CHAPTER 8

FOOD SAFETY ISSUES AND THE MICROBIOLOGY OF POULTRY

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8.1 INTRODUCTION

Poultry, including broilers, turkey, duck, and quail, rank in third place among products incriminated in foodborne illness. For the United States, annual per capita poultry consumption (73.5 lb) is highest among the meat groups, exceeding beef (62.4 lb) and pork (46.4 lb) (USDA-ARS, 2007).

In 1996–1998, the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) conducted nationwide microbial baseline surveys of beef, hogs, poultry, and turkey carcasses (Table 1). The data show the highest contamination of poultry carcasses, including broilers and turkeys, with *Campylobacter* (~90%), *Salmonella* (~20%), and *L. monocytogenes*. FSIS baseline of ground products similarly recovered *Salmonella* in ground chicken (44.6%) and in ground turkey (49.9%) meat (USDA-FSIS, continuously updated). Performance standards for *Salmonella*, based on these national surveys, are in place with a limit for carcass contamination of 18.2% of turkeys and 20% of broilers. *Campylobacter* performance standards are pending.

Pathogen intervention strategies have reduced human illness and deaths. CDC FoodNet estimates an overall 21% decrease in bacterial foodborne illnesses in the 1996–1999 interval (Fig. 1). *Salmonella* levels in raw poultry have declined since 1990, when approximately 40% of carcasses tested were *Salmonella* positive, to 2000, when less than 10% of carcasses were positive. However, from 2002 to 2005, when 16% of carcasses were positive, FSIS recorded an increase in *Salmonella* in broilers. Because the reduction of human salmonellosis is lagging behind that of other human foodborne infections, in 2007 USDA-FSIS launched an initiative to reduce *Salmonella* in broilers, which included publishing the names of meat plants that have trouble controlling *Salmonella*.

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TABLE 1  Summary of Microbiological Baseline Data for Selected Foodborne Bacteria on Carcasses

<table>
<thead>
<tr>
<th></th>
<th>Steers/Heifers</th>
<th>Cows/Bulls</th>
<th>Hogs</th>
<th>Turkeys</th>
<th>Broilers</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. coli O157:H7</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Campylobacter</td>
<td>4</td>
<td>1.1</td>
<td>31.5</td>
<td>90.3</td>
<td>88.2</td>
</tr>
<tr>
<td>Salmonella</td>
<td>1</td>
<td>2.7</td>
<td>8.7</td>
<td>18.5</td>
<td>20</td>
</tr>
<tr>
<td>L. monocytogenes</td>
<td>4.1</td>
<td>11.3</td>
<td>7.4</td>
<td>5.9</td>
<td>15</td>
</tr>
</tbody>
</table>

Source: USDA-FSIS (continuously updated-b).

Percent positive samples; n = ca. 2000 each.

FIG. 1  Relative rates of bacterial foodborne pathogens compared with 1996–1999 baseline period. (From CDC, 2006.)

Federal agencies, in collaboration with the poultry industry, have implemented guidelines to remove contaminated meat and poultry products from commerce. For example, between 2000 and 2001, FSIS requested voluntary recall of approximately 31.5 million pounds of poultry products due to the presence of foodborne pathogens (USDA-FSIS, continuously updated-a).

Although the current emphasis is on pathogen reduction post-harvest at the processing level, clearly, reducing the on-farm prevalence of potential human pathogens will deliver clean birds to the abattoir, which may result in an overall decline in human foodborne illness. In this chapter we address methods to reduce foodborne pathogens from farm to fork: during poultry production, processing, and ultimately at the consumer’s table.

8.2 CHARACTERISTICS OF FOODBORNE ILLNESS

Campylobacter and Salmonella are the two most important bacterial pathogens incriminated in foodborne illness related to poultry products, while Listeria...
monocytogenes is more frequently associated with contaminated ready-to-eat products, including poultry. Campylobacter and Salmonella inhabit the intestinal tract of clinically healthy birds. In contrast, in humans, consumption of contaminated undercooked poultry results either in no clinical illness or in nausea, vomiting, diarrhea, fever, dehydration, and headaches. Antimicrobial characteristics of the avian mucosa may underlie this phenomenon (Young et al., 2007).

