Disinfectant and Antibiotic Susceptibility Profiles of *Escherichia coli* O157:H7 Strains from Cattle Carcasses, Feces, and Hides and Ground Beef from the United States

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ABSTRACT

The disinfectant and antibiotic susceptibility profiles of 344 *Escherichia coli* O157:H7 strains from cattle carcasses, feces, and hides and ground beef from the United States were determined. A low prevalence of antibiotic resistance was observed (14%). The highest prevalences of resistance were to sulfisoxazole (10.5%), tetracycline (9.9%), streptomycin (7%), and chloramphenicol (4.9%). Four strains were resistant to eight antibiotics (two strains from ground beef and one strain each from hide and previsceral carcass swabs of cull cattle at harvest). Pulsed-field gel electrophoresis analysis of the *E. coli* O157:H7 strains revealed two major groups (designated 1 and 2) composed of 17 and 20 clusters, respectively. Clusters 1A, 1B, 1C, and 1G.1 were associated with multidrug-resistant strains. There was no observed correlation between disinfectant resistance and antibiotic resistance. Sixty-nine (20%) of the 344 strains were resistant to chlorhexidine or benzalkonium chloride or the MICs of benzyldimethyldecylammonium chloride were elevated. Inducible resistance was observed at elevated concentrations of antibiotics (1.4%) and disinfectants (6.1%). The highest rate of disinfectant inducible resistance was to OdoBan, quaternary ammonium chloride, and the surface disinfectants F25, FS512, and MG, which are used in dairies, restaurants, and food processing plants. High MICs (1.024 to 4.096 μg/ml) of acetic, lactic, and citric acids were found. The decreasing order of acid potency based on molar MICs (MICs$_\text{molar}$) was acetic, citric, and lactic acid. The correlation of the concentration of dissociated organic acids and MICs$_\text{molar}$ strongly suggests that the observed inhibition of *E. coli* O157:H7 was primarily due to dissociated forms of the acids.

*Escherichia coli* can cause serious illnesses or fatalities in elderly and immunocompromised people. Pathogenic *E. coli* primarily causes three types of infections in humans: enteric, urinary tract, and septicemic (32). Among Shiga toxin–producing *E. coli* strains, type O157:H7 is the most common (12). The Centers for Disease Control and Prevention (CDC) estimated that each year in the United States over 63,000 human illnesses, over 2,100 hospitalizations, and 20 deaths are caused by foodborne transmission of Shiga toxin–producing *E. coli* O157 (25).

The contamination of meat products with *E. coli* O157:H7 resulted in the recall of over 1 million pounds (454,000 kg) of meat in 2005 (29). During the decade prior to 2005, contamination of meat products with *E. coli* O157:H7 resulted in the recall of over 61.6 million pounds (27.9 million kilograms) of meat products (29). In 2008, *E. coli* O157:H7 contamination resulted in at least eight class I recalls totaling 292,813 lb (132,937 kg) of beef products, and other recalls that year involved undetermined amounts of beef products (30).

Pathogen prevention strategies must be comprehensive and must follow products from farm to table (31). Strategies to control bacteria include the use of biocides in the form of antiseptics and disinfectants. Biocides are routinely used in animal production, the food processing industry, veterinary medicine, human medicine, and consumers’ homes and are composed of a variety of active ingredients in multiple combinations (4). Chapman (9) stated that in reality, there are situations in which bacteria will be exposed to disinfectant concentrations lower than those required to deliver a lethal insult. Other researchers have described increased resistance to certain disinfectants in bacteria recovered from environments in which such agents have been used (14, 22).
Very limited information is available on disinfectant susceptibility of pathogens isolated from food producing animals. Therefore, we have described antibiotic and disinfectant susceptibilities of various pathogens from different animal sources. We found that 39 of 89 beta-hemolytic E. coli isolates from neonatal swine with diarrhea had increased resistance to the disinfectant chlorhexidine (Chlor) (4). Chlor resistance was significantly associated with resistance to the antibiotics gentamicin and streptomycin ($P = 0.04$ for both) (4). Maris (19) also found a link between the development of resistance to antiseptics and antibiotics in animal-derived bacterial isolates. We previously described the antibiotic and disinfectant susceptibility profiles of vancomycin-resistant Enterococcus faecium (VRE) isolated from community wastewater in Texas (5). These strains were tested against two panels of antibiotics, nine disinfectants, and five disinfectant components used on the farm, in hospitals, and in the home. Ninety-two percent of the strains had elevated resistance to the disinfectant triclosan, which is used in many commercial products and in the hospital environment. For a large percentage of these strains, the MIC of triclosan was higher than the concentration of triclosan found in household dish soap and in a septic bath wash used in the hospital setting. Both types of bacteria were more susceptible to the quaternary amine component didecyldimethylammonium chloride than to any of the benzyl quaternary amines (4, 5). When mixtures of quaternary amines were used as disinfectants, the activity of the disinfectants followed the didecyldimethylammonium chloride concentration.

Bacteria use a number of well-characterized mechanisms to resist the effects of antimicrobials, including (i) modification of the antimicrobial agent, (ii) alteration of the drug target, (iii) decreased accessibility to the drug target through the cell wall, and (iv) implementation of an alternative metabolic pathway not affected by the drug (20). In the case of disinfectants, alterations to the cell wall permeability or decreased accessibility to the target due to active efflux mechanisms that pump the chemical out of the cell can reduce the efficacy of the biocide (15). In some cases, genes that confer resistance to disinfectants may be linked to antibiotic resistance genes by their proximity on mobile genetic elements such as plasmids, transposons, or integrons. In such cases, acquisition of a genetic element may confer resistance to many other antimicrobials. This mechanism allows bacteria to rapidly adapt to hostile environments.

The objectives of this study were to describe the distribution of MICs of antibiotics and disinfectants for a diverse set of E. coli O157:H7 strains isolated from carcasses, feces, and hides of fed and cull cattle (preharvest and postharvest) and from ground beef to determine whether there is a link between antibiotic resistance and disinfectant susceptibility.

