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Antimicrobial Interventions in Poultry Processing to Improve Shelf Life and Safety of Poultry Meat: A Review with Special Attention to *Salmonella* spp.

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HIGHLIGHTS

- The poultry industry is facing major challenges in maintaining of safety and shelf life of the poultry meat.
- Poultry may be contaminated with pathogenic microorganisms posing significant health risk to the consumers.
- This article reviewed different antimicrobial interventions used in poultry processing.
- This review provides comprehensive knowledge on safety of poultry meat with special attention to *Salmonella* spp.

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Acronyms and abbreviations
CFU=Colony Forming Unit
PAA=Peracetic Acid
STPP=Sodium Tripolyphosphate
TSP=Trisodium Phosphate

ABSTRACT

Poultry meat is one of the most popularly consumed meats worldwide. With the increased consumption, the poultry industry is also facing major challenges in maintaining of safety and shelf life of the poultry meat. Microbial concerns related to poultry meat comprise of meat safety and shelf life as poultry meat is prone to contamination with spoilage as well as pathogenic microorganisms. Poultry may be contaminated with pathogenic microorganisms such as *Salmonella* spp. at various processing steps, posing significant health risk to the consumers. To reduce the predominance of food-borne pathogens such as *Salmonella* spp. as well as spoilage microorganisms, poultry processors can employ a multi-hurdle approach wherein antimicrobial interventions are applied at various steps of processing. This article reviewed different poultry processing steps and the antimicrobial interventions used in the poultry processing sector to improve safety, shelf life, and quality of poultry meat. This review provides comprehensive knowledge on safety of poultry meat with special attention to *Salmonella* spp. for the poultry industry as well as researchers throughout the world.

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Introduction

Microbial concerns related to poultry meat comprise of meat safety and shelf life as poultry meat is prone to contamination with spoilage as well as pathogenic microorganisms. Poultry may be contaminated with pathogenic microorganisms such as *Salmonella* spp. at various levels of handling (farm, feed, live bird handling, processing, and retail), posing significant health risk to the consumers (Mead, 2004; Rouger et al., 2017).

There are numerous reports quoting *Salmonella* spp. contamination related to raw poultry and products which have resulted in 1.2 million illnesses, 23000 hospitalizations and 450 deaths annually in the United States (CDC, 2018; Simmons et al., 2003) leading to an economic loss of $2600 million/year (Taskila et al., 2012). Besides, microbial shelf life of poultry meat is important from the commercial point of view.

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To improve the food safety and shelf life of poultry meat, the poultry carcasses are being subjected to several physical and antimicrobial interventions which are reviewed in this paper at various steps of poultry processing. The other objective of this review article is to outline the different strategies during poultry processing to inhibit *Salmonella* spp. and improve microbial shelf life of poultry meat.

Steps of poultry processing

This section briefly describes the sequence of steps involved in primary poultry processing. The poultry slaughter begins with hanging the live birds on the overhead shackles. Next, the birds are stunned using an electric current or a gas which makes the birds unconscious followed by bleeding of the bird. Scalding is the next step where birds are dipped in hot water maintained at 50-61 °C which promotes de-feathering. De-feathering of the carcass is achieved by the mechanical pickers with rubber fingers. Post feet removal, knife is used to cut off oil glands from tail area, and carcasses are rehanged on another line for further steps. The next step is the evisceration which involves the opening of the body cavity and removal of internal organs. Following this, the carcasses are washed and inspected. Following evisceration, carcasses are chilled to a temperature of 4 °C within 2-6 h of slaughter. Then, carcass weight is recorded followed by deboning and finally refrigerated transportation to further processing plants or retail packages (Barbut, 2010; Bolder, 2007).

Cross contamination of carcasses with *Salmonella* spp. may occur during the various processing steps such as scalding, picking, evisceration, and chilling (Rasschaert et al., 2008). These steps receive significant attention to improve food safety and reduce overall bacterial load on the carcasses during primary poultry processing. Additionally, maintaining low temperatures using adequate refrigeration or dry ice prevent the growth of microbes. Nonetheless, *Salmonella* spp. survive cooling and freezing, making the storage and transportation steps vulnerable to food safety (Bailey et al., 2000; Pradhan et al., 2012). Morey and Singh (2012) demonstrated that *Salmonella* spp. can survive refrigerated temperatures, and a potential temperature abuse can lead to increase the *Salmonella* spp. levels. Various in-plant interventions are being conducted by the poultry processors to reduce the population of pathogen during processing, but simple and advanced interventions are further required to enhance poultry meat safety during handling and distribution operations (Fratamico et al., 2012; Sofos, 2008).