8.2.1 Campylobacter

*Campylobacter jejuni* (Fig. 2) is the leading cause of human foodborne illness worldwide and infects 1% of the population of Western Europe each year (Humphrey et al., 2007). In the United States, the nearly 2 million human cases account for an estimated $1.2 billion in productivity losses annually. Based on attribution data, contaminated poultry (72%), dairy products (7.8%), and red meats, including beef (4.3%) and pork (4.4%), are vehicles of transmission and acknowledged risk factors (Hoffman et al., 2007; Miller and Mandrell, 2005). However, other factors, such as water, contact with pets, and worldwide travel, are significant. *Campylobacter* resides in protozoans, which may explain its survival in rivers and streams.

*Campylobacter* grow in low-oxygen environments (5% O\textsubscript{2}) and are termed *microaerophiles*. Therefore, growth media incorporate oxygen quenchers, such as blood and activated charcoal. In the laboratory a microaerobic environment is achieved with commercially available special gas packets or incubators (5% CO\textsubscript{2}, 85% N\textsubscript{2}, 10% CO\textsubscript{2}). *C. jejuni* and *C. coli* grow optimally at 42°C (thermotolerant), which coincides with the body temperature of poultry.

*Campylobacter* replicate in the mucus layer over the intestinal villi of its host, where minimal amounts of oxygen are available. They survive but do not multiply on poultry carcasses or on contact surfaces present in the slaughterhouse or on kitchen cutting boards. Drying and freezing kill *Campylobacter*. Freezing is a major critical

![Campylobacter](image-url)
control point in carcass processing. Thus, low infectious dose for humans (1000 CFU), coupled with Campylobacter’s inability to replicate during refrigeration, indicate that even modest reductions during processing and food preparation may alleviate human illness.

8.2.2 Salmonella

There are approximately 2500 serotypes of Salmonella enterica (Fig. 3). The most common serotypes isolated from turkeys and from broilers between 1997 and 2005 (Morningstar-Flugrad, 2006) and from human clinical cases in 2005 (CDC, 2006) are shown in Table 2.

8.3 APPROACHES TO MAINTAINING PRODUCT QUALITY AND REDUCING THE NUMBER OF MICROORGANISMS

8.3.1 Flock-to-Fork Concept

The FSIS/APHIS Animal Production Technical Analysis Group identified the critical control points of live production (Fig. 4). Good agricultural practices (GAPs) and hazard analysis of critical control points (HACCP) are intervention programs
Table 2: Salmonella enterica Serotypes Most Frequently Isolated from Turkeys, Broilers, and Human Clinical Cases

<table>
<thead>
<tr>
<th>Turkey Isolates, 1997-2005</th>
<th>Percent of Total</th>
<th>Broiler Isolates 1997-2005</th>
<th>Percent of Total</th>
<th>Human Isolates, 2005</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heidelberg</td>
<td>20.9</td>
<td>Kentucky</td>
<td>35.5</td>
<td>Typhimurium</td>
<td>19</td>
</tr>
<tr>
<td>Hadar</td>
<td>16.6</td>
<td>Heidelberg</td>
<td>20.3</td>
<td>Enteritidis</td>
<td>18</td>
</tr>
<tr>
<td>Senftenberg</td>
<td>8.1</td>
<td>Typhimurium</td>
<td>6.2</td>
<td>Newport</td>
<td>10</td>
</tr>
<tr>
<td>Reading</td>
<td>7.3</td>
<td>Typhimurium var. 5-</td>
<td>4.9</td>
<td>Heidelberg</td>
<td>6</td>
</tr>
<tr>
<td>Saint Paul</td>
<td>6.5</td>
<td>Enteritidis</td>
<td>4.3</td>
<td>Javiana</td>
<td>5</td>
</tr>
<tr>
<td>Agona</td>
<td>5.0</td>
<td>Hadar</td>
<td>4</td>
<td>14, (5), 12:i: -</td>
<td>154</td>
</tr>
<tr>
<td>Schwarzengrund</td>
<td>4.5</td>
<td>4(s)12:i:-</td>
<td>3.1</td>
<td>Montevideo</td>
<td>2.2</td>
</tr>
<tr>
<td>Muenster</td>
<td>3.7</td>
<td>Montevideo</td>
<td>2.7</td>
<td>Muenchen</td>
<td>2</td>
</tr>
<tr>
<td>Arizona</td>
<td>2.7</td>
<td>Thompson</td>
<td>2.3</td>
<td>Saintpaul</td>
<td>1.9</td>
</tr>
<tr>
<td>Typhimurium</td>
<td>2.5</td>
<td>Schwarzengrund</td>
<td>2.2</td>
<td>Braenderup</td>
<td>1.7</td>
</tr>
</tbody>
</table>


*Formerly Copenhagen.