**MATERIALS AND METHODS**

**E. coli O157:H7 strains.** A total of 344 E. coli O157:H7 strains were evaluated in this study. Ninety-seven strains were from cattle feces (isolated May to August 2001 from Kansas, Oklahoma, Nebraska, and Texas) (24), and 47 strains were from hides and carcasses (isolated in 2003 from Kansas, Montana, Texas, and Utah). One hundred strains were from cull cattle at harvest; 70 strains from hides and 30 strains from previsceration samples collected during 2005 from four distinct regions of the United States (7) (A, B, C, and D). One hundred strains were collected from ground beef by the U.S. Department of Agriculture, Food Safety Inspection Service from undisclosed locations. All of the strains were defined by disinfectant and antibiotic susceptibility testing and by pulsed-field gel electrophoresis (PFGE) analysis. All strains were confirmed as E. coli O157:H7 using E. coli O157:H7 chromogenic plating medium (M-0300, R&F Products, Downers Grove, IL).

**Antimicrobial susceptibility testing.** A broth microdilution method from the Clinical and Laboratory Standards Institute was used for antimicrobial susceptibility testing (10, 11). MICs were determined as the lowest concentration of a compound that resulted in no visible growth of the organism (1). Antibiotic MICs were obtained using the National Antimicrobial Resistance Monitoring System (NARMS) nonfastidious gram-negative plate (CMV1AGNF), the nonfastidious gram-positive and nonfastidious gram-negative fluorquinolone plate (CMV1DW) (Sensititre, Trek Diagnostic Systems, Cleveland, OH), demineralized water, and cation-adjusted Mueller-Hinton broth with TES (Tris, EDTA, and NaCl, pH 8) (Trek Diagnostic). The MICs of the following 15 antimicrobials were determined using the Sensititre susceptibility system according to the manufacturer’s instructions: amikacin (AMI), ampicillin (AMP), amoxicillin–clavulanic acid (AUG), ceftiraxone (AXO), chloramphenicol (CHL), ciprofloxacin (CIP), sulfisoxazole (FIS), cefoxitin (FOX), gentamicin (GEN), kanamycin (KAN), nalidixic acid (NAL), streptomycin (STR), trimethoprim-sulfamethoxazole (SXT), tetracycline (TET), and ceftiofur (XNL). Pseudomonas aeruginosa ATCC 27853 and E. coli ATCC 25922 were used as controls for antibiotic susceptibility testing, and E. coli ATCC 25922 was used as a control for disinfectant susceptibility testing.

**Disinfectant susceptibility testing.** The 15 disinfectants and six disinfectant components used in the study with their abbreviations, recommendations for where they should be used, and source are listed in Table 1. Propionic acid was obtained from Sigma-Aldrich (Milwaukee, WI). Dimethyl sulfoxide (DMSO; used to solubilize some disinfectants) was obtained from Sigma-Aldrich (St. Louis, MO). Reverse osmosis water was produced on site by a reverse osmosis system (Millipore Corp., Bedford, MA). The following disinfectants exist as mixtures of multiple components. DC&R has the following active ingredients: 19.2% THN, 3.08% (67% C12BAC, 25% C14BAC, 7% C16BAC, and 1% [C9, C10, C13]) benzyltrimethylammonium chloride, and 2.28% formaldehyde. The active ingredients of MG, FSS, F25, and FS512 are the following: 0.105% (5% C12BAC, 60% C14BAC, 30% C16BAC, and 5% C18 benzyltrimethylammonium chloride) and 0.105% (68% C12BAC and 32% C14BAC). The active ingredients of ATL are 12% o-phenylenediamine, 10% o-benzyl-p-chlorophenol, and 4% p-tert-amylphenol. The active ingredients of P-128 are 4.61% C10AC and 3.07% (40% C12BAC, 50% C14BAC, and 10% C16BAC). Because DC&R, Tek-Trol, MG, FSS, F25, FS512, and P-128 are mixtures of several disinfectant components, the MICs of these disinfectants were determined on the composite mixtures.

The disinfectants and disinfectant components were diluted with reverse osmosis water to make working solutions and then filter sterilized using a syringe filter (0.2 μm by 25 mm; no. 431224,
TABLE 1. Disinfectants and disinfectant components

