



Comparing thermal resistance of *Salmonella* in chili (*Capsicum*), cinnamon (*Cinnamomum cassia*), and black pepper (*Piper nigrum*) powders

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Highlights

- The synergistic effect of antimicrobial activity and thermal lethality varied among spices.
- Chili showed the strongest antimicrobial effect against *Salmonella*.
- *Salmonella* showed similar thermal resistance in cinnamon and black pepper.
- Milder temperature may be used for *Salmonella* control in chili compared to cinnamon and black pepper.

Abstract

Thermal treatment is one of the most effective methods used in the food industry for pathogen control in low-moisture foods. The water activity (a_w) at treatment temperatures, not room temperature, is an important factor influencing microbial thermal resistance. This study evaluated the thermal resistance of a three-strain *Salmonella* cocktail in chili, cinnamon, and black pepper powders that had been pre-conditioned to room temperature a_w of 0.30 or 0.50 (i.e., $a_{w,21^\circ\text{C}}=0.3$ and 0.5). a_w of these samples increased differently in sealed containers when they were heated from 20 to 90°C. Regardless of spice type, *Salmonella* thermal resistance decreased with increasing a_w . In chili, the observed $D_{70^\circ\text{C}}$ -values (the time required to inactivate 90% cells at a given temperature) for *Salmonella* in the samples of $a_{w,21^\circ\text{C}}$ 0.30 ($a_{w,70^\circ\text{C}}$ 0.35) was 15.4 min and in the samples of $a_{w,21^\circ\text{C}}$ 0.50 ($a_{w,70^\circ\text{C}}$ 0.52) was 1.8 min. At the same $a_{w,21^\circ\text{C}}$, the observed D -values of *Salmonella* in chili and cinnamon were significantly ($P < 0.05$) lower than in black pepper. However, based on a_w at treatment temperatures, *Salmonella* showed similar thermal resistance in cinnamon and black pepper but was less resistant in chili. The findings highlight the importance of a_w at treatment-temperature in determining microbial thermal resistance and suggest that milder temperatures may be sufficient for *Salmonella* control in chili powder.

Introduction

Chili (*Capsicum*), cinnamon (*Cinnamomum cassia*), and black pepper (*Piper nigrum*) are among the most widely used spices worldwide (Van Doren et al., 2013), commonly incorporated into ready-to-eat foods. Spices can be contaminated with foodborne pathogens in field and during post-harvest handling, leading to food safety concerns. Outbreaks and costly recalls associated with spices and spiced-foods are not new (Food Safety News, 2014; CDC, 2010; CFSAN, FDA, 2017; FDA, 2020, The American Spice Trade Association ASTA, 2017). From 2000 to 2012, *Salmonella* prevalence in chili, cinnamon, and black pepper was reported globally within spice supply chains (CFSAN, FDA, 2017). Notable, a 2009 *Salmonella* outbreak linked to contaminated black and red pepper in spiced salami affected 44 states in the United States (CDC, 2010). To ensure food safety, imported spices in the United States undergo certain microbial reduction treatments. In particular, approximately 50% of spices imported into the U.S. go through ethylene oxide fumigation to eliminate pathogens such as *Salmonella* (ASTA, 2017). However, ethylene oxide fumigation raises consumer concerns about residual toxicity. Another one third of commercial spices are irradiated, but consumer acceptance of irradiated spices remains limited (Andrews, 2014). Thermal treatments, on the other hand, are physical processes that leaves no

chemical residuals. However, poorly designed heat treatments can negatively alter the flavor and aroma of spices. Therefore, there is a need for an in-depth understanding about the thermal inactivation kinetics in spices. Such knowledge will support the development and validation of precision thermal treatments to ensure the safety of spices and associated ready-to-eat foods.