Designed for poultry to minimize and eliminate bacterial foodborne pathogens in poultry, which are transmitted in feed, water, and in ovo. On-farm strategies (e.g., best management practices, good agricultural practices) attempt to minimize pathogens in live birds that enter the slaughter facilities. On-farm intervention programs begin at the breeder farms, continue to the hatcheries, and through grow-out at the poultry farms. The more rigorous mandated HACCP guidelines, which require documentation, are in place at feed mills, slaughter operations, processing facilities, distribution centers, and continue through to retail.

Salmonella is the model used in developing on-farm best management practices (BMPs) since (1) all species of livestock are a source of the organism; (2) Salmonella was ranked number one for its impact on human health; (3) there is significant knowledge of salmonellosis compared with other foodborne pathogens; and (4) the poultry industry has a long history of voluntary control and eradication programs for Salmonella. Implementation of BMPs and microbiological control technologies against Salmonella at food safety control points during live production of turkeys should also control other pathogens (NTF, 1999).

8.3.2 On-Farm Interventions

Breeders: Foundation hatcheries supply not only future generations of breeder flocks but are also the ultimate source of meat birds for human consumption. Pathogen reduction begins with procurement of clean pathogen-free breeder stock at the foundation hatchery and requires strict biosecurity, vaccination, and regular surveillance of the breeder flocks for pathogens, especially Salmonella enteritidis (Fig. 3). Salmonella transmission occurs both by vertical transmission (in ovo, hen to progeny) and via the fecal–oral route (horizontal transmission). Because of the known routes of bacterial transmission (through progeny, feed, and water), a clean
breeder stock, clean environment, clean source of drinking water, and clean feed are critical during all phases of poultry production.

To maintain potable water, breeder and poultry farms use "closed"-nipple drinker systems to minimize fecal contamination of the drinking water, unlike "open" drinker systems, which used Bell or Plasson drinkers. The use of water sanitizers such as chlorine (2 to 3 ppm) or other organic acid to flush the water system periodically retards bacterial growth.

**Hatcheries** The high quality of eggs arriving at a multiplier hatchery will minimize problems during the hatching process. Procuring eggs from farms enrolled in the National Poultry Improvement Plan or other industry group ensures egg quality and *Salmonella*-free status. Eggs contaminated during and after the laying process introduce pathogens into the commercial hatchery. Baby chicks or turkey pouls are exposed to bacterial contaminants as early as 1 day of age.

Hatchery sanitation utilizing disinfectants and sanitizers retards the growth of pathogens. Stringent microbial monitoring and sampling of the hatchery environment and equipment assures the effectiveness of sanitation standard operating procedures. Evaluation of first-day mortality is a practical indicator of the effectiveness of hatchery intervention programs.

Turkey pouls are routinely immunized at the hatchery for Newcastle disease virus, turkey coryza (*Bordetella*), and coccidiosis. Antimicrobial injections (gentamicin) may be given to the day-of-hatch turkey poult to repress bacterial pathogens.

**Meat Bird** Live production of the meat bird begins at the commercial hatchery with the broiler chick or turkey poult, continues through grow-out, and concludes with the transportation of a market-weight bird to slaughter.

Day-of-hatch turkey pouls are delivered to the farm and placed on fresh litter in a clean, fumigated house. The food safety control points to block microbial, chemical, and physical contaminants during turkey production are detailed in Fig. 4. To avoid introduction of pathogens from adult birds, strict biosecurity is in place, with only farm personnel attending the young birds having access to the brooder house. Turkey pouls remain in the brooder house until about 3 weeks of age, at which time they are moved to the grower/finisher house. The brooder house is thoroughly cleaned, disinfected, and fresh litter is placed for the next group of turkey pouls. A source of clean water and *Salmonella*-free feed will ensure a *Salmonella*-free bird.