<table>
<thead>
<tr>
<th>Disinfectant</th>
<th>Abbreviation</th>
<th>Recommended use</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>Acetic acid</td>
<td>Veterinary clinics, human hospitals</td>
<td>EM Science (Gibbstown, NY)</td>
</tr>
<tr>
<td>Benzalkonium chloride</td>
<td>BKC</td>
<td>Veterinary clinics, human hospitals</td>
<td>Sigma-Aldrich (Milwaukee, WI)</td>
</tr>
<tr>
<td>Betadine solution, 10% povidone-iodine</td>
<td>P-I</td>
<td>Veterinary clinics, human hospitals</td>
<td>Medicine Chest Pharmacy (Bryan, TX)</td>
</tr>
<tr>
<td>Chlorhexidine diacetaete (Nolvasan solution)</td>
<td>Chlor</td>
<td>Veterinary clinics, human hospitals, farms</td>
<td>Producers Cooperative Association (Bryan, TX)</td>
</tr>
<tr>
<td>Citric acid</td>
<td>Citric acid</td>
<td>Veterinary clinics, farms</td>
<td>Sigma-Aldrich (St. Louis, MO)</td>
</tr>
<tr>
<td>DC&amp;R</td>
<td>DC&amp;R</td>
<td>Restaurants, food processing plants</td>
<td>Producers Cooperative Association (Bryan, TX)</td>
</tr>
<tr>
<td>Food Service Sanitizer</td>
<td>FSS</td>
<td>Restaurants, food processing plants, dairies</td>
<td>DadePaper (Loxley, AL)</td>
</tr>
<tr>
<td>F-25 Sanitizer</td>
<td>F25</td>
<td>Restaurants, food processing plants, dairies</td>
<td>DadePaper (Capital Heights, MD)</td>
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<tr>
<td>Final Step 512 Sanitizer</td>
<td>FS512</td>
<td>Restaurants, food processing plants, dairies</td>
<td>DadePaper (Loxley, AL)</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>Lactic acid</td>
<td>Restaurants, food processing plants, dairies</td>
<td>Alfa Aesar (Ward Hill, MA)</td>
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<tr>
<td>Magic Germicide</td>
<td>MG</td>
<td>Deodorizer, disinfectant, and sanitizer in the home,</td>
<td>Sam’s Club (College Station, TX)</td>
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<td></td>
<td></td>
<td>hospitals, restaurants, and schools</td>
<td></td>
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<td>OdoBan</td>
<td>OdoBan</td>
<td>Veterinary clinics, human hospitals</td>
<td>Burns Veterinary Supply, Inc. (Farmers Branch, TX)</td>
</tr>
<tr>
<td>P-128</td>
<td>P-128</td>
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<td>Burns Veterinary Supply, Inc. (Farmers Branch, TX)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>processing plants, dairies</td>
<td></td>
</tr>
<tr>
<td>Tek-Trol</td>
<td>Tek-Trol</td>
<td>Veterinary clinics, human hospitals, farms, food</td>
<td>Producers Cooperative Association</td>
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<tr>
<td></td>
<td></td>
<td>processing plants, poultry production, poultry</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>transportation vehicles</td>
<td></td>
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<tr>
<td>Triclosan (Irgasan)</td>
<td>Triclosan</td>
<td>Human hospitals, personal health care products and</td>
<td>Sigma-Aldrich (Milwaukee, WI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>soaps</td>
<td></td>
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<tr>
<td>Disinfectant components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Didecyldimethylammonium chloride</td>
<td>C10AC</td>
<td></td>
<td>Lonza Inc. (Fairlawn, NJ).</td>
</tr>
<tr>
<td>Benzylidimethylidodecylammonium chloride</td>
<td>C12BAC</td>
<td></td>
<td>Sigma-Aldrich (Milwaukee, WI)</td>
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<tr>
<td>Benzylidimethyltetradecylammonium chloride</td>
<td>C14BAC</td>
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<td>Sigma-Aldrich (Milwaukee, WI)</td>
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<tr>
<td>Benzylidimethylhexadecylammonium chloride</td>
<td>C16BAC</td>
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<td>Sigma-Aldrich (Milwaukee, WI)</td>
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<tr>
<td>J.T. Baker 37% formaldehyde solution</td>
<td>Formaldehyde</td>
<td></td>
<td>VWR International, Inc. (Marietta, GA)</td>
</tr>
<tr>
<td>Tris(hydroxymethyl)nitromethane</td>
<td>THN</td>
<td></td>
<td>Sigma-Aldrich (Milwaukee, WI)</td>
</tr>
</tbody>
</table>

Corning Inc., Corning, NY), DMSO was added to triclosan, C14BAC, C16BAC, and THN to aid chemical solubility, and the final solutions containing Mueller-Hinton broth (no. 275730, Difco, BD, Sparks, MD) and bacteria had a final concentration of ≤5% DMSO. The method of disinfectant susceptibility determination was similar to that used for disinfectant susceptibility testing of E. coli from neonatal swine (4), VRE from community wastewater (5), and Salmonella from turkeys (3). The following concentrations of disinfectants were tested: 1.024 to 1 µg/ml DC&R, 512 to 0.5 µg/ml Tek-Trol, 64 to 0.06 µg/ml Chlor, 4 to 0.004 µg/ml triclosan, 128 to 0.12 µg/ml MG, 128 to 0.12 µg/ml FSS, 128 to 0.12 µg/ml F25, 128 to 0.12 µg/ml FS512, 256 to 0.25 µg/ml OdoBan, 64 to 0.06 µg/ml P-128, 256 to 0.25 µg/ml BKC, 32,768 to 32 µg/ml P-I, 65,536 to 64 µg/ml acetic acid, 65,536 to 64 µg/ml lactic acid, 65,536 to 64 µg/ml citric acid, 2,048 to 2 µg/ml formaldehyde, 8,192 to 8 µg/ml THN, 64 to 0.06 µg/ml C10AC, 512 to 0.5 µg/ml C12BAC, 128 to 0.12 µg/ml C14BAC, and 128 to 0.12 µg/ml C16BAC.

PFGE analysis. PFGE analysis was performed according to the protocol developed by the CDC (25). Agarose-embedded DNA was digested with XbaI (New England Biolabs, Beverly, MA). Salmonella Braenderup H9812 was used as a control and for standardization of banding patterns on different gels (17). Banding patterns were inspected visually and then further analyzed and compared using BioNumerics software (Applied Maths, Saint-Martens-Latem, Belgium) employing the Dice similarity coefficient with a 1.5% band position tolerance in conjunction with the unweighted pair group method using arithmetic averages for clustering.

Calculation of the ratio of undissociated to dissociated acids. The concentration of an acid can be calculated when the pH is known by using the Henderson-Hasselbalch equation (16):

\[ \text{pH} = \log\frac{[A^-]}{[HA]} + \text{pK}_a \]

where pKₐ is the log-transformed acid dissociation constant (Kₐ), [A⁻] is the molar concentration of the conjugate base (or
dissociated weak acid), and [HA] is the molar concentration of the undissociated weak acid. The Henderson-Hasselbalch equation can be rewritten to give the ratio of undissociated acid to dissociated acid (6):

\[
\text{ratio} = \frac{[HA]}{[A^-]} = 10^{\text{pH} - \text{pK}_a}
\]

Therefore, when the pH and pKₐ of the acid in question are known, the ratio of undissociated acid to dissociated acid can be calculated. The pKₐ values for acetic acid, lactic acid, citric acid, and propionic acid are 4.75, 3.86, 3.14, and 4.87, respectively. When the total molar acid concentration is known, then the concentrations of the undissociated acid and dissociated acid can be calculated from the calculated ratio.