Antimicrobial interventions to control *Salmonella* spp. during poultry processing

The poultry industry employs several antimicrobial interventions to reduce or eliminate *Salmonella* spp. at multiple steps during poultry processing. Antimicrobials such as chlorine, Trisodium Phosphate (TSP), ozone, acetic acid, lactic acid, etc. have demonstrated efficacy against *Salmonella* spp. on poultry carcasses when applied during spray washing, chilling, or post chilling (Anang et al., 2010; Bauermeister et al., 2008; Fabrizio et al., 2002; Wideman et al., 2016).

Scalding

During processing, the carcasses are subjected to scalding where a hot water dip facilitates the removal of dirt as well as helps in feather removal from the follicles in the skin (Irshad and Arun, 2013). The next step is the hard scalding method in which carcasses are exposed to hot water at 60-66 °C and has been proved to be most effective in lowering *Salmonella* spp. when compared with soft scalding at 50-53 °C (Buhr et al., 2014). Moreover, the addition of sodium hydroxide (NaOH) to scald water assist in greater removal of bacterial load as the alkaline pH of NaOH causes enzyme malfunction in bacterial cells, destroying microbial population (McKee et al., 2008).

On-line spray washing

Berrang and Bailey (2009) documented the installation of on-line spray washers at numerous sites in the processing line aiming at a multi-hurdle approach which reduced *Salmonella* spp. prevalence on carcasses by 56%. Furthermore, Zaki et al. (2015) suggested that the antimicrobial efficiency of organic acids in reducing *Salmonella* inoculated on the chicken skin can be increased when used in combination with sodium dodecyl sulphate. Washing chicken skin in 2:1 solution of lactic acid and sodium dodecyl sulphate for 3 min led to *Salmonella* reductions by 7.43 log Colony Forming Unit (CFU)/cm^2, while lactic acid wash led to a reduction of 3.36 log CFU/cm^2 (Bales et al., 1998; Zaki et al., 2015).

Chilling of carcasses

The broiler carcasses undergo chilling to cool after evisceration and reduce the temperature to about 4 °C (USDA, 2003) . Pre-chiller as well as an immersion primary chiller can be employed in the poultry processing plant to reduce the temperature of carcasses. Several antimicrobials used in poultry chillers as chilling step

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involve the longest contact time of carcasses with the water or the antimicrobial solution. Immersion chilling with added antimicrobials is the most common method followed in the poultry industry to chill the carcasses and aids in the bacterial reduction (Wideman et al., 2016).

Poultry processing plant used chlorine to facilitate decontamination in the chillers as well as the processing areas. However, efficacy of chlorine gets compromised with high organic load such as debris attached to the chicken carcasses. The antimicrobial efficacy of chlorine is dependent on the pH of the solution (Paul et al., 2017).

Peracetic acid (PAA), also known as peroxyacetic acid, has emerged as the most commonly used processing treatment to decrease *Salmonella* spp. in poultry processing plant (Chen and Pavlostathis, 2019). Unlike chlorine, the presence of high organic loads does not affect the efficacy of PAA (Kitis, 2004). Bauermeister et al. (2008) reported that chilling the carcasses in 85 ppm mixture of PAA (15% PAA+10% Hydrogen peroxide) for 20 min decreases the prevalence of *Salmonella* spp. by about 92%; whereas 30 ppm of chlorine causes a reduction in the prevalence of *Salmonella* by 57%.

Another study indicated chilling carcasses in chill water containing 25 ppm of PAA in poultry chiller for 2 h results in 0.85 log higher reduction in *Salmonella* counts as compared to 30 ppm chlorine in the chiller water (Bauermeister et al., 2008). The lower efficacy of chlorine has been attributed to the higher pH and presence of organic matter in the chiller water. In addition to the immersion chillers, post-chill dip tanks are used to further lower the count of the pathogen when applied with other interventions in the processing plant (Wideman et al., 2016). PAA 0.1% (1000 ppm) was utilized for post-chill immersion of carcasses which exhibited a 2.14 log reduction in *Salmonella* spp. inoculated on carcasses (Nagel et al., 2013).

