacter strains isolated from humans and animals in many countries around the world has increased dramatically (12, 17, 25, 39, 43). In the United States, the prevalence of fluoroquinolone resistance among Campylobacter isolates increased significantly from 1.3% in 1992 to 8% to 13% during 1996 to 1998, and this resistance trend has increased steadily since 1998 (15, 26, 37). In 2001, the National Antimicrobial Resistance Monitoring System (NARMS) and Nachamkin et al. found that about 19% to 40% of Campylobacter strains isolated from humans in the United States were resistant to ciprofloxacin (15, 26). The emergence of antimicrobial resistance, particularly among food-borne pathogens, is in part because of the widespread use of antimicrobial agents in both humans and animals (17, 22, 39, 40, 43). In conventional production practice, antimicrobial agents can be used for treatment, control, and prevention of the diseases as well as for improvement of growth and feed efficiency of the animals (17, 22, 39, 40). Organic production practice, on the other hand, has restricted the use of antimicrobial agents in food production.
crobiological substances on the farms (11). In addition to being subjected to the strict rules regarding the use of antimicrobial substances, the organic birds must be fed only on organically produced feed and supplements. Moreover, these organic birds must be provided with uncrowded living areas, and they also need to have access to fresh air, sunlight, and the outside environment (11). Although many studies of antimicrobial resistance in conventional poultry operations have been done, relatively little is known about antimicrobial-resistant Campylobacter in organic poultry operations. Since no antimicrobials have been used in the organic poultry operations and the demand for organic animal produce has been increasing considerably over the last several years (10), the difference in antimicrobial resistance of Campylobacter isolates from conventional and organic poultry operations is of interest. In addition, despite the recent advances in understanding the epidemiology of antimicrobial-resistant Campylobacter, relatively little is known about the impact of conventional and organic animal production practices on the prevalence of antimicrobial-resistant Campylobacter. Therefore, the purpose of this study was to determine the prevalence and antimicrobial resistance of Campylobacter isolates from both conventionally raised and organically raised broilers and turkeys.

MATERIALS AND METHODS

Sample collection. This study focused on the prevalence of antimicrobial-resistant Campylobacter in slaughter-age birds. A total of 345 broiler and 360 turkey intestinal tracts originating from 10 conventional broiler farms and 10 conventional turkey farms were collected from processing plants, while the whole intestinal tract of conventionally raised broilers and turkey farms in Ohio, only five organic broiler farms and five organic turkey farms were collected from August 2000 to November 2002. Since there are only a limited number of large-scale certified organic broiler and turkey farms in Ohio, only five organic broiler farms and five organic turkey farms were included in this study. A total of 355 intestinal tracts of organic broilers and 230 intestinal tracts of organic turkeys were collected from a state-inspected organic processing plant. In general, the whole intestinal tract of conventionally raised turkeys, organically raised broilers, and organically raised turkeys was manually taken out from each carcass by an employee of the processing plant, while the whole intestinal tract of conventionally raised broilers was taken out from each carcass by automated equipment. The samples in this study were collected from August 2000 to November 2002.

Antimicrobial usage data. According to direct interviews with farmers, no antimicrobial agents were used in organic broiler or turkey operations from which the samples were collected. In contrast, antimicrobial agents were used in almost every conventional poultry farm according to direct interviews with farmers or production supervisors. For conventionally raised broilers, gentamicin was the most commonly used antimicrobial. This antimicrobial agent was found to be the birds at the hatchery to prevent early mortality due to E. coli infections. In addition to gentamicin, lincomycin was also used in some conventional broiler farms to prevent as well as to treat necrotic enteritis in conventionally raised broilers, at a dosage of 2 to 4 g/twon feed for prevention or 64 mg/gallon water for 5 to 10 days for treatment. If these conventional broiler flocks had necrotic enteritis, they were treated with amprolium at 0.004% in feed continuously or at 0.024% in water for 3 to 5 days. In addition, bacitracin and virginiamycin, which were supplemented in broiler feed at subtherapeutic levels in order to promote growth and improve feed efficiency as well as to prevent and control necrotic enteritis, were also used in these conventional broiler farms. If bacitracin was used for prevention of necrotic enteritis, it was given to the birds at a dosage of 100 mg/gallon water. But, if it was used for control of the disease, this antimicrobial agent was used at a dosage of 200 to 400 mg/gallon water. Virginiamycin was used to prevent necrotic enteritis in these conventionally raised broilers at a dosage of 3 to 15 g/twon feed. For the conventional broiler flocks surveyed in this study, the birds were not exposed to treatments with fluoroquinolones during the production period, according to information obtained from the producers; however, fluoroquinolones were used in the previous flocks of these conventional broiler farms. For conventionally raised turkeys, enrofloxacin was the drug routinely used for flocks with respiratory disease due to E. coli infections, while chlorotetracline was used only for the farms that had a high prevalence of fowl cholera. As with the conventionally raised broilers, bacitracin was also used as a feed additive and used to control necrotic enteritis in conventionally raised turkeys at a dosage of 400 mg/gallon water for 5 to 7 days.

