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Review

An overview of *Salmonella* thermal destruction during food processing and preparation

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ABSTRACT

Each year there are an estimated one million non-typhoidal *Salmonella* infections in the U.S. and about 20,000 of those infected persons require hospitalization. These infections cost Americans almost $4 billion per year. Worldwide, there are more than 80 million cases of foodborne salmonellosis. Numerous food preservation methods have been developed for extending the shelf life of food and inhibiting the growth of foodborne pathogens such as *Salmonella*. Food processing and preparation methods using heat (thermal treatments) are considered to be the most effective methods for elimination of *Salmonella* in food. In this review we discuss the use of thermal treatments for elimination of *Salmonella* in or on many food products, including poultry, meats, eggs, produce and low water activity foods.

Contents

1. Introduction

The bacterial genus *Salmonella* has only 2 species, *enterica* and *bongori*; *Salmonella enterica* is further divided into 6 subspecies, one of which is *S. enterica* subspecies *enterica* (Issenhuth-Jeanjean et al., 2014). The *enterica* subspecies encompasses 1586 serovars

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and is the only subspecies which contains human and/or animal pathogens (Issenhuth-Jeanjean et al., 2014). Animals used for human food consumption can be carriers of numerous serovars of *Salmonella*, some of which can cause disease in humans, although they may not cause disease in the carrier animals (Kingsley & Bäumler, 2000). This poses a challenge for the production of wholesome food products of animal origin. When food products are contaminated with sufficient quantities of *Salmonella* or are handled in such a way as to allow for the outgrowth of the organism in the food that is consumed, then salmonellosis in humans is possible.

There are an estimated one million human *Salmonella* infections, not including typhoid fever, in the U.S. each year with about 20,000 of those cases resulting in hospitalization (Scallan et al., 2011). Globally, best estimates put the number of foodborne cases of salmonellosis at 80.3 million (Majowicz et al., 2010). Diarrhea is the most consistent symptom of salmonellosis, although combinations of diarrhea, fever, abdominal cramps, and/or vomiting occur regularly (CDC, 2014a; O'Mahony et al., 1990). Salmonellosis usually occurs within 6–48 h of consuming a contaminated food, although longer time periods have been reported (Abe, Saito, Kasuga, & Yamamoto, 2004). Outbreak analyses suggest that the infectious dose of *Salmonella* could be as low as 1 to 10 cells in some individuals (D'Aoust, Warburton, & Sewell, 1985; Kapperud et al., 1990; Lehmacher, Bockemühl, & Aleksic, 1995) although data from some outbreaks has indicated the number of cells consumed was on the order of 10^6 per person (Abe et al., 2004).

Unlike many other foodborne pathogens, *Salmonella* has been implicated in outbreaks from a wide variety of food products including raw poultry, fresh sprouts, peanut butter and chocolate (CDC, 2007; CDC, 2014b; Van Beneden et al., 1999; Werber et al., 2005). *Salmonella* has traditionally been associated with poultry and egg products, but in recent years fresh produce, especially alfalfa sprouts, baby spinach, basil, cantaloupe, lettuce, peppers, and tomatoes have been found to be contaminated with this organism (Finstad, O'Bryan, Marcy, Crandall, & Ricke, 2012; Foley, Johnson, Ricke, Nayak, & Danzeisen, 2011; Franz & van Bruggen, 2008; Hanning, Nutt, & Ricke, 2009; Howard, O'Bryan, Crandall, & Ricke, 2012; Lynch, Tauxe, & Hedberg, 2009; Nayak, O'Bryan, Kenney, Crandall, & Ricke, 2012). *Salmonella* has been identified as the causative agent in 17% of fresh produce foodborne illness outbreaks for the period between 1998 and 2007 (Olaimat & Holley, 2012). It was estimated by Scharff (2010) that produce, either fresh or processed, was the cause of 27% of reported *Salmonella* outbreaks. Foods can be contaminated at any point in the food chain from production through processing, distribution, preparation and consumption (CDC, 2015a).

