Improvements for Poultry Slaughter Inspection

Appendix C – Literature Review of the Poultry Slaughter Process

APPENDIX C – LITERATURE REVIEW OF THE POULTRY SLAUGHTER PROCESS

Live Receiving and Live Hanging

Live receiving is the initial step in the poultry slaughter process and begins when live poultry are received onto the official premise. Live hanging is the process of suspending live poultry in shackles after removing them from transport cages and begins when transport cages are off-loaded. With chemical immobilization, live poultry may be immobilized prior to hanging.

Potential Risk Factors

Potential biological risk factors exist during live receiving and live hanging and include pathogenic and non-pathogenic microorganisms on the feathers and skin, and in the crop, cecum, and colon contents of live poultry. *Salmonella* and *Campylobacter* are significant pathogens; psychrophilic microorganisms are significant spoilage organisms; and other microorganisms are indicators of sanitation process control.

Large numbers of microorganisms can be found on live poultry at live receiving. Kotula and Pandya (1995) found that 60.7 percent of feather samples and 41.8 percent of skin samples contained 6.7 $\log_{10}$ and 5.9 $\log_{10}$ *Salmonella*/gram (g) respectively. Byrd et al. (1998) found *Campylobacter* spp. in 62 percent of crops and 4 percent of ceca. Wempe et al. (1983) recovered 3.8 to 4.8 $\log_{10}$ and 5.5 to 6.8 $\log_{10}$ *C. jejuni*/g of feathers and cecal content, respectively. Berrang et al., found more *Campylobacter* in feathers (5.4 $\log_{10}$) than in skin (3.8 $\log_{10}$, $p \leq 0.05$) but other enterics did not differ at the two sites. Cloaca harbored more microbes (including *E. coli* and other coliforms) than any other site ($p \leq 0.05$). Kotula and Pandya (1995) found that 77.5 percent of feather samples and 57.5 percent of skin samples contained 7.4 $\log_{10}$ and 6.5 $\log_{10}$ *Campylobacter jejuni*/g. respectively. Geornaras et al. (1997) found 3.8 $\log_{10}$ *Pseudomonas*/g of feathers. Mead et al. (1993) found 2 to 2.8 $\log_{10}$ *Pseudomonas*/g neck skin. Kotula and Pandya (1995) reported that the feathers and skin contained 7.9 $\log_{10}$ and 6.7 $\log_{10}$ *E. coli*/g, respectively.

Microorganisms present in/or live poultry at live receiving can cross-contaminate product. Bryan et al. (1968) demonstrated that *Salmonella* enters the establishment on incoming turkeys and contaminates equipment and subsequent poultry products. Clouser et al. (1995a) found that when *Salmonella* was present on the surface of turkeys prior to processing, the incidence of *Salmonella* tended to increase throughout the slaughter process. Herman et al. (2003) concluded that establishments cannot avoid contamination when *C. jejuni*-positive poultry are delivered to live receiving. Furthermore, there is a statistically significant correlation ($p \leq 0.001$) between contamination of the carcass and presence of the microbe after processing. Berrang et al. (2003b) found that >50 percent of *Campylobacter*-negative broilers were *Campylobacter*-positive following exposure to feces in a commercial dump cage. Newel et al. (2001) demonstrated a link between *Campylobacter*-positive poultry at live receiving and *Campylobacter*-positive carcasses following immobilization, exsanguination, scalding, feather removal, evisceration, and chilling. Fluckey et al. (2003) demonstrated a link between *Campylobacter*- and *Salmonella*-positive cecal content in live poultry and *Campylobacter*- and

Salmonella-positive carcasses following evisceration and chilling. By using PFGE profiles, which allows identification of specific serotypes, whole carcasses were sampled at eight stages of turkey processing. Prevalence data showed that contamination rates varied along the line and were greatest after defeathering and after chilling. The same profiles were found to be present all along the processing line, while on other occasions, additional serotypes were recovered that were not detected earlier on the line, suggesting that the birds harbored more than one serotype of *Salmonella*, or there was cross-contamination occurring during processing (Nde et al. 2006). Chemical potential risk factors introduced at live receiving include violative chemical residues from a pharmaceutical, feed additive, pesticide, industrial compound, and/or environmental contaminate present within the edible tissue of live poultry. The U.S. Department of Agriculture (USDA), Food Safety and Inspection Service (FSIS) monitors poultry products for the presence of chemical residues as part of its National Residue Program. **Table C-1** lists monitoring results from the 2003 National Residue Program.

Table C-1. National Residue Program Domestic Data (USDA, FSIS, OPHS, 2003)

	Sulfonamides			Arsenicals			Chlorinated Hydrocarbons			Avermectins & Milbemycins		
	N	P	V	N	P	V	N	P	V	N	P	V
Young Chicken	385			1,087	579		476					
Mature Chicken	97	1		202	5		221	1				
Young Turkey	234			502	4		249	1				
Mature Turkey	234	2		97	1	1	214	5				
Ducks	95			336		1	248					
Geese	17			13			15					
Squab	20						22					
Ratite	5						10	5		7		

N = number of analyses, P = number of non-violative positives, V = number of violations

Controls. Biological and chemical potential risk factors present in or on live poultry received onto the official premise cannot be prevented, eliminated, or reduced to acceptable levels during live receiving or live hanging. However, they can be reduced through preharvest interventions. Berrang et al. demonstrated that when the level of microorganisms on live poultry at live receiving is high, the presence of microorganisms on raw product is high, and visa versa. Fluckey et al. (2003) found that the incidence of *Salmonella* and *Campylobacter* on the farm correlates with *Salmonella* and *Campylobacter* incidence during evisceration. Campbell et al. (1982) reported a 9 percent post-evisceration incidence of *Salmonella* from *Salmonella*-free turkey flocks compared to 20 percent from non-*Salmonella*-free flocks. Producers can eliminate chemical potential risk factors through pre-harvest interventions that control pharmaceutical and chemical usage.

The National Chicken Council (NCC) (1992) and the National Turkey Federation (NTF) (2004) recommend that poultry producers implement pre-harvest sanitation and production practices shown to reduce hazards in edible poultry products. They recommend microbiological standards for feeds. Davies et al. (2001) and Corry et al. (2002) traced *Salmonella* serotypes recovered from the farm and during transportation back to the feed mills.

The NCC and NTF also recommend bio-security, maintenance, and sanitation programs for facilities and equipment to reduce pathogenic and nonpathogenic microorganisms in/on live poultry prior to live receiving. Davies and Wray (1996) identified rodents and faulty application of disinfectants as causes for the persistence of *Salmonella* in growing houses. Herman et al. (2003) identified employee clothing as the source of *Campylobacter*-positive flocks. Evans and Sayers (2000) identified important factors for preventing *Campylobacter* infection in a flock including buildings in good repair, boot dips, high standards of cleaning, and disinfecting drinking water. Higgens et al. (1981) demonstrated that failure to clean and disinfect air inlets and fans contributed to recontamination of facilities with *Salmonella*. The microbial composition of the air in a high-throughput chicken slaughtering facility was examined by sampling various areas. It was found that the highest counts of microorganisms were recorded in the initial stages of processing, comprising the receiving-killing and defeathering areas, whereas counts decreased toward the evisceration, air-chilling, packaging, and dispatch areas (Lues et al. 2007). Rose et al. (2000) identified the lack of cleaning and disinfection between flocks as a significant risk factor for the persistence of *Salmonella*. Corry et al. (2002) and Slader et al. 2002) linked failure to clean and sanitize transport crates with *Campylobacter*- and *Salmonella*-positive poultry being received onto the official premise during live receiving.