TABLE 1. Antimicrobial test ranges, MIC quality control ranges, and MIC breakpoints used for antimicrobial susceptibility testing

<table>
<thead>
<tr>
<th>Antimicrobial agent</th>
<th>MIC quality control range of C. jejuni ATCC 33560 (µg/ml)</th>
<th>MIC breakpoint (µg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ampicillin</td>
<td>0.06–128</td>
<td>≤8</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>0.06–128</td>
<td>≤4</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>0.06–128</td>
<td>≤4</td>
</tr>
<tr>
<td>Kanamycin</td>
<td>0.25–128</td>
<td>≤16</td>
</tr>
<tr>
<td>Clindamycin</td>
<td>0.06–128</td>
<td>≤0.5</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>0.06–128</td>
<td>≤0.5</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>0.008–128</td>
<td>≤1</td>
</tr>
<tr>
<td>Norfloxacin</td>
<td>0.06–128</td>
<td>≤4</td>
</tr>
<tr>
<td>Nalidixic acid</td>
<td>0.25–128</td>
<td>≤16</td>
</tr>
</tbody>
</table>

* MIC breakpoints for enteric bacteria for all agents except norfloxacin were used by the NARMS. MIC breakpoints for Enterobacteriaceae for norfloxacin were recommended by the CLSI (formerly NCCLS). S, susceptible strains; I, intermediate strains; R, resistant strains.

a Tentative agar dilution quality control ranges of C. jejuni ATCC 33560 were approved by the CLSI.

b N/A, no data available.

c MIC breakpoints for enteric bacteria for all agents except norfloxacin were used by the NARMS. MIC breakpoints for Enterobacteriaceae for norfloxacin were recommended by the CLSI (formerly NCCLS). S, susceptible strains; I, intermediate strains; R, resistant strains.

d Tentative agar dilution quality control ranges of C. jejuni ATCC 33560 were approved by the CLSI.

E. coli infections. In addition to gentamicin, lincomycin was also used in some conventional broiler farms to prevent as well as to treat necrotic enteritis in conventionally raised broilers, at a dosage of 2 to 4 g/twon feed for prevention or 64 mg/gallon water for 5 to 10 days for treatment. If these conventional broiler flocks had necrotic enteritis, they were treated with amprolium at 0.004% in feed continuously or at 0.024% in water for 3 to 5 days. In addition, bacitracin and virginiamycin, which were supplemented in broiler feed at subtherapeutic levels in order to promote growth and improve feed efficiency as well as to prevent and control necrotic enteritis, were also used in these conventional broiler farms. If bacitracin was used for prevention of necrotic enteritis, it was given to the birds at a dosage of 100 mg/gallon water. But, if it was used for control of the disease, this antimicrobial agent was used at a dosage of 200 to 400 mg/gallon water. Virginiamycin was used to prevent necrotic enteritis in these conventionally raised broilers at a dosage of 3 to 15 g/twon feed. For the conventional broiler flocks surveyed in this study, the birds were not exposed to treatments with fluoroquinolones during the production period, according to information obtained from the producers; however, fluoroquinolones were used in the previous flocks of these conventional broiler farms. For conventionally raised turkeys, enrofloxacin was the drug routinely used for flocks with respiratory disease due to E. coli infections, while chlorotetracline was used only for the farms that had a high prevalence of fowl cholera.
norfloxacin, ≥32 µg/ml for ampicillin and nalidixic acid, and ≥64 µg/ml for kanamycin (Table 1) (8, 28). If an isolate was resistant to three or more classes of antimicrobials, it was defined as multidrug resistant.

**Statistical analysis.** A chi-square test at a $P$ significance level of <0.05 (two tailed), with Yates' correction for continuity, was used for comparing the prevalence and antimicrobial resistance rates of Campylobacter isolates between conventional and organic operations and between broilers and turkeys.

### RESULTS

#### Prevalence of Campylobacter.

The prevalence of C. jejuni and C. coli plus other Campylobacter species in conventionally raised broilers was 66%, while the prevalence of these organisms in conventionally raised turkeys was 83%. In terms of the organic poultry production systems, the prevalences of Campylobacter spp. in organically raised broilers and organically raised turkeys were 89% and 87%, respectively (Table 2). On the basis of the hippurate hydrolysis test, C. jejuni was the predominant Campylobacter species in conventionally raised broilers, organically raised broilers, and organically raised turkeys, whereas C. coli and other Campylobacter species were the predominant species in conventionally raised turkeys (Table 2).