Numerous food preservation methods have been developed for extending the shelf life and inhibiting the growth of foodborne pathogens such as *Salmonella* (Chen et al., 2012; Gil et al., 2015; Ricke, Kundinger, Miller, & Keeton, 2005; Wheeler, Kalchayanand, & Bosilevac, 2014). These intervention treatments can be categorized as either thermal or non-thermal, with thermal including heat applied either directly such as in grilling or by the use of a heating medium such as water or steam; foods can also be heated with the use of thermal radiation (infrared or microwave). Non-thermal preservation methods include chemical, physical, or biological treatments including electron beam irradiation, high pressure processing, pulsed electric fields and ozone or ultraviolet light (Warriner, 2011). Thermal treatment is considered to be one of the more effective food processing techniques to eliminate *Salmonella* and other foodborne pathogens from food products (Bermúdez-Aguirre & Corradini, 2012; Silva & Gibbs, 2012). However, some *Salmonella* strains are capable of growing at temperatures as high as 54 °C and thus may survive thermal processing of some foods (Droffner & Yamamoto, 1991; Park et al., 2014).

Studies of thermal inactivation of *Salmonella* in foods such as those reported in this review have traditionally assumed that inactivation adheres to first-order kinetics; in other words there is a log linear decline in survivors based on time (Blackburn, Curtis, Humpheson, Billon, & McClure, 1997). However, it has been known for several years that there are many deviations from the first-order kinetics, including survival curves that are sigmoidal in shape as well as those with shoulders or tails (Cerf, 1977; Jackson, Hardin, & Acuff, 1996; Juneja, Eblen, & Marks, 2001; Mafart, Couvert, Gaillard, & Leguérinel, 2002). In order to avoid over- or under-processing food these deviations from first-order kinetics should be taken into account when developing guidelines for thermal treatment. This has led many researchers to develop mathematical models to predict effects of thermal treatments as well as combination treatments. A discussion of the models that have been developed is outside of the scope of this review, but several of the models and references are listed in Table 1 for further investigation by the reader.

This review considers the more recent literature on thermal processing of food products, pulls from fundamental microbiology to draw connections and overarching principles between studies and food products, notes the limitations of previous research and research technologies, and finally makes observations and recommendations for future research.

2. Thermal destruction of *Salmonella* in poultry

The United States Department of Agriculture-Food Safety and Inspection Services (UDSA-FSIS) has implemented a 7 $\log_{10}$ relative reduction in viable counts of *Salmonella* for fully and partially cooked poultry products (USDA-FSIS, 1999). Results from thermal inactivation experiments are often expressed as the D-value, the time needed at a particular temperature to inactivate 90% of the exposed bacteria (Table 2). Juneja et al. (2001) compared the inactivation of *Salmonella* in ground turkey and ground chicken and determined that the D-values for ground turkey were higher (0.59 min) than for ground chicken (0.50 min) at the highest temperature examined (65 °C). Murphy, Duncan, Beard, and Driscoll (2003) also concluded that D-values varied by animal species at lower temperatures, although at the highest temperature studied (70 °C) no statistical differences were seen among the D-values for duck breast meat, chicken breast meat or turkey breast meat (0.11, 0.10 and 0.12 min respectively). These authors concluded that there can be considerable differences in the time required for inactivation of *Salmonella* between avian species as well as with different fat levels within the same bird species at lower processing temperatures, but at temperatures as high as 70 °C these differences become insignificant.

Several researchers have also focused on methods of cooking poultry used in commercial kitchens or in homes. Murphy, Johnson, Marcy, and Johnson (2001) inoculated ground chicken patties with a cocktail of *Salmonella* serovars and cooked the patties in a pilot-scale air convection oven at an air temperature of 177 °C with either low or high humidity. The patties were cooked to a final center temperature of 65–75 °C. They determined that humidity affected survival of the pathogen, with *Salmonella* populations 2 logs higher in patties cooked under low as compared to high humidity. After cooking, *Salmonella* populations were also up to 6 logs greater when patties were allowed to touch or partially overlap as opposed to being cooked in a single layer (Murphy, Duncan, Johnson, & Davis, 2001).

The unsuitability of microwave ovens for cooking raw or partially cooked poultry products was highlighted by several