**RESULTS**

**Antimicrobial resistance.** The 344 *E. coli* O157:H7 strains were tested for antibiotic resistance against 15 spectrum antibiotics formulated to work against gram-negative bacteria: AMI, AMP, AUG, AXO, CHL, CIP, FIS, FOX, GEN, KAN, NAL, STR, SXT, TET, and XNL. Table 2 shows the susceptibility and resistance profiles of the *E. coli* O157:H7 strains by providing the MIC₅₀, MIC₉₀, antibiotic range, and the number of strains resistant to each antibiotic. Overall, a low prevalence of antibiotic resistance was observed in this group of strains, with only 48 (14%) of 344 strains resistant to at least one antibiotic. The highest prevalence of resistance was observed to the antibiotics FIS (36 strains), TET (34 strains), STR (24 strains), and CHL (17 strains). However, the strains that were antibiotic resistant were most often multidrug resistant (MDR). The following were the observed patterns of resistance: FIS, STR, and TET (eight strains); CHL, FIS, STR, and TET (five strains); AMP, AUG, CHL, FIS, FOX, STR, TET, and XNL (four strains, all from cull cows and ground beef); AMP, CHL, FIS, STR, and TET (3 strains); and FIS, KAN, and TET (3 strains).

Eight (19%) of 42 cattle hide strains and 1 (20%) of 5 cattle carcass strains were antibiotic resistant. *E. coli* O157:H7 strains from cull cow hide and cull cow preevisceration samples were obtained from four U.S. regions (7): A, B, C and D. In region A, 1 (6.25%) of 16 cull cow hide strains was resistant to TET, and none of the 11 preevisceration strains were antibiotic resistant. In region B, 3 (15%) of 20 cull cow hide strains and 2 (33.3%) of 6 preevisceration strains were resistant to FIS, STR, and TET. In region C, 1 (4.3%) of 23 cull cow hide strains and 1 (50%) of 2 preevisceration strains were resistant to eight antibiotics: AMP, AUG, CHL, FIS, FOX, STR, TET, and XNL. In region D, none of the 11 hide strains were antibiotic resistant, and only 1 (9.1%) of 11 cull cow preevisceration strains was resistant to TET.

Eight (8%) of 100 ground beef strains were antibiotic resistant: 1 to NAL; 2 to FIS and STR; 2 to FIS and TET; 1 to FIS, STR, and SXT; and 2 to AMP, AUG, CHL, FIS, FOX, STR, TET, and XNL. Of the 97 strains obtained from feedlot fecal samples from four U.S. states, 6 (26%) of 23 strains from Oklahoma were antibiotic resistant: 2 to FIS; 1 to FIS and TET; 2 to AMP, CHL, FIS, STR, and TET; and 1 to AMP, CHL, FIS, KAN, STR, SXT, and TET. In Texas, 5 (21%) of 24 fecal strains were antibiotic resistant: 1 to TET; 1 to FIS, STR, and TET; and 3 to CHL, FIS, STR, and TET. In Kansas, 7 (28%) of 25 fecal strains were antibiotic resistant: 1 to XNL; 2 to FIS and TET; 1 to FIS, STR, and TET; 2 to CHL, FIS, STR, and TET; and 1 to AMP, CHL, FIS, STR, and TET. In Nebraska, 4 (16%) of 25 fecal strains were antibiotic resistant: 1 to FIS, STR, and TET and 3 to CHL, FIS, KAN, and TET.

More antibiotic-resistant strains were found in fecal samples from feedlots than in samples from any other source. From the other locations, cattle hide, culled cows, and ground beef, nearly identical numbers of resistant strains were found. However, because only 42 cattle hide samples were evaluated, the percentage of antibiotic-resistant cattle hide strains was second to the percentage of resistant strains from feces in feedlots. Of the four strains that were resistant to the highest number of antibiotics (eight), two were found in cull cows and two were found in ground beef.

The *E. coli* O157:H7 strains were tested against a panel of fluoroquinolone antibiotics (CIP, danofloxacin, difloxacin, enrofloxacin, gatifloxacin, levofloxacin, marbofloxacin, and orbifloxacin), and the maximum CIP concentration on the gram-negative antibiotic panel was ≤0.06 µg/ml. The susceptibility tests for fluoroquinolone antibiotics revealed pansusceptibility for all the *E. coli* O157:H7 strains tested.

**Disinfectant susceptibility.** Table 3 shows the MIC distribution profiles of the 344 *E. coli* O157:H7 strains for the disinfectants and disinfectant components tested. The *E. coli* O157:H7 strains were pansusceptible to triclosan. The highest MICs, 1.042 to 8.192 µg/ml, were associated with P-1, acetic acid, lactic acid, and citric acid. The MICs of Chlor for these *E. coli* O157:H7 strains were 0.12 to 4 µg/ml. The strains had higher levels of susceptibility to BKC (4 to 32 µg/ml) than to MG, FSS, F25, FS512, OdoBan, and the component C10AC. The strains were slightly less susceptible to the individual components C12BAC, C14BAC, and C16BAC than to C10AC. All of the *E. coli* O157:H7 strains had high susceptibility to the disinfectant component THN, with MICs of 128 to 4,096 µg/ml, and to formaldehyde, with MICs of 16 to 128 µg/ml. The strains had high susceptibility to the two disinfectants DC&R and Tek-Trol with MICs of 64 to 512 µg/ml and 16 to 256 µg/ml, respectively, and the MICs of P-128 were 1 to 8 µg/ml. Sixty-eight of the 344 strains were resistant to either Chlor (39 strains) or BKC (12 strains) or had elevated MICs of C12BAC (32 strains). Of these 68 strains, 3 were resistant to both BKC and Chlor, 4 were resistant to Chlor and had elevated MICs of C12BAC, 2 were resistant to BKC and had elevated MICs of C12BAC, and 3 strains were resistant to both BKC and Chlor. The strains that were resistant to the disinfectant component C12BAC, and 22 of 44 strains were resistant to Chlor. One of two ground beef strains that were resistant to eight antibiotics had elevated MICs of C12BAC. In 16 (70%) of 23 Chlor-resistant strains, the MICs of C12BAC were not elevated. Some of the cull cow strains that were resistant to FIS, STR, and TET (nine strains) were also resistant to Chlor (two strains) or to
Inducible resistance occurred.