#### Table 2. Prevalence and antimicrobial resistance of C. jejuni and C. coli plus other Campylobacter species in conventional and organic broiler and turkey farms

<table>
<thead>
<tr>
<th>Farm</th>
<th>No. (%) of positive samples/total no. of samples</th>
<th>No. (%) of positive samples</th>
<th>Major antimicrobial resistance pattern&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. jejuni</td>
<td>C. coli</td>
<td></td>
</tr>
<tr>
<td>CB-1</td>
<td>20 (66.67)/30</td>
<td>20 (100)</td>
<td>TET or FO</td>
</tr>
<tr>
<td>CB-2</td>
<td>14 (56.00)/25</td>
<td>14 (100)</td>
<td>TET-KAN-FQ</td>
</tr>
<tr>
<td>CB-3</td>
<td>23 (76.63)/30</td>
<td>23 (100)</td>
<td>TET</td>
</tr>
<tr>
<td>CB-4</td>
<td>22 (73.33)/30</td>
<td>22 (100)</td>
<td>TET</td>
</tr>
<tr>
<td>CB-5</td>
<td>30 (66.67)/45</td>
<td>23 (76.67) 7 (23.33)</td>
<td>TET-FQ</td>
</tr>
<tr>
<td>CB-6</td>
<td>27 (67.50)/40</td>
<td>27 (100)</td>
<td>TET</td>
</tr>
<tr>
<td>CB-7</td>
<td>24 (60.00)/40</td>
<td>24 (100)</td>
<td>TET-FQ</td>
</tr>
<tr>
<td>CB-8</td>
<td>16 (53.33)/30</td>
<td>16 (100) 0 (0)</td>
<td>TET or TET-FQ</td>
</tr>
<tr>
<td>CB-9</td>
<td>11 (44.00)/25</td>
<td>11 (100) 0 (0)</td>
<td>TET or KAN</td>
</tr>
<tr>
<td>CB-10</td>
<td>40 (80.00)/50</td>
<td>40 (100) 0 (0)</td>
<td>TET or TET-FQ</td>
</tr>
<tr>
<td>Total</td>
<td>227 (65.80)/345</td>
<td>220 (96.92) 7 (3.08)</td>
<td></td>
</tr>
<tr>
<td>OB-1</td>
<td>85 (91.40)/93</td>
<td>53 (62.35) 32 (37.65)</td>
<td>TET</td>
</tr>
<tr>
<td>OB-2</td>
<td>82 (88.17)/93</td>
<td>61 (74.39) 21 (25.61)</td>
<td>TET or TET-KAN</td>
</tr>
<tr>
<td>OB-3</td>
<td>22 (81.48)/27</td>
<td>13 (59.09) 9 (40.91)</td>
<td>KAN or TET-KAN</td>
</tr>
<tr>
<td>OB-4</td>
<td>96 (100)/96</td>
<td>70 (72.92) 26 (27.08)</td>
<td>No resistance&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>OB-5</td>
<td>32 (69.57)/46</td>
<td>32 (100) 0 (0)</td>
<td>TET</td>
</tr>
<tr>
<td>Total</td>
<td>317 (89.30)/355</td>
<td>229 (72.24) 88 (27.76)</td>
<td></td>
</tr>
<tr>
<td>CT-1</td>
<td>20 (66.67)/30</td>
<td>8 (40) 12 (60)</td>
<td>TET-KAN-CLI-ERY&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-2</td>
<td>39 (86.67)/45</td>
<td>7 (17.95) 32 (82.05)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-3</td>
<td>44 (97.78)/45</td>
<td>17 (38.64) 27 (61.36)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-4</td>
<td>24 (80.00)/30</td>
<td>16 (66.67) 8 (33.33)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-5</td>
<td>19 (63.33)/30</td>
<td>11 (57.89) 8 (42.11)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-6</td>
<td>40 (88.89)/45</td>
<td>26 (65) 14 (35)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-7</td>
<td>21 (70.00)/30</td>
<td>11 (52.88) 10 (47.12)</td>
<td>TET</td>
</tr>
<tr>
<td>CT-8</td>
<td>29 (96.67)/30</td>
<td>16 (51.77) 13 (48.23)</td>
<td>KAN-ERY&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-9</td>
<td>21 (70.00)/30</td>
<td>12 (57.14) 9 (42.86)</td>
<td>No specific pattern&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>CT-10</td>
<td>42 (93.33)/45</td>
<td>13 (30.95) 29 (69.05)</td>
<td>TET-KAN-CLI-ERY-FQ&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>299 (83.06)/360</td>
<td>137 (45.82) 162 (54.18)</td>
<td></td>
</tr>
<tr>
<td>OT-1</td>
<td>40 (93.02)/43</td>
<td>20 (50) 20 (50)</td>
<td>TET</td>
</tr>
<tr>
<td>OT-2</td>
<td>42 (100)/42</td>
<td>33 (78.57) 9 (21.43)</td>
<td>TET or TET-KAN</td>
</tr>
<tr>
<td>OT-3</td>
<td>88 (93.62)/94</td>
<td>49 (55.68) 39 (44.32)</td>
<td>KAN or TET-KAN</td>
</tr>
<tr>
<td>OT-4</td>
<td>1 (5.56)/18</td>
<td>1 (100) 0 (0)</td>
<td>TET</td>
</tr>
<tr>
<td>OT-5</td>
<td>30 (90.91)/33</td>
<td>30 (100) 0 (0)</td>
<td>TET-KAN&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>201 (87.39)/230</td>
<td>133 (66.17) 68 (33.83)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> CB, conventional broiler farm; OB, organic broiler farm; CT, conventional turkey farm; OT, organic turkey farm.