Zhang et al. (2019) compared the efficacy of water, chlorine, cetyl pyridinium chloride, and PAA in chiller to reduce *Salmonella* spp. on chicken parts. These researchers found that cetyl pyridinium chloride is more efficacious at 30 s contact time in reducing the pathogen; however, its higher cost can limit usage of this antimicrobial in poultry processing. Bourassa et al. (2019) revealed a low prevalence of *Salmonella* spp. in commercial poultry processing plants used PAA intervention step. The antimicrobial activity of PAA is assumed to be due to the oxidization of sulfhydryl and sulphur bonds present in the proteins, disrupting the movement of ions across the cell membrane (Kitis, 2004).

Dip treatment

Previous studies reported that a 15 s dipping in 10% TSP followed by dipping in 0.1% acidified sodium chlorite decreased *S.* Typhimurium by 1.6 log on inoculated chicken breast skin (Ozdemir and Pamuk, 2006). The authors proposed that the antibacterial efficacy of TSP could be due to the high pH (12.1) of the solution which results in lethal or sublethal injury to *Salmonella* cells attached on the carcasses. Rodriguez de Ledesma et al. (1996) showed that dipping the chicken wings in a 10% solution of TSP for 15 s reduces the *S.* Typhimurium counts by 93.45%.

Anang et al. (2010) stated that dipping the chicken breast in a 2% lactic acid solution for 30 min results in a reduction of 1.71 log of *S.* Enteritidis. The antibacterial action of lactic acid is believed to be due to the decrease in the intracellular pH , following the disrupting of the pH balance in the cytoplasm of the cell (Davidson et al., 2013). Salts of organic acids such as lactates and acetates have been studied for their antimicrobial action mostly in ready-to-eat meats (Mbandi and Shelef, 2002).

Antimicrobial ice

Besides the spray or dip treatment of meat with antimicrobial agents, these antimicrobials can potentially be employed to the cut parts in an ice form. Even after utilizing various antimicrobial interventions during the processing of chicken, the processed carcasses are prone to contamination with food-borne pathogens like *Salmonella* spp. during distribution to retailers or further processing companies. During the transportation of processed poultry, the processed chicken might be subjected to temperature abuse, improper handling conditions or contamination from the environment which might result in an unsafe and low-quality product (USDA, 2003).

Dry ice i.e. solid CO_2 is commonly utilized during the transportation of chicken to preserve lower temperatures while in transit. Fratamico et al. (2012) conducted a study to examine the antibacterial activity of ozonated dry ice also known as ALIGAL Blue Ice against *S.* Typhimurium in chicken meat purge during the chilled storage and transportation. These authors indicated that ozonated ice decreased the *Salmonella* count 1.8 log CFU/ml whereas dry ice storage resulted in about 1 log reduction in the bacterial count. Higher efficacy of ALIGAL Blue Ice has been attributed to the greater cooling ability and antibacterial action of dry ice and ozone (Jeyasekaran et al., 2004; Kim et al., 1999).

In another investigation, antimicrobial ice made from a solution of chlorine dioxide and citric acid in water was

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tested for its efficacy in suppressing *S.* Typhimurium on fish skin. Findings of this study showed that storage of fish on ice containing chlorine dioxide 120 ppm for 120 min significantly decreases *Salmonella* counts on the fish skin by 2.6 log CFU/cm^2 (Shin et al., 2004). The researchers suggested that storage in antimicrobial ice containing chlorine dioxide exhibits a sustained release of chlorine dioxide on the surface of skin as the ice melted over the period of time.

Antimicrobial interventions to improve the shelf life and quality of poultry meat

Poultry meat makes a significant part of the present-day diets due to its relatively low cost of production, low fat content, and the high nutritional value of poultry meat. Therefore, maintaining the microbiological quality of poultry is of utmost importance to the poultry producers. As poultry meat is a perishable commodity, it is always susceptible to deterioration or spoilage of meat even at refrigeration temperature (Mantilla et al., 2011). Higher levels of microorganisms on raw meat results in undesirable and unappealing surface changes making it objectionable for consumption (Gram et al., 2002).

Spoilage of poultry meat depends on various factors such as initial microbial level, physiological status of the chicken at the time of slaughter, contamination in the processing plant, temperature, storage conditions, etc. (Nychas et al., 2008). For fresh meat distribution and consumption, it is extremely important to monitor the time/temperature conditions. To ensure both safety and overall meat quality, the vehicles for the transportation of meat must be equipped with a good refrigeration system. However, there are always chances of failure of refrigeration equipment which would lead to the spoilage of the meat products.