The NCC and NTF further suggest proper feed and water withdrawal to minimize fecal and ingesta contamination during processing. Wabeck (1972) recommended taking broilers off feed and water 8 to 10 hours prior to slaughter. Bilgili (1988) found that decreasing feed withdrawal times increased the likelihood of gastrointestinal breakage during processing. Northcutt et al. (2003) determined that increasing feed withdrawal to 12 hours increased *Campylobacter* and *Salmonella* levels in post carcass rinses 0.4 $\log_{10}$ CFU/ml and 0.2 $\log_{10}$ colony forming unit (CFU)/milliliter (ml), respectively. Bilgili and Hess (1997) found that feed withdrawal periods $\geq$14 hours increased intestine and gallbladder fragility, which increased fecal and bile contamination during evisceration. Hinton et al. (2000, 2002) found that providing broilers with a 7.5 percent glucose solution or a sucrose solution during feed withdrawal decreased the crop pH, increased the level of lactobacillus, and decreased the incidence of *Salmonella typhimurium* in the crop during feed withdrawal ($p \leq 0.05$). Line et al. (1997) found that feeding *Saccharomyces boulardii*, a non-pathogenic yeast, to broilers during feed withdrawal reduced the incidence of *Salmonella* in the cecum during to crating and transport. Acidifying the drinking water at the time of feed withdrawal may help also to reduce levels of *Salmonella* in incoming birds. Byrd et al. (2001) found that administering organic acids at the time of feed withdrawal maintained a more acidic pH in the crop and provided birds with an alternative to consuming potentially contaminated litter. Offering birds an organic acid in the water significantly lowered post-harvest crop contamination with *Salmonella* ($p \leq 0.001$) and *Campylobacter* ($p \leq 0.001$). This type of treatment could be a cost-effective approach that does not require radical changes in current management practices. Byrd et al. (2003) suggested that sodium chlorate added to the water at the time of feed withdrawal could significantly reduce levels of *Salmonella* in the crop and ceca.

Feed withdrawal may, however, affect the intestinal integrity, due to depletion of intestinal mucus (Thompson and Applegate 2006) as well as reduction of digestive tract mass (Nijdam et al. 2006), which can increase susceptibility to infection. Recent studies suggested that special diets could be a good substitute for the feed withdrawal period held before transportation to the processing plant. Special diets that show favorable results include semi-synthetic feed with high

carbohydrate concentration (Delezie et al. 2006) or a commercial whole wheat diet (Rathgeber et al. 2007). Alternatively, a commercial whole wheat diet fed prior to feed withdrawal eliminated the deleterious effects on gut weight and content (Delezie et al. 2006).

In addition to biosecurity measures, producers have other means of reducing *Salmonella* in poultry flocks. Vaccinations, especially those against *S. enteritidis*, reduce shedding of the organism in the intestine as well as in organs including the ovaries, theoretically decreasing the contamination of subsequently laid eggs (Davison et al. 1999). Reducing intestinal colonization and, consequently, fecal shedding of *S. enteritidis* could provide two-fold protection by reducing both vertical and horizontal transmission (Gast et al. 1993). After infection with *S. enterica* serovars *typhimurium* or *enteritidis,* the high titers of *Salmonella*-specific antibodies achieved has been shown to demonstrate a high degree of cross-reactivity against other serovars (Beal and Smith 2007). Furthermore, live attenuated vaccines given to very young chicks have been shown to provide protection through the "colonization-inhibition effect." Because a chick's gut is devoid of microbial flora, there is extensive multiplication by the vaccine, making it difficult for pathogenic organizations to become established (Barber et al. 1999). Autogenous bacterins are important interventions, and the poultry industry has petitioned the Animal Plant Inspection Service (APHIS) to rewrite the regulations to allow the use of autogenous vaccines.

Prebiotics and probiotics are established treatment alternatives for reducing *Salmonella* in poultry. Gibson and Roberfroid (1995) define prebiotics as "a non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one of a limited number of bacteria in the colon." Fuller (1989) defines probiotics as "live microbial feed supplements which beneficially affect the host animal by improving its intestinal balance." It is believed that prebiotics and probiotics act as dietary resources that might be instrumental in stabilizing gut flora, as well as helping to prevent pathogenic organisms from colonizing the gut and causing disease (Holzapfel et al. 1998). Tellez et al. (2001) found that significantly less *Salmonella enteritidis* was isolated from the cecum and tissue organs in birds treated with an Avian Pac Plus® that contained probiotics and egg-source antibodies for *S. enteritidis*, *S. typhimurium*, and *S. heidleberg*, as compared to untreated controls. Netherwood et al. (1999) found that once probiotics were discontinued, the microflora returned to levels found in untreated controls, suggesting that probiotics do not become established in the gut and continued use is required.

Other interventions that show promise are yet to be implemented. As the potential risk factor over antibiotic resistance increases, there has been renewed interest in exploiting the antibacterial properties of bacteriophages and bacteriocins. More effective vaccines may eventually come marketed within bacterial ghosts. Richardson et al. (2003) experimented with electric space charges as a means of reducing airborne transmission of bacterial pathogens. The poultry industry has continued interest in using undefined competitive exclusion (CE) products. Because undefined CE products make therapeutic claims, the Food and Drug Administration (FDA) classifies them as drugs. Since the FDA does not recognize these products as either safe or effective, it has labeled them as unapproved new drugs. The FDA did approve a defined CE product, PREMPT®, which has since been removed from the market. A recent study which included 118 commercial turkey hen lots, ranging from 1,542 to 30,390 hens per lot, of either Nicholas or Hybrid genetic lines was conducted to look at the effect of a selected commercial *Lactobacillus*-based probiotic (FM-B11) on turkey body weight, performance, and health. When each premise was compared by level of performance as good, fair, or poor (grouping based on

historical analysis of 5 previous flocks), the probiotic appeared to increase the performance of the poor and fair farms ($p \leq 0.05$) (Torres-Rodriguez et al. 2007).

Of the interventions discussed, not one alone is capable of eliminating pathogens. Interventions vary in their effectiveness for both researchers and producers. Some appear to have synergistic effects when used in combination. More research and application is needed to resolve these issues.

Immobilization and Exsanguination (Bleeding)

Immobilization renders live poultry unconscious in preparation for exsanguination (bleeding); however, death by slaughter can occur unintentionally or by design. Immobilization begins when the immobilizing agent is applied and ends when the cervical vessels are severed. Immobilization methods are classified as mechanical, chemical, and electrical, and should be implemented in accordance with good commercial practices in a manner that will result in thorough bleeding of the carcasses.

Mechanical immobilization is impractical in large poultry establishments. However, it is useful in emergencies or to immobilize small numbers of live poultry, which makes it a practical method in small and very small establishments. Decapitation, cervical dislocation, and blunt trauma to the head are the most common forms of mechanical immobilization.

Chemical immobilization exposes live poultry to a gas, individually in boxes or tunnels, or in batches. The most common gases are carbon dioxide (CO_2) (Drewniak et al. 1955, Kotula et al. 1961) and argon (Raj and Gregory 1990, 1994). When chemical methods are used, live poultry may be immobilized prior to live hanging.

Electrical immobilization is the most common method in use worldwide. It is the best method of achieving rapid brain failure and the cheapest and most effective method of poultry slaughter. The EEC recommends electrical immobilization with a minimum of 120 milliampere (mA) to instantaneous render poultry unconscious, effect ventricular fibrillation, and produce death by slaughter (Fletcher 1999). A majority of U.S. poultry processors utilize low-voltage, high-frequency methods (Fletcher 1999, Heath et al. 1994). The remaining U.S. processors utilize high voltage with no specified waveform. Gregory and Wooton (1986) determined that low-voltage immobilization with 30 to 60 volts (V), 20 to 45 mA does not result in death by slaughter, while high-voltage stunning with 150 V, 100 mA induces ventricular fibrillation and death by slaughter. Both systems accomplish the desired end result. Kuenzel et al. (1978) determined that 50 V/60 hertz (Hz) circuits are 35 percent more cost-effective than 100 V variable-frequency circuits, and 225 percent more cost-effective than direct current (DC) circuits. However, Kuenzel and Walther (1978) concluded that DC currents are safer and improve exsanguination time compared to alternating current (AC) circuits because blood is not shunted from peripheral to central blood vessels. A recent study examined different slaughter techniques to determine their effects on pH (24 hours), color (24 hours), lipid oxidation, residual hemoglobin concentration (24 hours), and sensory evaluation (d 1 and 4 post mortem) in broiler breast fillets, and concluded that the electrical stunning and decapitation method had the most favorable results for sensory quality regardless of whether the chickens were pre-bled (Alvarado et al. 2007).

Exsanguination guarantees death by slaughter and ensures that poultry have stopped breathing prior to scalding. Exsanguination begins when the cervical vessels are severed, and ends when the carcass enters the scald process. For exsanguination to cause death by slaughter, it is important that the cervical vessels be cut promptly and efficiently so that poultry do not regain consciousness and/or enter the scald tank before they have stopped breathing.