<sup>b</sup> Number (%) of intestines positive for Campylobacter species/number of intestines isolated for Campylobacter species.

<sup>c</sup> Number (%) of intestines positive for C. coli and other Campylobacter species.

<sup>d</sup> CLI, clindamycin; ERY, erythromycin; FQ, fluoroquinolones; KAN, kanamycin; TET, tetracycline.

<sup>e</sup> None of the Campylobacter isolates was resistant to antimicrobial agents tested in this study.

<sup>f</sup> Some isolates were also resistant to fluoroquinolones and ampicillin.

<sup>g</sup> Some isolates were also resistant to ampicillin.

<sup>h</sup> Some isolates were also resistant to fluoroquinolones and ampicillin.

<sup>i</sup> Some isolates were also resistant to fluoroquinolones and tetracycline.

<sup>j</sup> Only one isolate from this organic turkey farm was resistant to tetracycline and kanamycin, while the rest of the isolates were susceptible to all antimicrobial agents.
### TABLE 3. MIC distributions and resistance rates of *C. jejuni* isolated from conventional and organic poultry farms

<table>
<thead>
<tr>
<th>Antimicrobial agent</th>
<th>Operation type</th>
<th>No. of isolates inhibited by MIC (µg/ml)</th>
<th>No. (%) of resistant isolates</th>
</tr>
</thead>
</table>
|                     |                | 0.06 | 0.125 | 0.25 | 0.5 | 1 | 2 | 4 | 8 | 16 | 32 | 64 | 128 | >128 |<ref>

Ampicillin

- Conventional<sup>a</sup>,<sup>b</sup> 0 0 0 0 0 0 5 98 74 33 22 2 4 2 8/32 30 (12.50)<sup>+</sup>

- Organic<sup>c</sup> 0 0 0 0 0 1 39 80 24 56 4 4 3 0 4/16 11 (4.58)<sup>†</sup>

Tetracycline

- Conventional 0 8 5 2 6 0 2 4 12 60 51 66 24 64/128 213 (88.75)<sup>+</sup>

- Organic 0 7 35 42 13 4 0 0 7 15 25 28 35 16/>128 110 (52.13)<sup>†</sup>

Gentamicin

- Conventional 0 0 23 93 122 2 0 0 0 0 0 0 0 0 1/1 0

- Organic 0 0 39 100 72 0 0 0 0 0 0 0 0 0.5/1 0

Kanamycin

- Conventional 1 0 0 9 72 91 3 1 0 0 0 0 0 62 8/>128 63 (26.25)<sup>†</sup>

- Organic 0 0 6 20 69 86 1 0 0 0 0 0 0 0.5/1 0

Clindamycin

- Conventional 0 0 1 37 127 38 4 3 1 25 4 0 0 1/32 37 (15.42)<sup>†</sup>

- Organic 0 0 1 65 110 30 0 1 4 0 0 0 0 1/2 5 (2.37)<sup>†</sup>

Erythromycin

- Conventional 0 0 1 3 54 107 29 4 4 1 1 2 34 2/>128 46 (19.17)<sup>†</sup>

- Organic 0 2 1 37 71 78 17 0 0 0 0 0 5 1/4 5 (2.37)<sup>†</sup>

Ciprofloxacin

- Conventional 0 45 37 19 10 1 0 20 80 28 0 0 0 8/32 128 (53.33)<sup>†</sup>

- Organic 1 51 65 49 38 5 0 0 0 0 2 0 0 0.25/1 2 (0.95)<sup>†</sup>

Norfloxacin

- Conventional 0 0 9 58 34 8 0 0 2 0 1 48 75 5 64/128 129 (53.75)<sup>†</sup>

- Organic 0 5 77 74 41 7 5 0 0 0 0 0 2 0.5/1 2 (0.95)<sup>†</sup>

Nalidixic acid

- Conventional 0 0 2 3 56 29 20 0 1 22 107 128/>128 130 (54.17)<sup>†</sup>

- Organic 0 0 0 7 135 60 7 0 0 2 4/8 2 (0.95)<sup>†</sup>

### TABLE 4. MIC distributions and resistance rates of *C. coli* and other *Campylobacter* species isolated from conventional and organic poultry farms

<table>
<thead>
<tr>
<th>Antimicrobial agent</th>
<th>Operation type</th>
<th>No. of isolates inhibited by MIC (µg/ml)</th>
<th>No. (%) of resistant isolates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.06</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Ampicillin

- Conventional<sup>a</sup>,<sup>b</sup> 0 0 0 0 0 0 5 58 32 9 2 19 3 16/128 33 (25.78)<sup>†</sup>