Beyond the direct use as seasoning to flavor foods, many spices and their extracts (e.g., essential oils) are also utilized as natural preservatives in foods such as shrimp, fish, and meat due to the antimicrobial properties against pathogenic and spoilage bacteria (Adler and Beuchat, 2002; Fenwick et al., 1985; Lu et al., 2011; Sheng and Zhu, 2014; Van Haute et al., 2016; Weerakkody et al., 2011; Zhang et al., 2009). The antimicrobial activities and mechanisms vary across different spices (Morrine et al., 2018; Nazzaro et al., 2013). Our previous storage studies demonstrated different levels of *Salmonella* survival in chili, cinnamon, and black pepper during storage at room-temperature. For example, a 4-month storage at room temperature and water activity (a_w)=0.50 caused 5.1 log reduction of *Salmonella* in chili, 2.4 log in cinnamon, and 0.7 log in black pepper powders (Xie et al., 2022), respectively, after the samples were inoculated at a same initial population level of ~ 8 log CFU/g. Similar to other low-moisture foods, *Salmonella* survival was higher at $a_w=0.30$ compared to $a_w=0.50$ in the three spices.

Previous studies have also shown that the thermal resistance of *Salmonella* (characterized by decimal reduction time, D -value) is primarily influenced by the a_w of food matrices at treatment temperatures ($a_{w, \text{treatment-temperature}}$) (Alshammari et al., 2020; Liu et al., 2018a; Sun et al., 2023; Xu et al., 2019, 2021), which affects bacterial cell moisture content (Xie et al., 2020). Additionally, $D_{80^\circ\text{C}}$ -values of *Salmonella* Enteritidis in cinnamon were significantly lower than those in non-spice low-moisture foods at the same $a_{w,80^\circ\text{C}}$ (Xie et al., 2021), indicating possible synergistic lethal effects of antimicrobial compounds in cinnamon during thermal treatment. However, no study has systematically compared the influence of different spices on *Salmonella* inactivation during thermal processing. Thus, the objectives of this study were to: 1) investigate the thermal inactivation kinetics of a three-serovar *Salmonella* cocktail in chili, cinnamon, and black pepper powders as influenced by a_w and temperatures, and 2) compare the thermal resistance of *Salmonella* among the three spices during thermal treatments. To ensure a fair comparison, we determined the moisture isotherms of the three spices at room temperature and 70°C . Additionally, we measured changes in a_w as function of temperature across a wide range of moisture contents.

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Spice samples

Chili powder, ground cinnamon, and black pepper powder were purchased from a retail source (McCormick & Company, Inc., Hunt Valley, MD, USA). The initial a_w of each spice was measured in triplicate at room temperature ($\sim 21^\circ\text{C}$) using a water activity meter (Aqualab, Meter Group, Inc., Pullman, WA, USA). The measured a_w values for chili, cinnamon, and black pepper were 0.50 ± 0.02 , 0.51 ± 0.02 , and 0.53 ± 0.02 , respectively.

Proximate composition and particle size distribution of these three ...

a_w changes at treatment temperatures in the three spices

The a_w values of the three spices at room temperature and at $70\text{--}85^\circ\text{C}$, measured using HTC and modeled with CCE (Eq. (1)), are shown in Fig. 1. Similar to other carbohydrate-rich low-moisture foods, the a_w of the spices in sealed containers (fixed moisture contents) generally increased with increasing temperature. This effect was more apparent at lower moisture contents. For example, in chili powder with a moisture content of 5.6 ± 0.5 g water/100 g dry solids, a_w increased from 0.31 ± 0.0 to ...

Conclusion

This study investigated the thermal inactivation kinetics of a three-serovar *Salmonella* cocktail in chili, cinnamon, and black pepper powders as influenced by a_w and treatment temperatures. Although three spices were carbohydrate-rich, chili contained a relatively higher fat content than the other two spices. The difference in fat content influenced moisture sorption isotherms and the response of a_w to temperature changes. As temperature increased from $\sim 21^\circ\text{C}$ to 70 or 80°C , a_w increased in ...

CRedit authorship contribution statement

Yucen Xie: Writing – original draft, Investigation, Data curation, Conceptualization. **Mei-Jun Zhu:** Writing – review & editing. **Shyam Sablani:** Writing – review & editing. **Juming Tang:**

Writing – review & editing, Supervision, Project administration, Funding acquisition. ...

Declaration of competing interest

The authors declare no conflict of interest. ...

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