Potential Risk Factors. Potential biological risk factors include cross-contamination with pathogenic and nonpathogenic microorganisms. Immobilization (Mead et al. 1994) can void feces and further contaminate the carcass exterior, scald tank water, and feather removal equipment. Papa and Dickens (1989) found that 53 percent of broilers produced an average excretion of 1.5 g during electrical immobilization and that the volume of the excretion increased as feed withdrawal time increased. Musgrove et al. (1997) found that *Campylobacter* in whole carcasses rinses increased 0.5 $\log_{10}$ CFU/ml following electrical immobilization. Mead et al. (1994) found that the physical pressure of the killing knife against the carcass can void crop content with similar affect.

Trim nonconformance is an undesirable side effect of immobilization. Raj (1994) and Raj et al. (1990) identified a link between electrical and chemical immobilization and hemorrhage and broken bones in turkeys and broilers. Chemical immobilization results in a lower incidence of trim nonconformance compared to electrical immobilization (Raj and Nute 1995, Raj et al. 1997, 1998). Grossly significant hemorrhages can interfere with accurate post mortem disposition.

Failure to properly exsanguinate can result in poultry entering the scald tank before breathing has stopped. Heath et al. (1981) speculated that red discoloration of the skin results when live poultry enter the scald tank. Heath et al. (1983) later concluded that poultry entering the scald tank alive develop red discoloration of the skin, that the discoloration is confined to the pterylae, and that the apteria is never discolored. Griffiths (1985) demonstrated that only poultry entering the scald tank alive result in red discoloration of the skin. Poultry that are dead (either by slaughter or by other causes) when they enter the scald tank, do not develop in red discoloration of the skin. Griffiths further demonstrated that the red discoloration is due to marked peripheral vascular dilation of blood vessels in the skin and subcutis.

Controls. Biological and chemical potential risk factors present during immobilization and exsanguination cannot be prevented, eliminated, or reduced to acceptable levels during these process steps. However, they can be influenced through preharvest interventions and choice of processing method.

Feed withdrawal time influences the incidence of feces voided during immobilization. Papa and Dickens (1989) found that only 8 percent, 42 percent, 50 percent, and 58 percent of broilers produced an excretion when the feed withdrawal time was 4, 8, 12, and 16 hours, respectively. McNeal et al. (2003) found that exsanguination by decapitation following electrical immobilization produced less wing flapping, body motion, and quivering because decapitation kills poultry quicker than severance of the cervical vessels.

Scalding

Scalding begins when the poultry carcass enters the scald system and ends when feather removal commences. Scalding prepares the carcass for feather removal by breaking down the proteins that hold feathers in place and opening up feather follicles.

Variables requiring consideration during the scald process step are mechanical, physical, and chemical. Mechanical variables include counter-current flows and agitation to produce a washing effect. Counter-current systems move water counter to the direction of poultry carcasses at all points. Water enters the system at the point where poultry carcasses exit, and water exits at the point where poultry carcasses enter, producing a dirty-to-clean gradient that continually moves poultry carcasses into cleaner water. Cleaner water is a relative condition as the amount of dry matter and microorganisms in the scald water increase over time. Physical variables are time and temperature, which influence washing and antimicrobial effects. The chemical variable is pH, which also influences the antimicrobial effect.

Immersion scalding is the most common scald technology in use and is best described as dragging carcasses through a tank of hot water. Immersion systems come in single- and multi-stage configurations, incorporating mechanical and physical variables. Single-stage systems provide less washing effect than multi-stage systems.

U.S. Poultry processors in the United States prefer a "hard scald" combining shorter scald times and higher scald temperatures. A "hard scald" facilitates removal of the epidermis, which enhances the adhesion of coatings commonly used with fried foods. European poultry processors prefer a "soft scald," combining longer scald times and lower scald temperatures. A "soft scald" retains much of the epidermis and natural skin color.

Table C-2. Common Scalding Times and Temperature for Various Classes of Poultry

Broilers (hard scald)	30-75 seconds	59-64°C
Broilers (soft scald)	90-120 seconds	51-54°C
Turkeys	50-125 seconds	59-63°C
Quail	30 seconds	53°C
Waterfowl	30-60 seconds	68-82°C

Steam-spray scalding is a less popular alternative. Klose et al. (1971), Kaufman et al. (1972), and Dickens (1989) found that a mixture of steam and air at 50 to 60°C and 137.9 kPa pressure applied for approximately two minutes provided a uniform scald of either dry or damp broilers, facilitated feather removal, and yielded carcasses microbiologically equivalent to immersion systems. Some religious dietary laws prohibit scalding and soak poultry carcasses in cold water.

Potential Risk Factors. Potential biological risk factors include pathogenic and non-pathogenic microorganisms introduced during the scald process. These microorganisms are present on the internal and external surfaces of the carcass as well as in the scald water.

Salmonella and *Campylobacter* are the most common pathogenic microorganisms identified with the scalding process step. Berrang et al. (2000a) recovered 5.4 $\log_{10}$, 3.8 $\log_{10}$, 4.7 $\log_{10}$, 7.3 $\log_{10}$, and 7.2 $\log_{10}$ *Campylobacter*/g from feathers, skin, crop content, cecal content, and

colon content, respectively, prior to scalding. Georgnaras et al. (1997) isolated *Salmonella* from 100 percent, *Listeria* spp., from 33 percent, and *Staphylococcus aureus* from 20 percent of skin and feather samples collected prior to scalding. Cason et al. (2000) found that 75 percent of scald tank water samples were *Salmonella*-positive, and recovered an average of 10.9 MPN *Salmonella*/100 ml, or about 1 *Salmonella* bacteria/9 ml. They found significantly lower prevalence of microorganisms with increasing passes between tanks, but removal of coliforms and *E. coli* is more effective ($p \leq 0.02$) than removal of *Salmonella*. Wempe et al. (1983) recovered an average of 1.6 $\log_{10}$ *C. jejuni* CFU/ml from a scald tank water.

Because scalding washes much of the dirt and feces off of the carcass exterior, more microorganisms can be removed during scalding than during any other process step. Georgnaras et al. (1997) found a 38 percent decrease in *Salmonella*-positive carcasses. Acuff et al. (1986) reported a 312 MPN/100 cm^3 decrease in *C. jejuni* on turkey skin. Berrang and Dickens (2000) reported a 2.9- to 4.1-$\log_{10}$ reduction in *Campylobacter*/ml in carcass rinses. Lillard (1990) found a 1.1-$\log_{10}$ and 1.5-$\log_{10}$ CFU/ml decrease in aerobic bacteria and Enterobacteriaceae, respectively, in carcass rinses. Georgnaras et al. (1997) found a 1.0-$\log_{10}$ CFU/g decrease in *Pseudomonas* spp. in skin samples. Berrang and Dickens (2000) reported 2.1-$\log_{10}$ and 2.2-$\log_{10}$ CFU/ml reductions in coliforms and *E. coli*, respectively in carcass rinses.

However, Berrang et al. (2003a) found that immersion scalding increased aerobic bacteria 0.9 $\log_{10}$ CFU/ml, coliforms 0.8 $\log_{10}$ CFU/ml, *E. coli* 1.5 $\log_{10}$ CFU/ml, and *Campylobacter* spp., 0.8 $\log_{10}$ CFU/ml in lung rinses taken from broilers, indicating that microorganisms were added to the respiratory tract during immersion scalding. These microorganisms carry forward into subsequent processing steps. In contrast, Kaufman et al. (1972) found that the air sacs of steam-scalded broilers contain 3 $\log_{10}$ fewer microorganisms than the air sacs of immersion-scalded broilers. The number of microorganisms on poultry carcasses exiting the scald tank is relative to the number of microorganisms in or on the poultry carcass entering the scald tank. The scald process cannot eliminate excessively high numbers of microorganisms entering the process.

A disadvantage of washing dirt and feces off of the exterior carcass surface is the accumulation of microorganisms in the scald water, making the scald tank a source of cross-contamination for subsequent carcasses. Mulder et al. (1978) recovered a marker organism introduced prior to scalding from the 230th carcass exiting the scald. Cason et al. (1999) determined that the 4.2 $\log_{10}$ aerobic bacteria/ml, 2.7 $\log_{10}$ *E. coli*/ml, and 2.9 $\log_{10}$ *Campylobacter*/ml of carcass rinse present on carcasses post-feather removal originated from the scald process.