- Organic<sup>c</sup> 0 0 0 0 0 0 20 41 50 0 0 4 0 8/16 4 (3.49)<sup>†</sup>

Tetracycline

- Conventional 0 0 0 1 7 4 2 0 0 1 0 13 63 37 128/>128 114 (89.06)<sup>†</sup>

- Organic 0 0 3 19 21 2 0 0 2 14 1 7 46 32/>128 70 (60.87)<sup>†</sup>

Gentamicin

- Conventional 0 0 2 18 107 1 0 0 0 0 0 0 0 1/1 0

- Organic 0 0 7 37 71 0 0 0 0 0 0 0 0 1/1 0

Kanamycin

- Conventional 0 0 0 1 4 9 5 0 0 0 0 0 109 128/>128 109 (85.16)<sup>†</sup>

- Organic 0 0 0 0 0 10 50 5 1 0 0 0 49 8/>128 49 (42.61)<sup>†</sup>

Clindamycin

- Conventional 0 0 0 5 21 9 4 7 4 72 6 0 0 32/32 93 (72.66)<sup>†</sup>

- Organic 0 0 0 52 35 19 4 7 4 72 6 0 0 32/32 93 (72.66)<sup>†</sup>

Erythromycin

- Conventional 0 0 2 1 3 8 8 6 5 1 2 92 128/>128 114 (93.99)<sup>†</sup>

- Organic 0 1 3 17 10 35 24 7 0 0 0 0 8 2/8 15 (13.04)<sup>†</sup>

Ciprofloxacin

- Conventional 0 3 14 10 17 0 1 2 13 60 7 1 0 32/32 84 (65.63)<sup>†</sup>

- Organic 0 4 38 29 39 4 0 0 0 0 1 0 0 0.5/1 1 (0.87)<sup>†</sup>

Norfloxacin

- Conventional 0 0 3 12 20 9 0 2 0 1 37 41 3 64/128 82 (64.06)<sup>†</sup>

- Organic 0 0 4 70 35 4 1 0 0 0 0 0 1 0.5/1 1 (0.87)<sup>†</sup>

Nalidixic acid

- Conventional 0 0 0 5 24 17 0 1 22 59 128/>128 82 (64.06)<sup>†</sup>

- Organic 0 0 0 0 61 45 8 0 0 0 1 4/8 1 (0.87)<sup>†</sup>

---

<sup>a</sup> Thin vertical lines indicate the breakpoint between susceptible and intermediate strains. Thick vertical lines indicate the breakpoint between intermediate and resistant strains (except for nalidixic acid, for which it indicates the breakpoint between susceptible and resistant strains).

<sup>b</sup> *Campylobacter* isolates from conventional poultry farms (n = 240).

<sup>c</sup> *C. jejuni* isolates from organic poultry farms (n = 115).

<sup>d</sup> Different symbols between operation types (conventional and organic) indicate a significant difference (P < 0.05) by a chi-square test with Yates' correction for continuity.

<sup>e</sup> Different symbols between operation types (conventional and organic) indicate a significant difference (P < 0.05) by a chi-square test with Yates' correction for continuity.
2). In this study, *Campylobacter* spp. could be isolated from every conventional and organic broiler and turkey farm. The prevalence of *Campylobacter* spp. in conventional broiler farms ranged from 44% to 80%, while the prevalence of these organisms in conventional turkey farms ranged from 63% to 98%. Likewise, the prevalence of *Campylobacter* spp. ranged from 70% to 100% in organic broiler farms and 6% to 100% in organic turkey farms (Table 2).

**Antimicrobial resistance patterns.** The MIC distributions and the MICs at which 50% and 90% of *C. jejuni* and *C. coli* plus other *Campylobacter* species were inhibited are summarized in Tables 3 and 4. In general, a wider range of MICs of most antimicrobials was observed mainly among *Campylobacter* isolates from conventional poultry farms than among the isolates from organic poultry farms, except the MIC of gentamicin, for which the lowest concentrations of this antimicrobial agent against *Campylobacter* strains isolated from both operation types were comparable. When the MIC\(_{90}\) and the resistance breakpoint of each antimicrobial agent were compared, the MIC\(_{90}\) values of ampicillin, clindamycin, erythromycin, ciprofloxacin, norfloxacin, and nalidixic acid for *Campylobacter* isolates from conventionally raised broilers and turkeys were higher than their resistance breakpoints, while the MIC\(_{90}\) values of these antimicrobials for the isolates from organically raised broilers and turkeys were lower than the resistance breakpoints. Overall, the MIC\(_{90}\) values of these antimicrobial agents for *Campylobacter* strains isolated from conventional poultry farms were higher than those for the strains isolated from organic poultry farms (Tables 3 and 4). Although *Campylobacter* strains isolated from both conventional and organic poultry operations in this study were uniformly susceptible to gentamicin, with an MIC\(_{90}\) of \(\leq 1\) μg/ml, these *Campylobacter* isolates were highly resistant to tetracycline, with an MIC\(_{90}\) of \(\geq 128\) μg/ml.