*Salmonella* and *C. jejuni* are commensals of poultry with young birds colonized early in life. Because it can be transmitted vertically *in ovo* from the hen to the chick, *Salmonella* may enter the house with the day-of-hatch birds. Both *Salmonella* and *Campylobacter* gain access to the flock during grow-out via contaminated water, feed, arthropods, rodents, wild birds, via contamination on boots of farm workers, aerosol, and pecking of manure-contaminated litter (Berndtson, 1996; Corry and Atabay, 2001; Jacobs-Reitsma, 2000). The flock may be contaminated with *Campylobacter* by the third week of life. Maternal antibodies may prevent colonization at a younger age (Sahin et al., 2003).
On-farm intervention methods in place for *Salmonella* and *Campylobacter* include regular maintenance of drinkers, biosecurity (e.g., rodent and insect control, restricting house access to farm personnel), routine changing of boots or assignment of boots to individual bird houses (Berndtson, 1996). Improved house ventilation, which dries the litter, has been proposed as a means of reducing *Salmonella* in the flock (Mallinson, 2004). Some flocks may be free of *Salmonella* and *Campylobacter*, while others studies report nearly 100% contamination at market weight. Differences in flock management, especially biosecurity, may explain the prevalence differences.
**Vaccination**  The ideal *Campylobacter* vaccine must confer, at its best, protection for each of the 48 heat-stable Penner and 48 heat-labile Lior antigens as well as the 76 phage types that have been described (Newell et al., 2000). Based on the 66 serotypes and 76 defined phage types employed in routine typing schemes in the United Kingdom, the estimated 5016 different serotype–phage type combinations may overwhelm current vaccine strategies! The short life span of broilers (~6 to 8 weeks) suggests that vaccination of broilers for *Salmonella* and *Campylobacter* may not be cost-effective. Thus, alternatives, such as competitive exclusion have been explored.

**Competitive Exclusion**  Day-old baby chicks are sprayed with the intestinal flora obtained from adult specific pathogen-free (SPF) birds. Introduction of intestinal flora from an adult bird into newly hatched chicks accelerates gut maturation and may increase resistance to *Salmonella* colonization. If *Salmonella* is present in breeder flocks, it may contaminate the outer shell surface. Cox et al. (2000) reported that *Salmonella* penetrates porous egg shells and is ingested by the developing chick *in ovo*, which upon hatching would spread the infection to other birds. Hence, well-characterized microbial competitors of *Salmonella* may represent an effective early on-farm intervention (Bailey et al., 2000). Because it dwells in the mucus film overlying the villi, *Campylobacter* levels in the intestine are not abated by competitive exclusion cultures (Line et al., 1998).

**Feed Mill**  The major steps of feed production and their accompanying critical control points (CCPs) are shown in Fig. 5. Bacterial pathogens may be present in feed ingredients or may be introduced at any number of points in the production and delivery of finished feed to farm bins. Feed formulation, production, and quality control at the feed mill are central to the production of *Salmonella*-free birds. Healthy flocks are more resistant to disease agents during grow-out and arrive at market with a lower risk of infection with pathogens, resulting in a microbiologically safer food for human consumption (NTF, 1999).

Contaminants may enter the feed with the animal, vegetable, liquid, or bagged ingredients. Intervention programs at the feed mill begin with the purchase of high-quality, ideally *Salmonella*-free ingredients, and continue with dry grain storage areas free of rodents and wild birds, high-temperature pelleting, environmental controls (dust, moisture), biosecurity (rodent, insect control), and controlled access of employees (NTF, 1999).

Each feed ingredient supplier should be approved as a reputable source of material of acceptable quality. Ideally, a *Salmonella*-negative specification (specific number of negative samples) could be included in the ingredient-purchasing contract (NTF, 1999).

The pelleting process heats the mash feed (180 to 190°F/82 to 88°C for 45 s), followed by drying with clean air to 12% moisture. Thus, heat-treated, dried pelleted feed reduces the risk of introduction of *Salmonella* and other pathogens into flocks. However, moisture, rodents, dust, and air may recontaminate the finished feed.
Moisture control within the feed mill prevents the multiplication of pathogens in the ingredients during storage prior to grinding and in the finished product. Dust control blocks cross-contamination of ingredients and in finished feed. Routine cleanup in and around the mill prevents buildup of feed and feed ingredients, which attract wild birds and rodents and support the growth of mold, spoilage organisms, and bacterial pathogens.