Figure C-1 illustrates the reduction in microorganisms that occurs during the immersion scalding process step. For each microorganism considered, Berrang and Dickens (2000) and Berrang et al. (2003a) measured a reduction in the mean $\log_{10}$ CFU/ml of whole carcass rinse taken from broiler carcasses pre- and post-immersion scalding ($p \leq 0.05$ for all of the organisms tested).

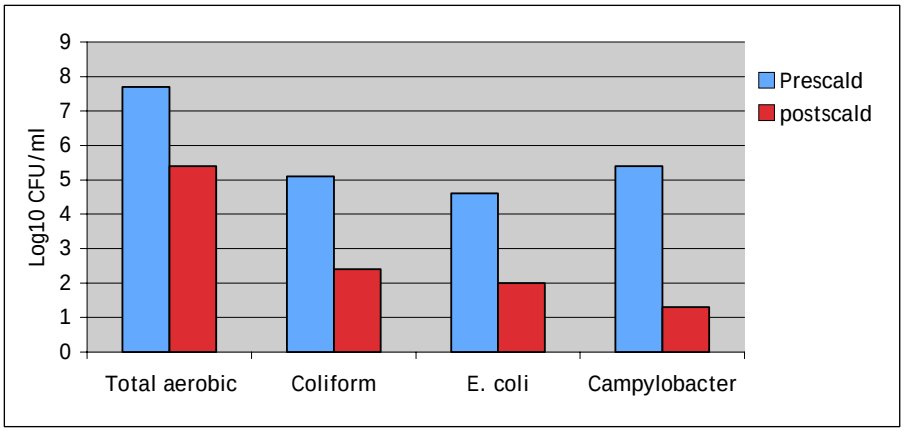

Figure C-1. Difference in Levels of Organisms Pre- and Post-scaling

Chemical potential risk factors include residues introduced during the scald process through the excessive application of technical processing aids and/or antimicrobial agents. Technical processing aids enhance the scalding process and include surfactants, denuding agents, and emollients. Surfactants reduce surface tension, improve wetting agent function, and inhibit foam. Alkaline denuding agents loosen the keratinized outer layer of the epidermis. Emollients retain moisture and prevent excessive drying of the denuded dermis. Many of these chemicals are generally regarded as safe (GRAS) by the FDA. Others are listed with restriction in the *Code of Federal Regulations*, 9 CFR 424.21, "Use of Food Ingredients and Sources of Radiation." When a processing aid produces the same technical effect at lower scald water temperatures, a greater number of microorganisms can survive the scald process.

Controls. Biological and chemical potential risk factors cannot be prevented or eliminated during the scald process step; however, they can be reduced.

The NCC (1992) and Waldroup et al. (1992) identified counter current systems, sufficient water replacement with, and a post-scald carcass rinse as good manufacturing practices for efficient immersion scalding. Waldroup et al. (1993) found that counter current scalding reduced aerobic bacteria, coliform, and *E. coli* 0.64 $\log_{10}$, 0.76 $\log_{10}$, and 0.72 $\log_{10}$ CFU/ml, respectively, and *Salmonella* prevalence by 10 percent in scald water. James et al. (1993) found that counter-current scalding combined with a carcass rinse reduced aerobic bacteria, Enterobacteriaceae, and *E. coli* 0.68 $\log_{10}$, 0.37 $\log_{10}$, and 0.08 $\log_{10}$ CFU/carcass respectively, and the incidence of *Salmonella*-positive carcasses by 3 percent. Multi-tank immersion systems further improve the microbiological quality of the scald water. In a three-stage counter current system, Cason et al. (2000) reported a reduction in coliforms from 3.4 $\log_{10}$ to 2.0 $\log_{10}$ to 1.2 $\log_{10}$ CFU/ml, and in *E. coli* from 3.2 $\log_{10}$ to 1.5 $\log_{10}$ to 0.8 $\log_{10}$ CFU/ml in tanks 1, 2, and 3, respectively ($p \leq 0.05$). Cox et al. (1974) determined that 1 minute of agitation reduced aerobic bacteria on broiler skin by 0.42 $\log_{10}$ CFU/cm^2.

Failure to maintain a proper time/temperature combination diminishes the desired technical effect of preparing feathers for removal and detracts from sanitary dressing. High scald temperature can cause the carcass to become oily, which favors the retention of microorganisms on the carcass surface. Cox et al. (1974) determined that immersion in hot water for 1 minute reduced aerobic bacteria 0.91 $\log_{10}$ CFU/cm^2. Yang et al. (2001) found that a 5-minute exposure

at 50 to 60°C produced reductions of 3.8 $\log_{10}$ *C. jejuni*/ml and 3.0 $\log_{10}$ *S. typhimurium*/ml in the scald tank water, and 1.5 $\log_{10}$ *C. jejuni*/ml and 1.3 $\log_{10}$ *S. typhimurium*/ml on chicken skins.

Immersion scalding produces a relatively smooth, microbiologically superior skin surface compared to steam-spray and kosher methods that result in a highly wrinkled microtopography that facilitates attachment of microorganisms. Kim and Doores (1993) concluded that the incidence of *Salmonella*-positive turkey carcasses is higher with kosher processing, due to trapping of *Salmonella* in the keratinized epithelium. Lillard (1989) concluded that microorganisms become entrapped in ridges and crevices that become more pronounced in skin following immersion in water and are less accessible to antimicrobial treatments. Clouser et al. (1995b) recovered *Salmonella* from 57 percent of steam-spray and 37 percent of kosher skin samples, compared to 23 percent with conventional methods.

Within 120 minutes of the start of operations, the dissociation of ammonium urate from poultry feces to uric acid and ammonium hydroxide can reduce scald water pH from 8.4 to 6.0 (Humphrey 1981). The protein and minerals in the scald tank water then act as a buffer to maintain this pH for the rest of the working day. *S. typhimurium* and *S. newport* are most heat resistant at pH 6.1 (Okrend et al. 1986), *C. jejuni* at 7.0 (Humphrey and Lanning 1987), *Aerobacter aerogenes* at pH 6.6 (Strange and Shon 1964), and *Streptococcus feacalis* at pH 6.6 (White 1963). Hydrogen ion concentration influences the rate of endogenous Ribonucleic acid (RNA) degradation and a shift in pH away from optimal (while probably not the primary cause of microbial death in scald water) increases RNA degradation, hinders microbial metabolism, and contributes to microbial death.

Increasing scald water pH reduces microbial levels in the water. When scald water pH was increased from 7 to 9, Humphrey and Lanning (1987) determined that the time needed to achieve a 1-$\log_{10}$ reduction in *C. jejuni* was reduced from 11½ to 2 minutes, *Salmonella* levels were reduced from 13.9 MPN/100 ml to 3 MPN/100 ml, and the incidence of *Salmonella*- and *Campylobacter*-positive water samples from 100 percent to 26 percent. When scald water pH was adjusted to 9 after 4 hours of production and maintained for the remainder of the day, Humphrey et al. (1984) determined that aerobic bacteria and Enterobacteriaceae levels decreased by 0.4 $\log_{10}$ CFU/ml and 0.5 $\log_{10}$ CFU/ml, respectively; and the death rate of *Salmonella typhimurium* attached to the skin increased 57 percent. Lillard et al. (1987) reported that reducing scald water pH to 3.6 by the addition of 0.5 percent acetic acid decreased aerobic bacteria 2.2 $\log_{10}$ CFU/ml in scald water.

The same can be said for decreasing scald water pH. Okrend et al. (1986) determined that reducing scald tank water pH to 4.3 by the addition of 0.1 percent acetic acid increased the death rate of *S. newport* and *S. typhimurium* 91 percent. However, the same is not true for microorganisms on the surface of poultry carcasses. Humphrey and Lanning (1987) reported that scalding at pH 9.0 had no affect on the incidence of *Salmonella* and *Campylobacter* on broiler carcasses. Lillard et al. (1987) found that reducing scald water pH to 3.6 did not reduce aerobic bacteria or Enterobacteriaceae on carcass surfaces. It is important to understand that these reductions take place in the scald tank water and not on the carcass surface.

Feather Removal

Feather removal eliminates the feathers and stratum corneum in preparation for evisceration. Feather removal begins when carcasses enter the feather removal equipment and continues until the exterior surface of the poultry carcass is free of feathers and cuticle. Feather removal technology is fairly uniform across the poultry industry. Carcasses pass through one or more pieces of equipment that remove feathers by the mechanical action of rubber picking fingers beating against the carcass. Most establishments utilize a continuous process; however, batch processes are common in small, low-volume establishments. Some very small establishments rely on manual methods to remove feathers. Following mechanical feather removal, goose carcasses are immersed in molten wax and dipped in ice water to facilitate removal of the down feathers. The hardened wax is manually removed, taking the down feathers with it.