One of the most striking findings in this study was the difference in quinolone and fluoroquinolone resistance between *Campylobacter* strains isolated from conventional poultry farms and organic poultry farms. Approximately 46% of *Campylobacter* strains isolated from conventionally raised broilers and 67% of *Campylobacter* strains isolated from conventionally raised turkeys were resistant to ciprofloxacin, norfloxacin, and nalidixic acid. In contrast, none of the *Campylobacter* strains isolated from organically raised broilers and turkeys were resistant to these antimicrobials (Table 5). Compared to *Campylobacter* strains isolated from conventionally raised broilers and organically raised broilers and turkeys, the isolates from the conventional turkey operation were significantly more resistant to erythromycin, clindamycin, kanamycin, tetracycline, and ampicillin (\(P < 0.05\)) (Table 5). Regardless of the sources of isolation, none of the *Campylobacter* strains tested in this study were resistant to gentamicin, while more than 80% of *Campylobacter* strains isolated from conventionally raised broilers and turkeys and 50% to 60% of *Campylobacter* strains isolated from organically raised broilers and turkeys were resistant to tetracycline (Table 5). In terms of multidrug resistance, the occurrence of multidrug-resistant *Campylobacter* strains was observed mainly among the isolates from conventionally raised turkeys, with 81% of these isolates showing resistance to three or more classes of antimicrobials (Table 6). Moreover, about 58% of *Campylobacter* isolates

### Table 5. Resistance rates of *Campylobacter* strains isolated from different poultry production systems

<table>
<thead>
<tr>
<th>Antimicrobial agent</th>
<th>Conventional broiler farms (n = 167)</th>
<th>Organic broiler farms (n = 165)</th>
<th>Conventional turkey farms (n = 201)</th>
<th>Organic turkey farms (n = 161)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amoxicillin</td>
<td>0 A</td>
<td>5 (3.03) A</td>
<td>63 (31.34) B</td>
<td>10 (6.21) A</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>141 (84.43) A</td>
<td>99 (60) B</td>
<td>186 (92.54) C</td>
<td>81 (50.31) B</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kanamycin</td>
<td>19 (11.38) A</td>
<td>28 (16.97) A</td>
<td>153 (76.12) B</td>
<td>50 (31.06) C</td>
</tr>
<tr>
<td>Clindamycin</td>
<td>2 (1.20) A</td>
<td>9 (5.45) A</td>
<td>129 (64.18) B</td>
<td>5 (3.11) A</td>
</tr>
<tr>
<td>Erythromycin</td>
<td>0</td>
<td>15 (9.09) B</td>
<td>160 (79.60) C</td>
<td>5 (3.11) D</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>76 (45.51) A</td>
<td>0 B</td>
<td>136 (67.66) C</td>
<td>3 (1.86) B</td>
</tr>
<tr>
<td>Norfloxacin</td>
<td>77 (46.11) A</td>
<td>0 B</td>
<td>134 (66.67) C</td>
<td>3 (1.86) B</td>
</tr>
<tr>
<td>Nalidixic acid</td>
<td>77 (46.11) A</td>
<td>0 B</td>
<td>135 (67.16) C</td>
<td>3 (1.86) B</td>
</tr>
</tbody>
</table>

\*Antimicrobial resistance rates of *Campylobacter* isolates from different poultry production systems are compared by a chi-square test with Yates' correction for continuity. Numbers in the same row with different letters are significantly different (\(P < 0.05\)), while numbers with the same letters do not differ significantly.

### Table 6. Major multidrug resistance patterns of *C. jejuni* and *C. coli* plus other *Campylobacter* species isolated from conventional and organic poultry operations

<table>
<thead>
<tr>
<th>Operation type (no. of isolates)</th>
<th>C. jejuni (n = 167)</th>
<th>C. coli (n = 165)</th>
<th>Total (n = 167)</th>
<th>Resistance pattern*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional broiler farms</td>
<td>15 (8.98)</td>
<td>4 (2.42)</td>
<td>19 (11.38)</td>
<td>TET-KAN-CIP-NOR-NAL</td>
</tr>
<tr>
<td>Organic broiler farms</td>
<td>7 (4.24)</td>
<td>104 (51.74)</td>
<td>111 (67.66)</td>
<td>TET-KAN-CIP-NOR-NAL</td>
</tr>
<tr>
<td>Conventional turkey farms</td>
<td>59 (29.35)</td>
<td>104 (51.74)</td>
<td>163 (81.09)</td>
<td>TET-KAN-CIP-NOR-NAL</td>
</tr>
<tr>
<td>Organic turkey farms</td>
<td>4 (2.42)</td>
<td>4 (2.42)</td>
<td>8 (4.97)</td>
<td>TET-KAN-CIP-NOR-NAL</td>
</tr>
</tbody>
</table>

* C. coli and other *Campylobacter* species.

* AMP, amoxicillin; CIP, ciprofloxacin; CLI, clindamycin; ERY, erythromycin; KAN, kanamycin; NAL, nalidixic acid; NOR, norfloxacin; TET, tetracycline.