**Inducible resistance.** Inducible resistance occurred with both antibiotics and disinfectants. Inducible resistance was defined as growth of the organism above twice the dilution level or four times the MIC during a susceptibility test. The organisms were isolated, evaluated, and further tested to determine whether the elevated resistance was permanent. In all cases of inducible resistance (26 [7.6%] of 344 strains), no permanent elevated resistance was found. Five strains (1.4%) had inducible resistance to the antibiotics AXO, CIP, and TET. Only two of these five strains were resistant in susceptibility tests. Twenty-one strains (6.1%) had inducible resistance to the disinfectants OdoBan (5 strains), C14BAC (4 strains), C10AC (2 strains), C12BAC (2 strains), Chlor (2 strains), FS512 (2 strains), MG (2 strains), F25 (1 strain), and Tricosan (1 strain). Only 6 of these 21 strains were resistant to disinfectants in susceptibility tests. The highest frequency of inducible resistance was to OdoBan followed by C14BAC. There was no observed inducible resistance to the acids.

**PFGE analysis.** The 344 *E. coli* O157:H7 strains also were analyzed by PFGE. The PFGE patterns fell into two major groups, identified in Figures 1 and 2 as group 1 (n = 192) and group 2 (n = 142), respectively. Overall, the PFGE profiles of these *E. coli* O157:H7 strains were 62.1% similar. PFGE group 1 comprised 17 clusters with 86.6% or greater similarity (Fig. 1). PFGE group 2 comprised 20 clusters with 81.6% or greater similarity (Fig. 2). In the PFGE analysis, eight singletons and two outliers are not shown in the clusters in Figures 1 and 2.

**Calculation of DC&R and P-128 component MICs.** An individual component MIC of DC&R or P-128 was calculated by multiplying the DC&R MIC or P-128 MIC by the component of interest percentage and dividing by the sum of all the active component percentages for the disinfectant. For example, the MIC of the benzylidimethylammonium chloride (BAC) component (primarily C12BAC, C14BAC, and C16BAC) of DC&R at the DC&R MIC of 64 μg/ml (Table 3) is calculated as follows: the BAC component MIC = 64 μg/ml × 3.08/24.56 = 8 μg/ml. Therefore, the BAC component at DC&R MICs of 128 and 256 μg/ml are calculated to be 16 and 32 μg/ml, respectively. In a similar manner, the THN component of the DC&R MICs can be calculated as 50, 100, and 200 μg/ml for the DC&R MICs of 64, 128, and 256 μg/ml, respectively (Table 3), and the calculated formaldehyde portions of the DC&R MIC are 5.9, 11.88, and 23.76 μg/ml, respectively.

The BAC component of disinfectant P-128 can be calculated in a similar manner. The BAC component at a P-128 MIC of 2 μg/ml (Table 3) is as follows: BAC MIC = 2 μg/ml × 3.07/7.68 = 0.8 μg/ml. The BAC component at a P-128 MIC of 4 and 8 μg/ml is 1.6 and 3.2 μg/ml, respectively. In like manner, the C10AC component of P-128 at MICs of 2, 4, and 8 μg/ml (Table 3) are 1.2, 2.4, and 4.8 μg/ml, respectively.

**Calculation of the ratio of undissociated to dissociated acids.** For direct comparison of MICs of chemicals with different molecular weights, the values for molar MICs (MICs_molar) are used. The pH at all the *E. coli* O157:H7 MICs_molar for each of the acids (acetic, lactic, and citric) is shown in Figure 3. The number of strains at each MIC_molar is shown next to each data point. The MICs_molar for all 344 strains occurred at an acetic acid pH that was much less acidic than that of the other two acids. The MICs_molar for 99.7% of all strains occurred at an acetic acid pH of 4.29, whereas the MICs_molar for 98.3% of the strains occurred at a lactic acid and citric acid pH of 3.73 and 3.95, respectively.

### Table 2. NARMS antibiotic MICs and resistance profiles for 344 *E. coli* O157:H7 strains

<table>
<thead>
<tr>
<th>Antibiotic&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MIC&lt;sub&gt;50&lt;/sub&gt; (μg/ml)</th>
<th>MIC&lt;sub&gt;90&lt;/sub&gt; (μg/ml)</th>
<th>Conc. range (μg/ml)</th>
<th>No. (%) resistant strains</th>
<th>Breakpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMI</td>
<td>2</td>
<td>2</td>
<td>≦0.5–8</td>
<td>0 (0)</td>
<td>≧64</td>
</tr>
<tr>
<td>AMP</td>
<td>2</td>
<td>4</td>
<td>≦1–32</td>
<td>9 (2.6)</td>
<td>≧32</td>
</tr>
<tr>
<td>AUG</td>
<td>4/2</td>
<td>4/2</td>
<td>≦1/0.5–32/16</td>
<td>4 (1.2)</td>
<td>≧32/16</td>
</tr>
<tr>
<td>AXO</td>
<td>≤0.25</td>
<td>≤0.25</td>
<td>4–32</td>
<td>17 (4.9)</td>
<td>≧32</td>
</tr>
<tr>
<td>CHL</td>
<td>8</td>
<td>16</td>
<td>≦0.015–0.25</td>
<td>0 (0)</td>
<td>≧4</td>
</tr>
<tr>
<td>CIP</td>
<td>0.03</td>
<td>0.03</td>
<td>≦0.16–256</td>
<td>—</td>
<td>≧512</td>
</tr>
<tr>
<td>FIS</td>
<td>≤16</td>
<td>&gt;256</td>
<td>≦16–256</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>FOX</td>
<td>8</td>
<td>8</td>
<td>2–32</td>
<td>4 (1.2)</td>
<td>≧32</td>
</tr>
<tr>
<td>GEN</td>
<td>0.5</td>
<td>1</td>
<td>0.25–8</td>
<td>0 (0)</td>
<td>≧16</td>
</tr>
<tr>
<td>KAN</td>
<td>≤8</td>
<td>≤8</td>
<td>1–32</td>
<td>0 (0)</td>
<td>≧32</td>
</tr>
<tr>
<td>NAL</td>
<td>4</td>
<td>4</td>
<td>0.015–0.25</td>
<td>0 (0)</td>
<td>≧4</td>
</tr>
<tr>
<td>STR</td>
<td>≤0.12/2.38</td>
<td>≤0.12/2.38</td>
<td>≤0.12/2.38–≤4/76</td>
<td>2 (0.6)</td>
<td>≧4/76</td>
</tr>
<tr>
<td>SXT</td>
<td>≤4</td>
<td>8</td>
<td>4–32</td>
<td>34 (9.9)</td>
<td>≧16</td>
</tr>
<tr>
<td>TET</td>
<td>≤4</td>
<td>8</td>
<td>4–32</td>
<td>34 (9.9)</td>
<td>≧16</td>
</tr>
<tr>
<td>XNL</td>
<td>0.5</td>
<td>1</td>
<td>0.25–8</td>
<td>8 (2.3)</td>
<td>≧8</td>
</tr>
</tbody>
</table>