Potential Risk Factors

Potential biological risk factors include pathogenic and nonpathogenic microorganisms introduced during the feather removal process. These microorganisms are present on the internal and external surfaces of the carcass, as well as on the feather removal equipment, and increase as an unavoidable consequence of the process. *Salmonella* and *Campylobacter* are the most common pathological microorganisms identified with the feather removal process. Acuff et al. (1986) determined that regardless of the number of *C. jejuni* present on turkey carcasses entering the establishment, on average, *C. jejuni* increased 150 MPN/100 cm^3 during feather removal. Izat et al (1988) found that feather removal increased *C. jejuni* on broiler carcasses 1.7 $\log_{10}$ CFU/1,000 cm^3. Abu-Ruwaida et al. (1994) reported that *Campylobacter* and *S. aureus* levels rose 1.6 $\log_{10}$ CFU/gm and 0.30 $\log_{10}$ CFU/gm, respectively, and the incidence of *Salmonella* was 100 percent post-feather removal. Berrang and Dickens (2000) found that *Campylobacter* in whole carcass rinses increased 1.9 to 2.9 $\log_{10}$ CFU/ml and that *Salmonella* (Berrang et al. 2001) on breast swabs increased 1.2 $\log_{10}$ CFU/cm^3.

Clouser et al. (1995a) found a >200 percent increase in *Salmonella*-positive turkey carcasses after feather removal, and concluded that when *Salmonella* is present prior to feather removal, the incidence of *Salmonella* tends to increase throughout evisceration and chilling. Geornaras et al. (1997) isolated *Salmonella* from 100 percent of carcasses following feather removal. The feather follicle has been implicated as a harborage for microorganisms. However, Cason et al. (2004) found no statistically significant difference ($p>0.05$) in aerobic bacteria, *E. coli*, and *Campylobacter* levels between feathered and featherless birds and concluded that microbial adhesion, not harborage in follicles, is the mechanism behind microorganisms present on poultry skin.

Figure C-2 summarizes data compiled from various authors cited in this document and illustrates the increase in biological potential risk factors during feather removal.

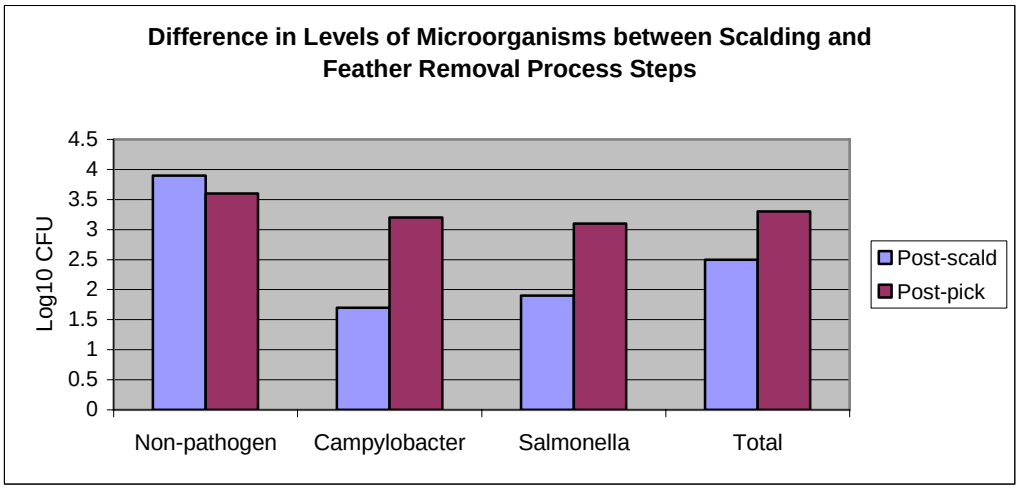

Figure C-2. Difference in Levels of Microorganisms between Scalding and Feather Removal Process Steps

Within the feather removal equipment, the rubber picking fingers and recycled water are sources of cross-contamination. Geornaras et al. (1997) isolated *Salmonella* from 33 percent of the picking fingers. Wempe et al. (1983) recovered an average of 3.88 $\log_{10}$ *C. jejuni*/ml from 94 percent of feather removal water samples. Whittemore and Lyon (1994) recovered 5.46 to 5.73 $\log_{10}$ *Staphylococcus* spp., 5.83 to 6.04 $\log_{10}$ aerobic bacteria, and 5.05-5.44 $\log_{10}$ Enterobacteriaceae from the rubber picking fingers. Mead et al. (1975) and Allen et al. (2003b) found that a marker organism inoculated onto post-scalding carcasses dispersed for ≤200 carcasses via feather removal. Mulder et al. (1978) found that a marker organism introduced prior to feather removal could be recovered from the 580th carcass exiting the feather removal equipment. Geornaras et al. (1997) attributed increases of 1.1 $\log_{10}$ aerobic bacteria/g, 0.9 $\log_{10}$ Enterobacteriaceae/g, and 3.1 $\log_{10}$ *Pseudomonas* spp./g in neck skin samples following feather removal to the action of the rubber picking fingers.

Allen et al. (2003a) concluded that feces forced out of the cloaca by the action of picking fingers against the carcass cross-contaminated adjacent carcasses. Berrang et al. (2001) found that the incidence of *Campylobacter*-positive carcass rinses decreased 89 percent and *Campylobacter* levels decreased 2.5 $\log_{10}$ CFU/ml when the escape of feces from the cloaca was prevented. Buhr et al. (2003) confirmed the result, finding that plugging the cloaca decreased *Campylobacter*, coliforms, *E. coli*, and aerobic bacteria 0.7 $\log_{10}$, 1.8 $\log_{10}$, 1.7 $\log_{10}$, and 0.5 $\log_{10}$ CFU/ml, respectively, in rinse samples.

A clear demonstration for the role of fingers in cross contamination was shown by means of molecular characterization. *Salmonella* subtypes found on the fingers of the picker machines were similar to subtypes isolated before and after defeathering, indicating that the fingers facilitate carcass cross contamination during defeathering (Nde et al. 2007). Similar conclusions were made for cross contamination of *Campylobacter* spp., using molecular profiling (Takahashi et al. 2006) in a poultry plant in Japan.

Airborne microorganisms have been implicated as a source of cross-contamination during feather removal. Whyte et al. (2001a) recovered 12.7 $\log_{10}$ *Campylobacter* per 15 ft^3 of air in

broiler and hen establishments. Northcutt et al. (2004) recovered 1.5 $\log_{10}$ Enterobacteriaceae/ml of air during commercial processing of Japanese quail. Lutgring et al. (1997) recovered 2.5 to 6 $\log_{10}$ psychrophilic bacteria/m^3 in turkey and duck processing establishments. However, Berrang et al. (2004) found that exposing *Campylobacter*-negative broiler carcasses to air near feather removal equipment for 1 minute only increased *Campylobacter* 0.20 $\log_{10}$ CFU/ml in carcass rinses, and concluded that airborne contamination does not contribute to high levels of *Campylobacter* routinely found on broiler carcasses after feather removal (95 percent CI).

Controls. Biological hazards and potential risk factors cannot be prevented, eliminated, or reduced to acceptable levels during feather removal.

The NCC (1992) and Waldroup et al. (1992) recommend preventing feather buildup, continuous rinses for equipment and carcasses, and regular equipment adjustment to minimize cross-contamination.

Changes in technique and/or equipment can affect microbial numbers on equipment and product. After increasing the number of rubber feather removal fingers, decreasing chlorine levels, and increasing cabinet temperature, Purdy et al. (1988) found that *S. aureus*, coliforms, and Enterobacteriaceae on the feather removal fingers increased by 3.2 $\log_{10}$ CFU, 2.0 $\log_{10}$ CFU, and 4.6 $\log_{10}$ CFU, respectively, and *S. aureus*, coliforms, and Enterobacteriaceae on the poultry skin samples increased by 2.8 $\log_{10}$ CFU, 5.0 $\log_{10}$ CFU, and 5.6 $\log_{10}$ CFU, respectively. Allen et al. (2003a) determined that increasing the distance between carcasses and water curtains at the entrance and/or exit of the feather removal cabinet had no effect on cross-contamination. Clouser et al. (1995a) concluded that when aerobic plate counts are high at the start of feather removal, they remain proportionately high throughout processing.