The type of spoilage microorganisms that thrive on the poultry meat depends on the storage conditions. For instance, when chicken meat is stored in limited oxygen conditions or in the absence of oxygen, facultative anaerobes or anaerobic Gram-positive microbiota dominate; whereas when chicken meat is stored under aerobic conditions (i.e. high oxygen conditions), the aerobic or facultative anaerobic Gram-negative bacteria increase (Doulgeraki et al., 2012). The metabolic activities of spoilage microorganisms comprise the primary spoilage mechanism and result in the production of off-odors (Mead, 2004).

Temperature of storage of the meat products determines its microbial spoilage by affecting the lag phase duration, maximum specific growth rate, and final microbial count (Mataragas et al., 2006). Also, the freshly processed poultry will predominantly have the mesophilic bacteria which grow at an optimum temperature of 35 °C. Besides, psychrotrophic microorganisms proliferate during chill storage of raw meat (Smaoui et al., 2011). Different storage temperature conditions influence the growth of different genera of microorganisms. For example, psychrotrophic bacteria belonging to Gram-positive genera such as lactic acid bacteria and Gram-negative bacteria such as *Pseudomonas* spp. and *Enterobacteriaceae* prefer chilled temperature conditions to grow (Hinton et al., 2004). *Pseudomonas* spp. primarily results in spoilage due to the formation of slime and malodorous sulfides, esters, acids, and amines in meat stored at refrigerated conditions (Ercolini et al., 2007). Also, pseudomonads prefer aerobic atmosphere for their growth whereas the spoilage of vacuum packed is mainly caused by psychrotrophic lactic acid bacteria forming lactic acid and volatile fatty acids (Pothakos et al., 2015).

Production of off-odors and formation of slime in meat make the product unpalatable and unacceptable to consumers. Therefore, upgrading the keeping quality and lowering or destroying the spoilage causing microorganism of chicken are the principal objectives of the poultry producers and food microbiologists. So, using antimicrobial agents is an effective way for improving shelf life and quality of poultry meat which is discussed as follow.

Antimicrobials for improving microbial shelf life of poultry meat

Several decontamination treatments such as physical, chemical, or a combination of both have been studied by researchers to determine their efficacy for reducing the spoilage microflora in poultry. TSP has been proved to be effective in reducing mesophilic, psychrotrophic, and lactic acid bacteria on chicken legs during the 5-day period (Del Río et al., 2005). Okolocha and Ellerbroek (2005) documented that dipping the chicken carcasses in 10% TSP for 6 s results in about 0.9 log reduction in *Lactobacillus* after up to 6 days of storage at 4 °C.

Kim and Marshall (1999) noted that a 10 min dip treatment of chicken legs in 5% TSP (w/v) significantly reduces the aerobic plate counts and increases the shelf life of chicken legs to 12 days as compared to monosodium phosphate and sodium pyrophosphate. TSP was also proved to be effective in reducing the counts of *P. fluorescens* inoculated on chicken legs by 1.8 log after 5 days of chilled storage at 4 °C. However, there are scarce records of comparison of antibacterial action of Sodium Tripolyphosphate (STPP) and TSP. Vareltzis et al. (1997) found that a dip treatment of chicken carcasses in 10% solution of STPP results in the shelf life extension by 3 days as compared to regular tap water dip. The antimicrobial activity of STPP can be attributed to its ability to sequester metallic ions in the cell wall of

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bacteria which prevents the cell wall division and suppresses the growth of microorganisms (Buňková et al., 2008).

The effect of sodium lactate on the shelf life of low-fat Chinese-style sausage was evaluated by Lin and Lin (2002). According to these researchers, relatively lower aerobic plate counts and pyshcrotrophic counts were found in sausages which contained 3% sodium lactate under chilled storage for 12 weeks. They also suggested that sodium lactate acts as a bacteriostatic agent extending the lag phase of bacteria whereas TSP acts as a surface antimicrobial agent. In another study, combinations of 1.8% sodium lactate with 0.25% sodium diacetate were effective in reducing lactic acid bacteria in pork bologna stored at 4 °C (Barmpalia et al., 2005). Oral et al. (2008) studied the effect of antimicrobial ice made from wild thyme hydrosol on the shelf life of fish (*Capoeta capoeta capoeta*) and reported that antimicrobials applied in the form of ice possess the ability to delay the spoilage in fish.