<sup>a</sup> AMI, amikacin; AMP, ampicillin; AUG, amoxicillin–clavulanic acid; AXO, ceftriazone; CHL, chloramphenicol; CIP, ciprofloxacin; FIS, sulfisoxazole; FOX, cefoxitin; GEN, gentamicin; KAN, kanamycin; NAL, nalidixic acid; STR, streptomycin; SXT, trimethoprim–sulfamethxazole; TET, tetracycline; XNL, cefotiofur.

<sup>b</sup> The FIS range on the antibiotic plates is not large enough to discern the resistance breakpoint.
TABLE 3. Disinfectant and disinfectant component susceptibility profiles for 344 E. coli O157:H7 strains

<table>
<thead>
<tr>
<th>Disinfectant or component</th>
<th>No. of strains at MIC (μg/ml) of:</th>
<th>MIC&lt;sub&gt;50&lt;/sub&gt; (μg/ml)</th>
<th>MIC&lt;sub&gt;90&lt;/sub&gt; (μg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC&amp;R</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Tek-Trol</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Chlor</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Triclosan</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>P-128</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>BKC</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>P-I</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>MG</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>FSS</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>F25</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>FS512</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>OdoBan</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Acetic acid</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Lactic acid</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Citric acid</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>C10AC&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>C12BAC&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>C14BAC&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>C16BAC&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>THN&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
<tr>
<td>Formaldehyde&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>0.06 0.12 0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048 4,096 8,192</td>
<td>128 256</td>
</tr>
</tbody>
</table>

<sup>a</sup> Chlor, chlorhexidine; BKC, benzalkonium chloride; P-I, povidone-iodine; MG, Magic Gemicide; FSS, Food Service Sanitizer; F25, F-25 Sanitizer; FS512, Final Step 512 Sanitizer; C10AC, didecyldimethylammonium chloride; C12BAC, benzylidimethyldecylammonium chloride; C14BAC, benzylidimethyltetradecylammonium chloride; C16BAC, benzylidimethylhexadecylammonium chloride; THN, tris(hydroxylmethyl)nitromethane.

<sup>b</sup> Disinfectant components.
Figure 4 shows the distribution of calculated undissociated acid concentrations for acetic, lactic, and citric acid at the MICs-molar for the 344 *E. coli* O157:H7 strains. The undissociated citric acid and lactic acid concentrations at the MICs-molar for 98.3% of all strains tested were 2.86 and 26.11 mM, respectively. The undissociated acetic acid concentration at the MICs-molar for 99.7% of the strains tested was 50.63 mM. This was a difference of 47.77 mM between the undissociated acetic acid and citric acid concentrations required for disinfection of 98% of the strains (depicted by the shaded band in Fig. 4).

Concentrations of the dissociated acids at the MICs-molar for the 344 *E. coli* O157:H7 strains are shown in Figure 5. The narrow cross-hatched band in Figure 5 depicts the difference in the molar dissociated organic acid concentrations required to produce MICs-molar for 98.3% of the strains.
with acetic, lactic, and citric acids. The effective concentrations of the dissociated acids resulted in a small difference (D1.78 mM) among the three acids. Based upon the observed narrow band of effective dissociated acid concentrations, a small random group (n ~ 55) of strains were evaluated for MICs \( \text{molar} \) for propionic acid (Fig. 5). The shaded band plus the cross-hatched band show the difference in concentrations of the dissociated acids for MICs \( \text{molar} \) for 98.3% of the strains using acetic, lactic, and citric acids and 100% of the 55 strains tested with propionic acid. The overall difference in the dissociated acid concentration between the two regions was 5.44 mM.

**DISCUSSION**

Overall, a low incidence of antibiotic resistance (14%) was observed in the 344 \( E. \ coli \) O157:H7 strains. In 1998, Meng et al. (21) found a resistance rate of 24% among 125 strains of \( E. \ coli \) O157:H7 (n = 118) and O157:NM
(n = 7) obtained from animals, foods, and humans. Therefore, the larger group of 344 E. coli O157:H7 strains studied here had a reduced rate of resistance compared with that found by Meng et al. But similar to our study, Meng et al. found that the most common resistance type was to antibiotics FIS plus STR plus TET. The antibiotic-resistant strains in our study were most often MDR. The strains that were resistant to the highest number of antibiotics (eight), AMP, AUG, CHL, FIS, FOX, STR, TET, and XNL, were obtained from two cull cow and two ground beef samples. The lowest incidence of antibiotic resistance was observed in Nebraska feedlots, compared with those in Kansas, Oklahoma, and Texas.