**Feed Withdrawal** To minimize gut rupture, feed is withdrawn from the market-weight bird prior to transport to the slaughterhouse. The National Turkey Federation (1999) has compiled extensive guidelines for humane feed withdrawal, catching, crating, and transport of turkeys to the abattoir. Pathogen-reduction strategies on the farm include feed withdrawal to empty the gut and thus minimize fecal contamination.
of the carcass. Birds off feed will peck litter and may drink water to excess, increasing the rate of fecal contamination during processing. Inadequate feed withdrawal may result in birds being transported to the slaughter facility with excessive feed and feces in their intestine. An increase in intestinal contents of the caged bird during transportation to and holding at the abattoir increases the probability that the intestine may rupture during the evisceration, thereby contaminating the carcass. However, feed withdrawal, while lowering intestinal contents, decreases volatile fatty acids (increases the intestinal pH), which favor proliferation of *Salmonella* (Hinton et al., 2000a,b), and increases the contamination of the crop with *Salmonella* and *Campylobacter* (Smith and Berrang, 2006).

**Crating** Personnel chase, crate, and load turkeys onto live-haul trucks. This excites the birds, leading to bruising, scratching, and injury. To prevent transmission of pathogens between farms, loading equipment is disinfected between premises.

**Transport** Stress due to commingling and crowding further disseminates *Campylobacter* and *Salmonella*. Commingling of birds in crates as well as the crates themselves may transiently infect broilers immediately prior to slaughter. In addition, transport during rainy weather as well as transport stress may predispose to transient infections. An increase in intestinal fluid and a higher rate of fecal contamination during processing are correlated with excessive time on a truck.

**Lairage** Comfortable holding conditions at the holding areas at the abattoir (lairage) should minimize stress. High bird densities and high temperatures in the transport crates increase defecation and subsequent fecal contamination of the birds. Wind protection in winter and adequate water and ventilation in summer minimize stress during holding.

Feed withdrawal, crating, transport, and lairage at the abattoir have no effect on the prevalence of *Salmonella* in turkeys (Rostagno et al., 2006; Wesley et al., 2005a,b). *Salmonella* prevalence on-farm (33%) was identical to that of birds slaughtered after catching, crating, transport, and lairage at a commercial turkey establishment (33%) (Rostagno et al., 2006). In contrast, these identical perimarketing events were associated with shifts in the population of *Campylobacter jejuni* and *Campylobacter coli* pre- and post-transport (Wesley et al., 2005c).

**House Sanitation** Between flocks, the vacated turkey house is thoroughly cleaned, disinfected, the upper layer of the litter removed, and clean litter applied (top-dressed). Because of cost, disposal issues, and other considerations, complete litter removal after each flock is not practiced in the United States. However, it has been demonstrated that complete litter removal and fumigation of broiler houses in Sweden eliminated *Campylobacter* (Berndtson, 1996).
8.3.3 In-Plant Interventions

**Hazard Analysis Critical Control Points** HACCP systems were implemented by large poultry establishments on January 26, 1998. Each phase of current slaughter practices, from shackling to immersion in the chiller tank, provides opportunities for dissemination of microbial foodborne pathogens as well as spoilage organisms (Barbut, 2001; McNamara, 1997).

**Dressing** After resting (lairage), birds are unloaded from transport crates, shackled, stunned, exsanguinated, and scalded (4 min, 50 to 58°C) to facilitate defeathering (Fig. 6). Scalding may cross-contaminate carcass surfaces. Microbes that survive scalding may be more difficult to remove during later stages of processing, due to the selection of a more robust population. Similarly, the mechanical rubber fingers of the feather picker and equipment used for mechanical evisceration may transfer bacterial foodborne pathogens from one carcass to another. *Salmonella* and *Campylobacter*, which colonize the exposed deep feather follicles, are protected from disinfectants.

**Evisceration** The vent is opened, internal organs removed, and gizzards, liver, heart, and testicles may be harvested. Whereas the broiler industry has mechanized the evisceration process, turkeys are eviscerated manually.

After evisceration, carcasses pass through a chlorinated spray wash and enter a chlorinated chiller, where body temperatures drop to 40°F (4°C). Addition of chlorine to the chiller reduces *Salmonella* and *Campylobacter* (Corry and Atabey, 2001). However, cooling of carcasses by immersion in chiller may cross-contaminate carcasses. Therefore, critical control points (CCPs) for the chiller water include maintaining effective temperature, pH, antimicrobial concentrations, flow rate, and low levels of organic material. To illustrate, *Listeria* survives in water with low levels of chlorination, as shown in studies in Sweden in which *Listeria* was recovered from 58% of broilers immersed in chiller tanks with inconsistent chlorine levels (2 to 15 ppm) compared with 0% of carcasses in immersed in chiller tanks, which consistently measured 10 ppm of free available chlorine (Loncarevic et al., 1994).