Antimicrobials for improving quality of poultry meat

When buying chicken, appearance is the first factor which determines the choice of selection of poultry products for the consumers. Besides the appearance or color of the chicken, the other factors which might interest the consumes are drip loss, tenderness, juiciness, and cook loss (Hinton et al., 2004). The color of poultry meat can be determined in terms of color reflectance which can be measured using a colorimeter (Fletcher, 2002). The most common color scales to measure the reflectance is the Hunter Lab. The 'L' value depicts how lighter or darker the product is i.e. a value of 100 denotes pure white and a value of 0 denotes pure black. The 'a' value signifies the redness whereas the 'b' value symbolizes the yellowness of the product.

The effect of different antimicrobial interventions on the color of poultry has been evaluated by various researchers. Chilling of carcasses in 0.02% PAA (v/v) may lead to lighter color of carcasses whereas flavor, texture, and juiciness of breast fillets remained unaffected with this intervention (Bauermeister et al., 2008). Similar results were reported by Smith and Young (2007) where phosphate marination did not bring any noticeable differences in the color of chicken breasts. Carroll et al. (2007) observed no adverse impact on the lightness (L*) and redness (a*) of turkey lobes marinated with STPP as well as sodium lactate and sodium diacetate. All the aforementioned findings suggest that the different processing treatments used to improve the microbial shelf life and quality might affect the appearance of meat depending on the type and concentration of antimicrobials. Therefore, the type of processing antimicrobial utilized during the processing should be chosen in such way that it should not compromise with sensory attributes of the product.

Some processing treatments may have an impact on the cooking quality and texture of the meat product. Turkey breast fillets marinated with STPP resulted in 14.11% cooking loss which was significantly lower than cook loss observed in marinated with sodium lactate and sodium diacetate treated fillets (Carroll et al., 2007). The probable reason behind the lower cooking losses is the increased moisture retention in the chicken meat treated with STPP. Sen et al. (2005) reported lower cooking losses in the breast meat samples injected with 3% sodium bicarbonate and 3% tetra sodium pyrophosphate for 24 h. This is probably due to the potential effect of bicarbonates and phosphates on the moisture retention property of the meat, as the bicarbonates and phosphates ions interact with the protein of chicken breast and enhance the hydration.

The effect of sodium lactate on the cooking yield of tray-packed broiler breast meat was studied by Williams and Phillips (1998). This study showed that sodium lactate at a pH of 7.3 exhibits the highest cooking yield followed by sodium lactate at pH 5.0. It was suggested that the lower cooking yield of sodium lactate at pH 5.0 might be due to the moderate denaturation of surface proteins that are in the immediate vicinity of sodium lactate. Protein denaturation leads to decrease water holding capacity of proteins and eventually, lower cooking yields.

Another important quality attribute of meat is the texture/tenderness of the cooked meat product. Texture of the cooked meat product, in general, is the force required to cut through the muscle fibers of the meat during chewing. To improve the textural properties of the chicken meat, different food additives are being added to the meat, especially phosphates (Zheng et al., 2001). A study conducted to investigate the effects of injecting NaCl, STPP, and sodium lactate on the shear force documented that there were no significant differences in the shear force values of steaks when compared with the untreated control samples (McGee et al., 2003). Furthermore, chicken breasts injected with STPP exhibited lower shear force establishing the idea that STPP improves the tenderness in meat (Zheng et al., 2001).

Tenderness in STPP treated meat can be connected with the improved cooking yields and water holding capacity (Alvarado and McKee, 2007). Phosphates result in unfolding the myofibrillar proteins of meat, including actin, myosin, and actomyosin due to the electrostatic repulsions which helps in accommodating greater number of water molecules between the muscle fibers of meat (Wynveen et al., 2001).

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Conclusion

Safety and shelf life of the poultry meat are still a major concern from public health viewpoint. So, the poultry processors must evaluate various antimicrobial options and determine its effectiveness for their process to reduce *Salmonella* spp. and spoilage microorganisms in the poultry meat.

Author contributions

J.K. wrote the manuscript; A.M. critically revised the manuscript. Both authors read and approved the final manuscript.

Conflicts of interest

The authors declared that they have no conflicts of interests.

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