The E. coli O157:H7 strains in this study were more resistant to DC&R, Tek-Trol, P-I, acetic acid, lactic acid, citric acid, and the components THN and formaldehyde than they were to Chlor, triclosan, P-128, BKC, MG, FSS, F25, FS512, OdoBan and the amino chloride components C10AC, C12BAC, C14BAC, and C16BAC. All strains were pansusceptible to triclosan. The components of DC&R are THN (19.2%), BACs (3.08%; primarily 67% C12BAC, 25% C14BAC, and 7% C16BAC), and formaldehyde (2.28%). Tek-Trol is a phenolic disinfectant. The application rates for DC&R and Tek-Trol are 1,919 and 1,016 mg/ml, respectively, and the MICs of these disinfectants were just below the application concentrations. An interesting MIC relationship can be seen when the concentration of individual components in DC&R are examined and compared. The calculated MICs for the components THN and formaldehyde in DC&R are well below the concentrations required for disinfection of E. coli O157:H7. However, the BAC components C12BAC, C14BAC, and C16BAC have calculated MICs of 8, 16, and 32 mg/ml, which are equivalent to the BAC MICs required for disinfection of E. coli O157:H7. These BAC concentrations in DC&R would then be responsible for the entire antimicrobial activity of DC&R, and these results are similar to those obtained for DC&R used to disinfect VRE (5) and Salmonella in turkeys (3). The application rate of DC&R at 1,919 µg/ml is higher than that required for killing E. coli O157:H7 (512 µg/ml).

A larger proportion of the disinfectant-resistant strains were resistant to Chlor (57%) than to C12BAC (47%). We used the same definition for Chlor resistance as have other researchers, who defined Chlor resistance in staphylococci based on whether they were able to grow at or above a Chlor concentration of 1 µg/ml (18). Chlor resistance in beta-hemolytic E. coli strains from neonatal swine with diarrhea
was significantly linked to resistance to GEN and STR (both 
$P = 0.04$) (4). Chlor resistance also was found in 
Salmonella strains from turkeys in processing plants (3). In 
the present study, 22% of all ground beef strains were 
resistant to Chlor. A high proportion (87.5%) of Chlor-
resistant strains from fecal samples in feedlots were MDR; however, overall only 41% of the feedlot Chlor-resistant strains and only 18% of the ground beef Chlor-resistant 
strains were MDR. The Chlor-resistance in strains appeared 
not to be correlated with a particular type of antibiotic 
resistance, and often these strains had no corresponding 
antibiotic resistance. Therefore, antibiotic resistance did not 
appear to be related to Chlor resistance nor was any other 
disinfectant resistance related to antibiotic resistance. In this 
group of 344 E. coli O157:H7 strains, no link was found 
between antibiotic resistance and disinfectant resistance.

C10AC is the key active ingredient in P-128, at 60% of 
the active ingredients. At the observed P-128 MICs of 2, 4, 
and 8 µg/ml, the C10AC component MICs were calculated as 
1.2, 2.4, and 4.8 µg/ml, respectively. This distribution is 
similar to that of 1, 2, and 4 µg/ml for disinfection of E. coli 
O157:H7 by the C10AC component. However, the calculated 
MICs of the BAC component of P-128 were 0.8, 1.6, and 
3.2 µg/ml at the P-128 MICs of 2, 4, and 8 µg/ml, respectively. 
These calculated MICs are far below the 
concentrations required for disinfection of E. coli O157:H7 
by the individual BAC components (4 to 32 µg/ml). Therefore, C10AC is considered the primary active component 
in P-128 against E. coli O157:H7. C10AC was the primary active component in P-128 against VRE (5) and against Salmonella from turkeys (3).

Sidhu et al. (26) defined food-associated gram-negative 
bacteria as susceptible to BKC at MICs of <30 µg/ml, and 
the bacteria were considered to have low resistance to BKC 
at MICs of 31 to 50 µg/ml. Therefore, 12 of the E. coli 
O157:H7 strains in the present study had low BKC resistance. These BKC MICs are similar to those observed for Salmonella strains from turkeys in processing plants (3).

Higher MICs of the individual ammonium chlorides 
(C10AC, C12BAC, C14BAC, and C16BAC) were found in 
the present study than were reported from a previous study 
of VRE (5). However, in a few cases (1.4%) inducible 
resistance at antibiotic concentrations higher than the MIC 
were observed, but a higher prevalence (6.1%) of inducible 
resistance at disinfectant concentrations above the MIC 
as observed. The highest rate of inducible resistance was 
observed for the disinfectant OdoBan and the components 
C14BAC, C10AC, and C12BAC. However, inducible resistance was also found with F25, F5512, and MG, which 
are all surface disinfectants and sanitizers used in dairies, 
restaurants, and food processing plants and have quaternary 
ammonium chlorides as their active components. The 
inducible resistance of E. coli O157:H7 may be problematic 
because some bacteria may survive a disinfectant applica-
tion, therefore putting the public and employees of dairies, 
restaurants, or food processing plants at risk.

The E. coli O157:H7 strains in the present study had 
high MICs of the three acids: acetic, lactic, and citric. This 
finding is consistent with the understanding that E. coli 
O157:H7 has multiple acid-resistance systems to protect it 
from extreme acid stress (2). At first glance, it appears that 
the order of acids with the best disinfection results is acetic, 
lactic, and citric acid with MICs of 1.024, 2.048, and 
4.096 µg/ml, respectively. However, recalculation of the 
MICs to molar values reveals that acetic, lactic, and citric 
acids have MICs of 16, 22.5, and 19.4 µmole/ml, 
respectively, suggesting that citric acid is better than lactic 
as a disinfectant against E. coli O157:H7.