Irradiation, steam pasteurization, and crust freezing are alternatives to immersion of carcasses in the chlorinated chiller (James et al., 2007). Freezing is a major CCP and reduces *Campylobacter* on carcasses originating from known contaminated flocks (Lindqvist and Lindblad, 2008). However, the consumer’s preference for fresh, nonfrozen poultry may have resulted in increased cases of campylobacteriosis in Iceland (Stern et al., 2003).

Cross-contamination occurs during processing and may be attributed to (1) spillage of gut ingesta onto the carcass during evisceration, (2) abattoir workers handling of carcasses, (3) contaminated knives, (4) aerosol contamination, and (5) immersion in the chiller. Since birds are shackled upside down during processing, wings (30% *Salmonella* positive) are more readily contaminated than drumsticks (17% *Salmonella* positive) (Plummer et al., 1995). In the United States, line speeds of about 70 to 90 birds per minute will contribute to cross-contamination. The interval from...
time of shackling to exiting the chiller is approximately 3 h for turkeys slaughtered commercially.

**Further Processing** Cooled carcasses are butchered for retail purchase as fresh meat, frozen, or sent to the cooking area and prepared as precooked or ready-to-eat (RTE) product. To eliminate recontamination of the finished product, some
poultry processors deliver the cooked product off-site for slicing. In the past, extensive handling transferred bacterial pathogens, such as *Listeria*, from the plant environment to meat during processing (Genigeorgis et al., 1990). In an earlier evaluation of a turkey frank facility, the post-peeling conveyor belt was contaminated with *L. monocytogenes* of the identical genotype that caused a listeriosis fatality attributed to consumption of turkey franks produced at that site (Wenger et al., 1990). Contamination of cooked products by faulty ventilation systems may have compromised delicatessen meats incriminated in a later multistate listeriosis outbreak. Strict adherence to HACCP plans has significantly reduced post-cooking contamination. Since there is zero tolerance for *L. monocytogenes* in ready-to-eat products, processing plants have implemented state-of-the-art cutting rooms, which rival surgical suites in sanitation for slicing cooked meat to avoid contamination with *L. monocytogenes*.

HACCP in-plant intervention strategies target reduction of spoilage and bacterial foodborne pathogens in RTE products. A program of verification, record maintenance, and contingency planning monitors and controls critical points (Buchanan and Whiting, 1998), especially when it addresses the cooking, smoking, pickling, and canning process. Any deviation in time and temperature control compromises the safety of the RTE poultry product. Microbial testing ensures that all means of contamination have been identified, monitored, and are being controlled (Kvenberg and Schwalm, 2000).

**Plant Environment** Ventilation, air-handling systems, and worker movements also disseminate foodborne bacterial pathogens. To lower the risk associated with airborne product contamination, air movement is directed from the finished product to the live bird area. In studies of airborne microbes in commercial processing plants, *Campylobacter* were recovered in air samples taken from defeathering (21 CFU/15 ft³) and evisceration (8 CFU/15 ft³) areas, but not in air samples collected in postevacuation locations (Whyte et al., 2001). Worker movements are restricted to prevent cross-contamination between evisceration and cutting/packaging areas. Good manufacturing practice guidelines address personal hygiene practices of employees (see Chapter 20).

**Biofilms** Aggregation in biofilms in the plant and attachment to the skin, especially feather follicles, enhances the resistance of bacteria to disinfectants, including chlorine, compared with the sensitivity of unattached suspended microbes in pure culture (Joseph et al., 2001; Kumar and Ananed, 1998). *Salmonella* and *Campylobacter* form biofilms on plastic as well as stainless steel surfaces. Although *Campylobacter* survives in biofilms, this microbe, unlike *Salmonella*, cannot replicate on poultry carcasses or on contact surfaces present in the slaughterhouse.