* The prevalence of multidrug-resistant *Campylobacter* strains in conventionally raised turkeys was significantly higher (\(P < 0.05\)) than that of other operation types.
from conventionally raised turkeys were resistant to both erythromycin and ciprofloxacin, whereas none of the Campylobacter strains isolated from conventionally raised broilers and organically raised broilers and turkeys, was concomitantly resistant to these antimicrobial agents. When antimicrobial resistance in individual conventional and organic broiler and turkey farms was investigated, tetracycline resistance was the major resistance pattern observed in almost every conventional broiler farm, organic broiler farm, and organic turkey farm (Table 2). Unlike the isolates from conventionally raised broilers and organically raised broilers and turkeys, the majority of Campylobacter isolates from 6 out of 10 conventional turkey farms were multidrug resistant to tetracycline, kanamycin, clindamycin, erythromycin, and fluoroquinolones (Table 2).

**DISCUSSION**

In this study, it is clearly shown that thermophilic Campylobacter is highly prevalent in both organic and conventional poultry production systems. However, the antimicrobial resistance rates vary significantly in different production types. In general, conventionally raised broilers and turkeys harbor more antimicrobial-resistant Campylobacter strains than organically raised broilers and turkeys, and the differences are obvious with fluoroquinolones. The highest resistance rates and multidrug resistance to three or more classes of antimicrobials are observed mainly among the isolates from the conventional turkey operation.

Although the prevalences of Campylobacter species in conventionally raised broilers and organically raised broilers were significantly different \( (P < 0.05) \), it should be noted that the average ages of the birds at the processing plants were not the same. Since the average market age of these organically raised broilers was about 8 to 12 weeks old, compared to 6 weeks old for conventionally raised broilers, the high prevalence of Campylobacter strains in organically raised broilers in part seems to be associated with the increased age of the birds at slaughter. The prevalences of Campylobacter species in conventionally raised and organically raised turkeys, on the other hand, were not significantly different \( (P = 0.19) \). This is likely because conventionally raised turkeys and organically raised turkeys were sent to the processing plants at approximately the same age (18 to 20 weeks). The association between the Campylobacter colonization rate and the age of the birds at the processing plant was also noted by other studies, which indicated that the prevalence of Campylobacter in poultry elevated when the age of the birds at the processing plant increased (6, 13, 29, 30). Besides the market age of the birds, other factors such as environmental exposure, which is seen particularly in organic poultry operations, can also play a role in the prevalence of Campylobacter in poultry (16, 29).

Although Campylobacter spp. could be isolated from every conventional and organic poultry farm, it should be noted that the prevalences of these organisms varied among farms. Among Campylobacter-positive flocks, C. jejuni was the predominant species in both conventional broiler farms and organic broiler farms, although the prevalence of C. jejuni in conventionally raised broilers was significantly higher \( (P < 0.05) \) than that in organically raised broilers. The high prevalence of C. jejuni in conventionally raised and organically raised broilers was also reported in other studies (5, 6, 13, 16, 42). In contrast, the predominant Campylobacter species in the conventional turkey operation was different from that in the organic turkey operation. C. coli and other Campylobacter species were the predominant species in conventionally raised turkeys, while C. jejuni was the predominant species in organically raised turkeys. Although C. coli and other Campylobacter species are the predominant Campylobacter strains isolated from conventionally raised turkeys in this study, it should be noted that the distributions of C. jejuni and C. coli plus other Campylobacter species in the conventional turkey operation are remarkably different among studies. As mentioned earlier, about 46% and 54% of Campylobacter isolates from conventionally raised turkeys in this study were identified as C. jejuni and C. coli plus other Campylobacter species, respectively, while Wallace et al. reported that almost 100% of Campylobacter isolates from conventional turkey flocks were C. jejuni (41). In contrast, Smith et al. revealed that 80% to 90% of Campylobacter strains colonizing turkey flocks were C. coli (36).

A significant difference \( (P < 0.001) \) in quinolone and fluoroquinolone resistance rates between Campylobacter strains isolated from conventional poultry operations and organic poultry operations was observed in this study. Since fluoroquinolones are used for therapeutic purpose only, it is not unusual that some conventional broiler and turkey flocks in this study were not treated with these antimicrobial agents. Although no fluoroquinolones were used in the conventional broiler flocks from which the samples were collected, they were used in previous flocks. In addition, because certain quinolone-resistant clones were stable and able to persist on the farms during several rotations even though there had been no selective pressure on that farm for a long period of time (31, 32) and because fluoroquinolone-resistant Campylobacter strains could out-compete fluoroquinolone-susceptible Campylobacter strains in the absence of antimicrobial usage (21), it is not surprising that a high fluoroquinolone resistance rate was observed among Campylobacter strains isolated from conventionally raised broilers in this study. This finding is consistent with previous studies by Pedersen and Wedderkopp and Price et al., who also reported that fluoroquinolone-resistant Campylobacter isolates continued to persist in the flocks that did not use these antimicrobial agents (31, 32). Since fluoroquinolones have never been used in organic poultry operations, it is not surprising that there was little or no resistance to this class of antimicrobials in Campylobacter strains isolated from organic poultry farms.