Carter et al. (8) provided an example of how bacterial 
pathogens maintain phenotypes that facilitate survival and 
adaptation. Two subpopulations of E. coli O157:H7, the C+ 
and C− variants proficient or deficient, respectively, in curli 
production, were modulated with respect to their environ-
ment to help improve their survival. The C+ variants grew 
greater in nutrient-limited conditions, and the C− variants 
were more acid resistant than the C+ variants. However, 
the authors speculated that the C+ variants dominate popula-
tions of E. coli O157:H7 in natural environments. The 
C− variants were observed by exposing the E. coli O157:H7 in 
pH 2.5 broth. These results contrast with those shown in 
Figure 3, in which no strains survived below pH 3.4. 
Therefore, we expect that the E. coli O157:H7 isolates in 
this study that were obtained from natural environments are 
most likely predominantly the C+ variant.

The most populated PFGE clusters were 1A, 1B, and 
2A and likely represent epidemic E. coli O157:H7 strains (15, 28), although multiple-enzyme PFGE analysis would 
be needed to support this hypothesis. PFGE cluster 2A was 
associated with only one antibiotic resistant strain, which 
was resistant only to TET. Clusters 1A and 1B were 
associated with resistance to multiple antibiotics and 
comprised fecal strains from feedlots in Oklahoma (n = 
3), Texas (n = 1), Kansas (n = 3), and Nebraska (n = 2). 
Primarily, clusters 1A, 1B, and 2A were associated with 
strains from ground beef that were resistant to the 
disinfectants BKC or Chlor or both and resistant to high 
centralizations of C12BAC. One ground beef strain in 
cluster 1B also was resistant to Chlor, FIS, and TET. Six 
strains from cattle hides were grouped in cluster 1A. Three 
of these strains were resistant to one antibiotic; one was 
resistant to Chlor, FIS, and TET; one was resistant to high 
centralizations of the disinfectant component C12BAC; and 
one was resistant to high concentrations of BKC. Cluster 1A 
included a bull cow previsceration strain resistant to Chlor, 
and cluster 1B included a bull cow hide strain resistant to 
high concentrations of C12BAC. Cluster 1C included two 
ground beef strains that were resistant to the same eight 
antibiotics as were the two bull cow strains, one from a hide 
and one from a previsceration carcass. Both of these 
cull cow strains were resistant to the same eight antibiotics 
and had a PFGE cluster designation of 1G1. However, for most 
of these 344 strains, the strains with significant antibiotic 
resistance were not resistant to the disinfectants.

Bacterial inhibition by organic acids was not dependent 
singly on pH or on the undisassociated acid as has been 
suggested by others (6, 27). However, the MICs of acetic, 
citric, and lactic acids for these 344 E. coli O157:H7 strains 
were closely associated with the dissociated acid species. The
cross-hatched band in Figure 5 defines the concentrations of dissociated acids required to produce MICs\textsubscript{molar} for 98.3% of the \textit{E. coli} O157:H7 strains tested. The difference was only 1.78 mM among the acids, so a small drop in the concentration of the dissociated acids may result in a large number of bacteria escaping disinfection. In particular, citric acid and lactic acid appear to require a higher concentration of dissociated acid for effective disinfection. Following these tests, we tested 55 strains randomly chosen from the 344 \textit{E. coli} O157:H7 strains for susceptibility against propionic acid, and the results were similar to those for the other acids. The observed correlation of the concentration of dissociated organic acids with the MIC\textsubscript{molar} strongly suggests that the observed inhibition of \textit{E. coli} O157:H7 was primarily due to the dissociated form of the acids.

In summary, the disinfectant and antibiotic susceptibility profiles of 344 \textit{E. coli} O157:H7 strains from cattle carcasses, feces, and hides and ground beef in the United States were determined. A low prevalence (14% of strains) of resistance to at least one antibiotic was observed. The highest prevalences of resistance were observed for sulfisoxazole (10.5% of strains), tetracycline (9.9%), streptomycin (7%), and chloramphenicol (4.9%). Four \textit{E. coli} O157:H7 strains were resistant to the same eight antibiotics (two strains from ground beef and one each from hide and pre- or post-slaughter carcass swabs of cattle at harvest). One of the two ground beef strains resistant to eight antibiotics had elevated MICs of C12BAC, but the other three strains resistant to the same eight antibiotics had no resistance to the 15 disinfectants and six disinfectant components tested. PFGE analysis of these 344 strains partitioned the strains into two major groups (1 and 2) composed of 17 and 20 clusters, respectively. Clusters 1A, 1B, 1C, and 1G.1 were associated with MDR strains. The most populated PFGE clusters were 1A, 1B, and 2A, which likely included epidemic \textit{E. coli} O157:H7 strains. However, multiple-enzyme PFGE analysis would be needed to confirm this finding. Overall, 22% of all ground beef strains were resistant to Chlor. A small number of Chlor-resistant strains were also resistant to one or more antibiotics; however, these strains were not consistent in the types of antibiotic resistance observed, and antibiotic resistance did not appear to be related to Chlor resistance. No other disinfectant resistance was related to antibiotic resistance. Therefore, within these \textit{E. coli} O157:H7 strains no link between antibiotic resistance and disinfectant resistance was found. Sixty-nine (20%) of the 344 strains were resistant to Chlor or BKC or had elevated MICs of BAC. Inducible resistance was observed when strains were tested with elevated concentrations of antibiotics (1.4%) and disinfectants (6.1%). The highest rate of disinfectant inducible resistance was to OdoBan, quaternary ammonium chlorides, and the surface disinfectants F25, FS512, and MG used in dairies, restaurants, and food processing plants. The inducible resistance of \textit{E. coli} O157:H7 may be problematic by allowing some bacteria to survive a disinfectant application, therefore putting the public and employees of these facilities at risk. High MICs (1,024 to 4,096 \mu g/ml) of the organic acids were found, and the decreasing order of acid potency based on MICs\textsubscript{molar} was acetic, citric, and lactic acid. Bacterial inhibition from organic acids was not dependent solely on pH nor on the undissociated acid, but inhibition of these 344 \textit{E. coli} O157:H7 strains was closely associated with the dissociated acid. A small drop in the concentration of the dissociated acids may result in a large number of bacteria escaping disinfection.

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