Interventions applied during feather removal have yielded mixed results. Berrang et al. (2000b) concluded that rinsing carcasses with 71°C (159°F) water for 20 seconds post-feather removal spraying had no significant effect on microbial contamination. Mead et al. (1975) found that a 10 to 20 ppm available chlorine carcass rinse did not reduce carriage of a marker organism on turkey carcasses passing through the feather removal equipment and contributed the result to inadequate contact time. Later, Mead et al. (1994) found that an 18 to 30 parts per million (ppm) available chlorine rinse reduced carriage of a marker organism on hen carcasses passing through the feather removal equipment. Dickens and Whittemore (1997) found that a 1 percent acetic acid rinse post-feather removal reduced aerobic bacteria 0.6 $\log_{10}$ CFU/ml in whole carcass rinse without altering carcass appearance; but a similar application of 0.5 percent to 1.5 percent hydrogen peroxide caused bleaching and bloating of carcasses.

Evisceration

Evisceration removes the internal organs and any trim/processing defects from the carcass in preparation for chilling. The technology varies widely across the poultry industry but always includes the following basic process steps.

- Remove the crus.
- Remove the oil gland.
- Sever the attachments to the vent.
- Open the body cavity.

- Extract the viscera.
- Harvest the giblets.
- Remove and discard the intestinal tract and air sacs.
- Remove and discard the trachea and crop.
- Remove and discard the lungs.

Potential Risk Factors

Potential chemical risk factors include antimicrobial treatments, as well as sanitizers, used to prevent cross-contamination and control microbial growth on product contact surfaces. Biological potential risk factors include pathogenic and nonpathogenic microorganisms on carcasses and equipment surfaces.

The incidence of biological potential risk factors on carcasses and equipment, as well as the change in absolute numbers, varies widely between poultry processing operations. Hargis et al. (1995) recovered *Salmonella* from 15 percent of ceca and 52 percent of crops; and 8 percent of crop removal devices. Byrd et al. (1998) recovered *Campylobacter* from 4 percent of ceca and 62 percent of crops. Berrang et al. (2003a) recovered 1.0 $\log_{10}$ *Campylobacter*/ml of rinse from lungs. Lillard (1990) found that the incidence of *Salmonella*-positive carcasses increased 2.4 percent during evisceration. Oosterom et al. (1983) found an increase of 1.5 $\log_{10}$ *C. jejuni*/g of skin and 7.0 $\log_{10}$ *C. jejuni*/g from intestinal content during evisceration. Acuff et al. (1986) found that *C. jejuni* increased 278 MPN/100 cm^3 during evisceration. Izat et al. (1988) found that evisceration increased *C. jejuni* 0.41 $\log_{10}$/1,000 cm^3 on skin samples. Berrang and Dickens (2000) found a 0.3-$\log_{10}$ decrease in *Campylobacter*/ml in carcass rinses during evisceration. Berrang et al. (2003a) found that aerobic bacteria, coliforms, *E. coli*, and *Campylobacter* in carcass rinses decreased 0.5 $\log_{10}$, 0.3 $\log_{10}$, 0.67 $\log_{10}$, and 0.3 $\log_{10}$ CFU/ml, repectively, during evisceration. Lillard (1990) found that evisceration decreased aerobic bacteria and Enterobacteriaceae 0.61 $\log_{10}$ and 0.18 $\log_{10}$ CFU/ml, respectively. Variations in the number of microorganisms recovered from carcasses and equipment are attributable to the differences in the processing and sanitation practices.

Carcass handling during evisceration cross-contaminates product prior to opening the body cavity and after extracting the viscera. Mead et al. (1975, 1994) recovered a marker organism from the 50^{th} revolution of the transfer point, the 450^{th} carcass to pass through the vent opener, and from head removal and lung extraction machines. Byrd et al. (2002) recovered a marker organism placed in the crops prior to live hanging from 67 percent of carcasses at the transfer station, 78 percent at viscera extraction, 92 percent pre-crop removal, 94 percent post-crop removal, and 53 percent after the final carcass rinse. Berrang et al. (2003a) found that the lung picks up contaminated water from the scald tank that contaminates equipment and product during evisceration. Wempe et al. (1983) recovered 2.8 $\log_{10}$ *C. jejuni*/ml from recycled carcass rinse water. Thayer and Walsh (1993) found that aerobic bacteria, Enterobacteriaceae, and *E. coli* on the probe retracting viscera from chicken increased 0.10 to 0.18 $\log_{10}$ CFU during operation. Clouser et al. (1995a) recovered *L. monocytogenes* from 20 percent of kosher carcasses sampled post-evisceration, but found no link with *L. monocytogenes* preharvest and concluded that the *L. monocytogenes* originated from the equipment.

The relative presence or absence of enteric microorganisms on carcasses is an indicator of sanitation process control. Jimenez et al. (2003) found that, on carcasses with visible feces, a

carcass rinse reduced Enterobacteriaceae. *E. coli*, and coliforms by 0.11 $\log_{10}$, 0.10 $\log_{10}$, and 0.02 $\log_{10}$ CFU/ml respectively, and on carcasses without visible feces by 0.36 $\log_{10}$, 0.23 $\log_{10}$, and 0.18 $\log_{10}$ CFU/ml, respectively. Statistical significance was achieved only for the latter case ($p \leq 0.05$). However, Fluckey et al. (2003) concluded that there is no relationship between the presence or absence of enteric microorganisms and the presence or absence of *Salmonella* or *Campylobacter* ($p > 0.05$). Lillard (1990) found that a carcass rinse decreased Enterobacteriaceae by 0.24 $\log_{10}$ CFU/ml, but had no effect on the incidence of *Salmonella*.

The presence or absence of visible feces is also an indicator of sanitation process control. However, there is no direct correlation between the presence or absence of visible fecal material and the presence or absence of *Salmonella* or *Campylobacter*. Jimenez et al. (2002) found that 12 percent of broiler carcasses with visible fecal contamination were *Salmonella*-positive, compared to 20 percent without visible fecal contamination ($p > 0.05$) and that 37 percent of carcasses with visible fecal contamination were *Salmonella*-positive following the carcass rinse, compared to 10 percent without visible fecal contamination. Fletcher and Craig (1997) found that *Campylobacter* levels on reprocessed carcasses with visible fecal contamination were 0.21 $\log_{10}$ CFU higher than reprocessed carcasses without visible fecal contamination, and that the incidence of *Campylobacter* and *Salmonella* on reprocessed carcasses with visible fecal contamination was 5 percent and 3 percent lower than on reprocessed carcasses without visible fecal contamination. Blankenship et al. (1975) found no significant difference in the level of aerobic bacteria, Enterobacteriacae, and presumptive *Clostridium* spp., in carcass rinses of inspected and passed, fecal-condemned, and reprocessed fecal-condemned broiler carcasses. Bilgili et al. (2002) found no correlation between the microbiological quality of broiler carcasses and the presence or absence of visible contamination.

Evisceration systems process steps also influence the incidence of carcass contamination. Russell and Walker (1997) found visible contamination on 3 percent of carcasses eviscerated with the Nu-Tech® system, compared to 19 perecnt eviscerated with the streamlined inspection system. Jimenez et al. (2003) found feces and/or bile on 11 percent and 5 percent of carcasses post-viscera extraction. Russell and Walker (1997) found feces on 10 percent of carcasses post-viscera extraction and 19 percent post-crop removal. Crop rupture and leakage is a significant source of contamination during evisceration. Buhr and Dickens (2001, 2002) and Buhr et al. (2000) determined that crops rupture because of greater adhesion to surrounding tissues, and that fewer crops rupture when extracted toward the head compared to extracted toward the thoracic inlet ($p \leq 0.05$).

Controls. The NCC (1992) recommends proper feed and water withdrawal, maintenance and adjustment of equipment, continuous rinsing and sanitizing, enforcing employee hygiene standards, and a whole-carcass rinse with 20 ppm free available chlorine to control biological potential risk factors during evisceration. The most common methods used to mitigate biological potential risk factors are carcass rinses, off-line reprocessing, and on-line reprocessing.