Compared to Campylobacter strains isolated from organic poultry operations, both C. jejuni and C. coli plus other Campylobacter species isolated from conventional poultry operations, particularly the isolates from conventionally raised turkeys, had significantly higher resistance rates \( (P < 0.05) \) not only to quinolone and fluoroquinolones but also to erythromycin, clindamycin, kanamycin, tetracycline, and ampicillin than the isolates from organically raised poultry. The high prevalence of multidrug-resistant Campylobacter strains observed in almost every conventional turkey farm in this study is interesting, since not all antimicrobial agents to which Campylobacter isolates from conventionally raised turkeys were resistant were used in...
those conventional turkey farms. However, due to the persistence and transmission of antimicrobial-resistant Campylobacter isolates, the antimicrobial resistance rate in a particular flock may not be directly correlated with the antimicrobial usage data. The occurrence of multidrug resistance among Campylobacter isolates from turkeys was also reported by Lee et al. (18).

The high prevalence of tetracycline resistance in Campylobacter isolates from organically raised broilers and turkeys observed in this study is quite interesting. Although tetracycline had never been used in those organic poultry farms, tetracycline-resistant Campylobacter strains were present in four out of five organic poultry farms surveyed in this study. The high prevalence of tetracycline resistance in Campylobacter isolates from the organic production system was also reported by other studies (10, 35). Tetracycline-resistant Campylobacter strains were not limited to the isolates from organic broilers and turkeys; these strains were also noticed among Campylobacter isolates from organic dairy cattle (35). Since tetracyclines have been used as feed additives for livestock and poultry for both therapeutic and subtherapeutic purposes for a long period of time (9, 14), it is possible that Campylobacter may have evolutionally become resistant to this class of antimicrobials, leading to the widespread distribution of tetracycline-resistant Campylobacter in animal reservoirs regardless of the production types. As with tetracycline resistance, the occurrence of kanamycin resistance was also observed in Campylobacter strains isolated from organically raised broilers and turkeys. However, these kanamycin-resistant Campylobacter strains were present mainly in only two organic poultry farms.

Interestingly, none of the C. jejuni and C. coli plus other Campylobacter species isolated from both conventionally raised and organically raised broilers and turkeys in our study was resistant to gentamicin. This finding is in agreement with previous studies by other research groups (19, 20), who reported that no gentamicin resistance was observed among Campylobacter isolates from poultry, except for one study from Spain (33), indicating that 25% of Campylobacter strains isolated from broilers were resistant to this antimicrobial. Although gentamicin was the most commonly used antimicrobial in conventionally raised broilers in this study, it was given to the birds at the hatchery by subcutaneous injection in the neck region. Since gentamicin is seldom absorbed in the gut (1) and Campylobacter is rarely present in the intestinal tracts of the birds during the first week of life, it is not surprising that the use of gentamicin has little or no impact on the selection of gentamicin resistance in Campylobacter species.

In this study, the difference in antimicrobial resistance rates between conventional poultry operations and organic poultry operations was observed mainly among C. coli and other Campylobacter species isolates rather than among C. jejuni isolates. Consistent with other findings (5, 19, 33), the high prevalence of antimicrobial resistance, particularly to erythromycin, clindamycin, and kanamycin, in this study was much more common in C. coli and other Campylobacter strains than in C. jejuni. A coresistance between erythromycin and clindamycin among Campylobacter isolates was also observed in this study as well as in other studies (19, 33, 38).

In summary, this study revealed significant differences in antimicrobial-resistant Campylobacter isolates between conventional poultry operations and organic poultry operations. The results suggest that the practice of antimicrobial usage in conventional poultry production systems influences the prevalence of antimicrobial-resistant Campylobacter organisms in conventionally raised broilers and turkeys. However, antimicrobial usage alone may not be solely responsible for the increased antimicrobial resistance in Campylobacter because even in the absence of antimicrobial exposure, a high level of tetracycline resistance was observed in organically raised broilers and turkeys. Similarly, the resistance rates to fluoroquinolones were also high in the surveyed conventional broiler flocks which were not directly exposed to the class of antimicrobials during the entire production period. These observations suggest that antimicrobial-resistant Campylobacter isolates are stable and able to transmit and persist in poultry even in the absence of selection pressure. Together, these findings reveal the complex nature of the occurrence and spread of antimicrobial resistance as well as underscore the difficulty in eliminating antimicrobial-resistant Campylobacter isolates, especially fluoroquinolone-resistant strains, from conventional poultry productions. In addition, this study also further highlights the need for prudent measures to prevent the occurrence and transmission of antimicrobial-resistant Campylobacter in the poultry reservoir.

ACKNOWLEDGMENTS

We thank Sonya M. Bodeis at the Center for Veterinary Medicine, Food and Drug Administration, for her technical assistance in this study. We also thank Amna B. El-Tayeb, Elisabeth J. Angrick, and fellow colleagues at the Avian Disease Investigation Laboratory at Ohio State University for their help, advice, and technical support. This work was supported by National Research Initiative Competitive grants 00-51110-9741 and 2003-35212-13316 from the USDA Cooperative State Research, Education, and Extension Service and grant 2003-38640-13225 from the North Central Region program for Sustaina ble Agriculture Research and Education (NCR-SARE).

REFERENCES