**Additional Pathogen Reduction Strategies** Significant improvement occurs when clean birds (*Campylobacter*- and *Salmonella*-free) are slaughtered before contaminated birds, as is practiced in Scandinavia. A further reduction of bacterial food-borne pathogens is achieved by freezing carcasses from known contaminated flocks (Lindqvist and Lindblad, 2008). The lower market price for frozen versus fresh
poultry is a major incentive for the producer to provide *Campylobacter*-free birds in Scandinavia. Multiple hurdles may be needed. To illustrate, campylobacteriosis cases declined significantly in Iceland following consumer education, reinitiating the freezing of carcasses originating from known *Campylobacter*-contaminated flocks, heightened on-farm biosecurity and possibly climate conditions (Stern et al., 2003). In the Netherlands, Campylobacter Risk Management and Assessment (CARMA) is a multidisciplinary project to integrate information from risk assessments, epidemiology, and economics. It has provided an extensive cost–benefit analysis for reduction of *Campylobacter* from the farm through slaughter (Havelaar et al., 2007). In analyzing broiler production, CARMA summarized that although theoretically possible, attaining *Campylobacter*-free birds is unrealistic in the short term, despite aggressive on-farm practices. Thus the emphasis is on processing and consumer education. Interestingly, although chemical decontamination of carcasses is not practiced in the EU, CARMA calculates that it is less expensive than either freezing or heat treatment.

Industry-initiated HACCP strategies in place at the processing plant may be correlated with the decline in human campylobacteriosis (Stern and Robach, 2003). Pre- and post-slaughter data collected in 1995 prior to implementation of HACCP were compared with data obtained in 2001. *Campylobacter* counts on-farm in chicken feces were comparable at both sampling intervals (ca. $10^5$ CFU/g). However, the levels of *Campylobacter* on broiler carcasses exiting the chiller in 2001 ($3.03 \log_{10}$ CFU/g) were lower than 1995 estimates ($4.11 \log_{10}$ CFU/g). This indicates the cost-effectiveness of bacterial pathogen reduction during processing.

**Plant Sanitation** HACCP guidelines address cleaning and sanitizing of the processing facilities. Proper usage of detergents and sanitizers ensures that product contact surfaces are clean. Sanitation can only be accomplished on surfaces free of organic material at the optimal concentration of sanitizers, applied at the correct temperature for the correct time interval. The modern poultry plant allocates an entire 8-h shift to cleanup at the end of the processing day.

### 8.3.4 Distribution and Consumption

USDA-FSIS uses advertisements and labels to educate the consumer on proper storage, transportation, cooking, and holding of meat and poultry products. To further protect consumers, the USDA requires safe-handling instructions on packages of raw or partially cooked meat and poultry product.

### 8.3.5 Consumer Awareness

The Partnership for Food Safety Education was formed in 1997 as a part of the National Food Safety Initiative. The Partnership—composed of industry, state, and consumer organizations and government liaisons from FDA, FSIS, Cooperative State Research, Education, and Extension Service (CSREES), CDC, and EPA—cooperatively developed the consumer-friendly FightBAC campaign (www.fightbac.org).
The messages are based on four key food safety practices:

1. **Clean**: Wash hands and surfaces often.
2. **Separate**: Don’t cross-contaminate.
3. **Cook**: Cook to proper temperatures.
4. **Chill**: Refrigerate promptly.

Cross-contamination during food preparation can be averted by consumer education as well as by improved kitchen hygiene and rinsing of raw food items (Mylius et al., 2007). For example, *Campylobacter* is transmitted from raw poultry to utensils and chopping boards, which are then used to prepare to clean foods. Dining at home may actually lower the risk of campylobacteriosis. To illustrate, Hawaii has the highest infection rate of *Campylobacter* in the United States (69/100,000 population). Interestingly, a case–control study revealed that consuming ready-to-eat chicken out of the home is a significant risk factor, whereas eating chicken prepared at home is a protective factor (Effler et al., 2001). This demonstrates the need to educate food handlers on the need to cook poultry thoroughly, to keep raw and cooked food separate, and to avoid recontamination of poultry after cooking (Effler et al., 2001).

### 8.4 CONCLUSIONS

To minimize the risk of foodborne illness associated with poultry consumption, microbial pathogens must be properly controlled. Intervention programs at the production (day-of-hatch bird to market-weight bird), distribution, and consumer levels must be in place, monitored to determine their effectiveness and continuously improved. Future initiatives in the poultry sector will continue to yield microbiologically safe, wholesome, and high-quality poultry to the global customer.

**Acknowledgments**

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**REFERENCES**