Carcass Rinses

Carcass rinses are effective interventions for removing loose material from the carcass surface during evisceration (Byrd et al. 2002). Waldroup et al. (1992) recommended a 20 ppm chlorine carcass rinse post-evisceration as part of a strategy shown to decrease microbial contamination and improve food safety. Mead et al. (1975) found that a 10 to 20 ppm free available chlorine

rinse did not eliminate a marker organism; but, 18 to 30 ppm free available chlorine reduced recovery of the marker organism from the 50th to the 20th revolution at the transfer point. Jimenez et al. (2003) found that carcass rinses reduce visible feces and bile on post-evisceration broiler carcasses by 3.4 percent and 2.9 percent, respectively. Carcass rinses can also reduce biological hazards (Notermans et al. 1980). Notermans et al. (1980) found that the incidence of *Salmonella* positive carcasses decreased 36.5 percent when carcass rinses were incorporated into the evisceration process, compared to a 20.5 percent increase without carcass rinses. However, carcasses rinses are not an effective intervention against attached pathogens (Kotula et al. 1967, Mead et al. 1975).

Off-line Reprocessing

Off-line reprocessing is a manual process and addresses disease conditions and contamination that cannot be removed by other means. When properly performed, off-line reprocessing eliminates visible conditions and yields carcasses microbiologically equivalent to inspected and passed carcasses (Blankenship et al. 1975); however, reductions in microorganisms are not certain. Blankenship et al. (1993) found the microbiological quality of conventionally processed and reprocessed carcasses to be equivalent for aerobic bacteria, Enterobacteriacea, and *E. coli.* With respect to *Salmonella* prevalence, the overall difference between conventionally processed and reprocessed carcasses of 5.2 percent was not statistically significant.

On-line Reprocessing

On-line reprocessing addresses incidental fecal and/or ingesta contamination during evisceration. Acuff et al. (1986) and Izat et al. (1988) found that an on-line carcass wash reduced *C. jejuni* 344 MPN/100 cm^3 and 0.7 $\log_{10}$ CFU/1,000 cm^3, respectively. On-line reprocessing is automated and relies on washing systems in combination with antimicrobial agents to achieve desired results. Water temperature, pressure, nozzle type and arrangement, flow rate, and line speed all influence the effectiveness of the washing system. Multiple washers in series are generally more effective then a single large washer. Bashor et al. (2004) and Kemp et al. (2001b) found that a three-stage system decreased *Campylobacter* by 0.45 $\log_{10}$ CFU/ml compared to 0.31 $\log_{10}$ CFU/ml in a single stage system ($p \leq 0.05$). Online reprocessing systems installed in one plant may not perform equally well in another plant.

The addition of antimicrobial agents generally increases the effectiveness of an on-line reprocessing system. Fletcher and Craig (1997) found that 23 ppm free available chlorine reduced the incidence of *Campylobacter*-positive carcasses from 77 percent to 72 percent, and *Salmonella*-positive carcasses from 5 percent to 2 percent. Bashor et al. (2004) found that TSP and acidified sodium chlorite decreased *Campylobacter* by 1.3 $\log_{10}$ CFU/ml and 1.52 $\log_{10}$ CFU/ml, respectively ($p \leq 0.05$). Yang and Slavik (1998) reduced *Salmonella* on carcasses 1.36 $\log_{10}$ CFU with 10 percent TSP, 1.62 $\log_{10}$ CFU with 5 percent cetylpyridinium chloride, 1.21 $\log_{10}$ CFU with 2 percent lactic acid, and 1.47 $\log_{10}$ CFU with 5 percent sodium bisulfate ($p \leq 0.05$). Whyte et al. (2001b) found that 10 percent TSP combined with 25 ppm free available chlorine decreased *Salmonella* and *Campylobacter* by 1.44 $\log_{10}$ CFU/g and 1.71 $\log_{10}$ CFU/g, respectively. On-line reprocessing is not as effective against tightly attached pathogens. Reducing tightly attached microorganisms requires longer contact times then normally occurs under commercial conditions (Morrison and Fleet 1985, Teotia and Miller 1975).

If properly performed, on-line reprocessing of contaminated carcasses can yield better results than off-line reprocessing, and improve food safety and the microbiological quality of raw poultry (Kemp et al. 2001a). However, if process control is not maintained, results can be mixed (Fletcher and Craig 1997) and biological potential risk factors enhanced (Blankenship et al. 1993).

CHILLING

Chilling removes the natural heat from the carcass and is complete when regulatory temperature requirements are met. Immersion and air chilling are the primary chilling technologies in use in the world today. Immersion chilling is the more common method; however, both methods acceptably decrease carcass temperature and inhibit biological potential risk factors.

Potential Risk Factors

Potential chemical risk factors are introduced during the immersion chilling process. Tsai et al. (1987) found that lipids account for 84 to 98 percent of the organic matter in immersion chiller water and that aldehydes, which form as these lipids auto-oxidize, react with chlorine to form chlororganics, mutagenic chemicals that potentially impact the safety and wholesomeness of poultry products. Marsi (1986) found that when free available chlorine levels are ≤50 ppm, minimal free available chlorine reacts with aldehydes and forms chlororganics. However, when free available chlorine levels ≥250 ppm, chlororganic formation rises sharply.

Biological potential risk factors exist during the chilling process as pathogenic and nonpathogenic microorganisms on the carcass and in the chiller environment. *Salmonella* and *Campylobacter* are the most common pathogenic microorganisms present on carcasses and in the immersion chiller environment. Clouser et al. (1995a) recovered *Salmonella* from 60 percent of carcasses pre-chill, and 57 percent of carcasses post-chill. Wempe et al. (1983) isolated an average of 2.20 $\log_{10}$ *C. jejuni*/ml from the chiller water. Loncarevic et al. (1994) recovered *L. monocytogenes* from 21 percent of post-chill skin samples taken from pre-chill *Listeria*-negative carcasses and determined that *L. monocytogenes* was a biological potential risk factor when the chlorine concentration of the chiller water was ≤10 ppm free available chlorine. Clouser et al. (1995a) found a 57 percent incidence in *Listeria monocytogenes*-positive kosher carcasses post-chilling, compared to 7 percent incidence with conventional slaughter methods, found no relationship between the incidences of *L. monocytogenes* in the flock pre- or post-chilling, and concluded that the *L. monocytogenes* originated from the chiller water.

Jimenez et al. (2003) found that immersion chilling reduced Enterobacteriaceae, *E. coli*, and coliforms on noncontaminated carcasses by 0.36 $\log_{10}$, 0.89 $\log_{10}$, and 0.61 $\log_{10}$ CFU/ml in carcass rinses, respectively, compared with 1.02 $\log_{10}$, 1.16 $\log_{10}$, and 1.23 $\log_{10}$ CFU/ml in rinses from fecal contaminated carcasses. Berrang and Dickens (2000) found that immersion chilling decreased APC, coliform, and *E. coli* in carcass rinses by 0.7 $\log_{10}$, 0.3 $\log_{10}$, and 0.4 $\log_{10}$ CFU/ml, respectively, ($p \leq 0.05$). Lillard (1990) found that immersion chilling decreased APC and Enterobacteriaceae by 0.92 $\log_{10}$ and 0.74 $\log_{10}$ CFU/ml.

Sarlin et al. (1998) found that *Salmonella*-negative carcasses remain negative, provided they are not preceded by a *Salmonella*-positive flock and that the immersion chiller is a major site for cross-contamination between *Salmonella*-negative and -positive flocks. Jimenez et al. (2003)

($p>0.05$) found no correlation between visible ingesta on carcasses and the presence or absence of *Salmonella* during immersion chilling. Twelve percent of carcasses with visible fecal contamination were *Salmonella*-positive following immersion chilling, compared to 30 percent without visible fecal contamination.

Air chill systems come in two basic configurations: clip-bar and vent-stream. Allen et al. (2000) determined that microbial counts on poultry carcasses are lower in air chilling systems, compared to immersion chill systems. Sanchez et al. (2002) reported the incidence of *Salmonella*-positive carcasses in air chillers at 18 percent, compared to 24 percent with immersion chillers; and the incidence of *Campylobacter*-positive carcasses in air chillers at 39 percent, compared to 48 percent with immersion chillers ($p\leq0.05$). Conversely, they found that coliforms and *E. coli* in whole carcass rinses were 0.25 $\log_{10}$ CFU/ml and 0.26 $\log_{10}$ CFU/ml higher with air chillers than immersion chillers, respectively. The differences are not significant with regard to the cooling efficiency, but do affect the degree of physical contact between carcasses and the potential for cross-contamination. Mead et al. (2000) found that dispersal of a marker organism was greater in a vent-stream system than in a clip-bar system. Dispersal of the marker organism decreased when water sprays were turned off.

Controls. Chemical potential risk factors introduced during the chilling process through the excessive application of antimicrobial agents can be prevented, eliminated, or reduced to acceptable levels during the chilling process. Biological potential risk factors cannot be prevented or eliminated during the chilling process; however, they can be reduced to acceptable levels.

Mulder et al. (1976) found that immersion chilling decreased *Salmonella*-positive carcasses by 5 percent. Acuff et al. (1986) found that immersion chilling decreased *C. jejuni* 69 MPN/100 cm^3. Berrang and Dickens (2000) found that immersion chilling decreased *Campylobacter* spp., levels 0.8 $\log_{10}$ CFU/ml. Izat et al. (1988) found that immersion chilling decreased *C. jejuni* on carcasses by 0.9 $\log_{10}$ CFU/1,000 cm^3. Bilgili et al. (2002) found that immersion chilling decreased *Campylobacter* by 0.86 $\log_{10}$ CFU/ml, and the incidence of *Salmonella*-positive carcasses from 20.7 percent to 5.7 percent. Lillard (1990) found that, on average, immersion chilling increased the incidence of *Salmonella* by 20.7 perecnt.

More reduction in biological potential risk factors can be accomplished in a properly balanced immersion chiller than at any other processing step. Conversely, an improperly balanced immersion chiller can increase biological potential risk factors. However, regardless of how well any immersion system is operated, it cannot overcome excessive biological potential risk factors entering the chilling process. The NCC (1992) recommends that processors focus on proper water temperature and water quality to control biological hazards in the immersion chiller. Water temperature should be maintained to ensure that product temperatures are in accordance with 9 CFR 381.65. l.

Maintaining proper water quality requires balancing pH, maintaining a free available chlorine concentration, and minimizing organic matter. Diffusion of hypochlorous acid (HOCl) in solution into hydrogen (H^+) and hypochlorite (OCl^-) ions is influenced by pH. At pH <7.5 the hypochlorite ion is favored, which increases the concentration of free available chlorine. At pH >8, the hypochlorous acid moiety is favored, which decreases the concentration of free available chlorine.

Chlorine is the most common and most effective antimicrobial intervention in use in immersion systems worldwide, and the effect is directly proportional to the free available chlorine concentration. Thiessen et al. (1984) could not recover *Salmonella* from chiller water when the ClO_2 residual was ≥1.3 ppm. Wabeck et al. (1969) found that 20 ppm chlorine destroyed 3.0 $\log_{10}$ *Salmonella*/ml in solution after 4 hours, but not *Salmonella*, on the surface of inoculated drumsticks. Villarreal et al. (1990) found that ClO_2 could eliminate recoverable *Salmonella* from carcass rinses. James et al. (1992) found that the incidence of *Salmonella*-positive carcasses increased from 48 percent to 72 percent during immersion chilling in a nonchlorinated system compared to 43 percent to 46 percent when free available chlorine at the overflow was maintained at 4 to 9 ppm. Yang et al. (2001) found that 10 ppm free available chlorine eliminated *S. typhimurium* and *C. jejuni* from the water in 120 and 113 minutes respectively; 30 ppm produced the same result in 6 and 15 minutes; and 50 ppm in 3 and 6 minutes ($p \leq 0.05$).

Three factors determine the amount of organic matter in the immersion chiller: flow rate, flow direction, and the cleanliness of the scald water. When the chiller is more like a pond than a river, the water is stagnant and organic matter accumulates in the water, on the paddles, and on the sides of the chiller. Thomas et al. (1979) found that when fresh water in-flow drops to <½ gallon/bird, organic matter accumulates in the chiller water. Lillard (1980) found that more organic matter in the chiller will result in less chlorine available to kill bacteria, as it will be bound to and rendered useless by the organic matter. The recommended method for performing water replacement is with a counter-current system.

Tsai et al. (1987, 1992) found that organic matter in an immersion chiller equilibrates after 5 to 6 hours of operation and requires 2 to 3 times more free available chlorine to achieve a 2-$\log_{10}$ reduction in bacteria. Lillard (1979) calculated the concentration of organic matter at equilibrium to be 91 ppm. Allen et al. (2000) found that the concentration of organic matter increases closer to the exit and is reflected in the concentration of free available chlorine at different locations within the chiller. Filtration of recycled water reduces the level of organic matter and spares free available chlorine for bactericidal activity.

Russell (2005) recommended a pH of 6.5 to 7.5, a water temperature 4°C (<40°F), a high flow rate, and counter-current flow direction. Waldroup et al. (1992) recommended 20 to 50 ppm free available chlorine in the intake water in order to reduce the total microbiological load in the chiller water. The amount of chlorine added at the intake should be sufficient to achieve 1 to 5 ppm free available chlorine at the chiller overflow.

A recent study designed to examine the prevalence and number of *Campylobacter* on broiler chicken carcasses in commercial processing plants in the United States (Berrang et al. 2007) can provide an indicator for the effectiveness of reducing pathogen loads during all of the steps involved in poultry processing. In the study, carcass samples were collected from each of 20 U.S. plants 4 times, roughly approximating the 4 seasons of 2005. At each plant on each sample day, 10 carcasses were collected at rehang (prior to evisceration), and 10 carcasses from the same flock were collected post-chill. A total of 800 carcasses were collected at rehang and another 800 were collected post-chill. All carcasses were subjected to a whole-carcass rinse, and the rinse diluent was cultured for *Campylobacter*. The overall mean number of *Campylobacter* detected on carcasses at rehang was 2.66 log CFU/ml of carcass rinse. In each plant, the *Campylobacter* numbers were significantly reduced ($p \leq 0.001$) by broiler processing; the mean concentration after chill was 0.43 log CFU/ml. Overall prevalence was also reduced by

processing from a mean of ≥30 of 40 carcasses at rehang to ≥14 of 40 carcasses at post-chill. Seven different on-line reprocessing techniques were applied in the test plants, and all techniques resulted in <1 log CFU/ml after chilling. Use of a chlorinated carcass wash before evisceration did not affect the post-chill *Campylobacter* numbers. However, use of chlorine in the chill tank was related to lower numbers on post-chill carcasses ($p<0.0003$). Overall, U.S. commercial poultry slaughter operations are successful in significantly lowering the prevalence and number of *Campylobacter* on broiler carcasses during processing.

CONCLUSIONS

1. Physical potential risk factors are quality issues that rarely exist during poultry slaughter operations, and can be eliminated or reduced to acceptable levels when good commercial practices are implemented. Physical potential risk factors present a negligible risk.

2. Chemical potential risk factors are food safety and quality issues that seldom exist during poultry slaughter operations and can be prevented, eliminated, or reduced to acceptable levels through prerequisite programs. Violative chemical residues are a pre-harvest issue and the primary chemical potential risk factor. According to the 2000 National Residue Program, the incidence of violative residues was 0.11 percent for all classes of poultry. In 2000, U. S. poultry processors slaughtered more than 8 billion live poultry, which means approximately 9.5 million poultry carcasses passed through Federally-inspected slaughter establishments with violative chemical residues. Chemical potential risk factors present a minimal risk.

3. Biological potential risk factors are unavoidable food safety and quality issues that continually exist during poultry slaughter operations. Biological potential risk factors are present in and on all live poultry received onto official establishments and cannot be prevented or eliminated; however, they can be reduced to acceptable levels through the application of good manufacturing practices and process control. Biological potential risk factors present a significant risk.

4. The cited data for *E. coli,* Enterobacteriaceae*, Campylobacter, Pseudomonas*, Coliform and APC show that more microorganisms exist in and on poultry at live receiving than at any other process step in slaughter operations. The scalding and immersion chilling steps produce the greatest overall reduction by washing microorganisms from the carcass surfaces. The feather removal and evisceration steps result in an increase from the previous steps in the number of microorganisms. However, overall microorganisms are reduced from the number present when the poultry are at live receiving to when the carcasses are exiting the chiller.

5. Numerical data are not available for *Salmonella*, however, *Salmonella* prevalence follows a similar distribution pattern. No single process step, no matter how well controlled, can prevent, eliminate, or reduce to acceptable levels, a biological potential risk factor.

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