Thermal Inactivation Kinetics for *Salmonella* Enteritidis PT30 on Almonds Subjected to Moist-Air Convection Heating

[1]Sanghyup Jeong, [1]Bradley P. Marks, and [2]Alicia Orta-Ramirez
[1]*Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI 48824, Food Science,*
[2]*Cornell University, Ithaca, NY 14853*
jeongsa1@msu.edu

Introduction

California almonds were implicated in two widely publicized outbreaks of salmonellosis in the past five years, prompting a recall of nearly 6 million kg of raw almonds *[1]*. The effect of such outbreaks can be enormous, because the U.S. produces almost half the world's almonds and, supplies 85 and 67% of the world export volume for in-shell and shelled almonds, respectively *[2]*. The Almond Board of California (a grower-enacted federal marketing order) therefore proposed mandatory pasteurization of California almonds, and the final rule was recently published (7 CFR Part 981). Given that raw almonds were not previously pasteurized, this has created a significant, industry-wide demand for technologies and process validation tools to achieve the goal of adopting solutions that do not adversely affect the sensory and quality characteristics of raw almonds.

Moist-air impingement is a technology that has been used in the food industry and proven its effectiveness for faster cooking, higher efficiency, and better water retention of processed products *[3]*. Moist-air impingement cooking systems jet a steam-air mixture through an array of nozzles or slots onto the food product, yielding a high heat transfer rate by reducing boundary layer thickness at the surface of the product *[4]*. In addition, at the initial stage of the process, steam is condensed on the product surface, which results in effective transfer of latent heat into the product and improved inactivation of bacteria on the product surface. As the product surface temperature exceeds the dew point temperature of the process gas, condensation stops and evaporation begins, which has a negative impact on the bacterial inactivation rate. Due to this dynamic process, moist-air impingement technology can be an effective surface pasteurization method. However, traditional thermal inactivation kinetics for microorganism typically are based on only temperature, which is insufficient to predict surface pasteurization results for the moist-air impingement process. Therefore, the objective of this study was to develop a predictive model for thermal inactivation of SE PT30 on the surface of almonds under moist-air impingement cooking condition.

Model development

Inactivation of *Salmonella* on the surface of almonds subjected to moist-air heating involves condensation and evaporation of water on the almond surface. Condensation and evaporation during moist-air heating alters the micro-environment at the surface of almond, which impacts the thermal resistance of bacteria present on the surface of the product. Traditional microbial inactivation models are based on D_{ref} (at T_{ref}) and z-values; however, this traditional model form does not account for the effect of the varying water status at the surface of the almonds during moist-air heating. Thus, a concept of 'surface wetness (W_s)' is proposed to quantify moisture status around the target bacteria. Ideally/theoretically, this is the local water activity (a_w) at the surface of the almond. However, because this is not a measurable property (due to the transient state of the micro-environment), we needed to represent moisture status as a function of measurable variables. Therefore, a modified model, which accounts for the impact of transient surface wetness (during condensation and evaporation) on the thermal resistance of *Salmonella* has been developed.

Model parameter estimation and validation

Inoculated almonds (on the metal rack) were subjected to a variety of time/temperature/humidity treatments in a custom-built, computer-controlled, laboratory-scale, moist-air convection oven. To estimate the model parameters, a two thirds of the experimental data sets were chosen randomly and grouped into five different sub-sets according to the level of humidity: (1) dry (~5%Mv) conditions (14 data sets), (2) low humidity (30-50%Mv) conditions (34 data sets), (3) medium humidity (50-70%Mv) conditions (35 data sets), (4) high humidity (70-90%Mv) conditions (30 data sets), and (5) the full range of humidity, from 5 to 90%Mv (78 data sets). In these data sets, dynamic temperature profiles and corresponding log reductions of duplicated samples were averaged. Due to the non-isothermal nature of the experimental data, numerical integration (Newton's method) was applied to calculate the predicted log reduction. Once the best-fit parameters were estimated for each sub-set of the data, the model parameters were applied to the remaining 1/3 of the data (40 data sets), in

order to calculate validation statistics for an independent set of data. The accuracy of the models was estimated in terms of the root mean squared error (RMSE) for the log reductions.

Results and discussion

Increasing humidity within a temperature significantly increased inactivation rate, which supports the model premise that humidity is a significant factor affecting inactivation rate of SE PT30 on the surface of almonds in moist-air conditions (Fig. 1). The error (RMSE) for the modified model for the full humidity range (5-90% Mv) was much less than that of the traditional model for the model fitting (44%) and validation tests (48%).

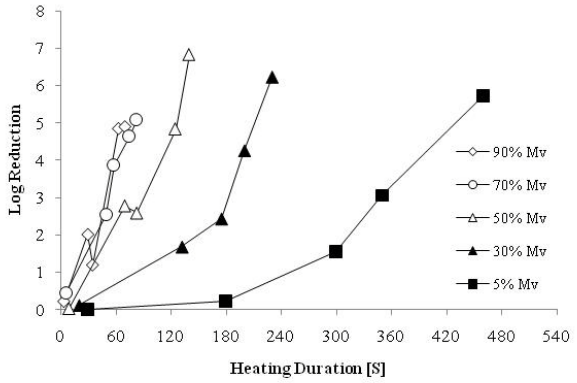

Figure 1. Effect of process humidity and temperature on log reduction of *Salmonella* Enteritidis PT30 on the surface of almond: (a) at 50% Mv; (b) at 177°C.

The traditional model (*D*- and *z*-value) yielded reasonable results for the dry (5%Mv) conditions, but, in the other humidity ranges, model prediction error was 0.94 to 2.52 log reduction. In addition, the magnitude of the *z*-value in the traditional model was not reasonable for any of the data sets that included humidity levels above 30%Mv. This reflects the inability of the traditional model to account for significant humidity effects on inactivation.

In contrast, the modified model yielded significantly improved results for all of the different sub-sets of data. Also, the error decreased as the domain of application was narrowed. When the modified model was estimated for the high humidity range (70-90%Mv), the best accuracy (RMSE=0.64) was achieved. It should be noted that the reference *D*-values (D_{ref}) of the modified model are the decimal reduction times at the combined condition of the reference temperature and reference dew point. The traditional model for the dry condition (~5 %Mv) also reflects the ineffectiveness (i.e., large D_{ref} value) of using dry air to inactivate surface inoculated *Salmonella* on almonds. In addition, the modified model showed reasonable magnitudes for the parameters at all conditions. Specifically, the parameters (z_T and z_M values) were fairly consistent across the data sets that included the higher humidity levels. The D_{ref} values varied across the data sets, because the reference condition (specifically humidity) was different across the different data sets.

The modified model accurately accounted for process humidity effect, with prediction errors ≤1.0-log reduction for validation data sets in the moist-air heating process range of 30-90%Mv. Although the model was developed and validated for the specific case of *Salmonella* Enteriditis PT30 on almonds, the model form has potential application to other similar process, in which a dry product is subjected to moist-air heating for surface pasteurization.

References

[1] Centers for Disease Control and Prevention. Date, 2004, Outbreak of *Salmonella* serotype Enteritidis infections associated with raw almonds - United States and Canada, 2003-2004. Available at: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5322a8.htm. Accessed September 3, 2008.

[2] FAOSTAT. Date, 2005, TradeSTAT: Crops and livestock products, [Online database]. Available at: http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535. Accessed September 3, 2008.

[3] Geedipalli, S., A. K. Datta, and V. Rakesh. 2008. Heat transfer in a combination microwave-jet impingement oven. *Food Bioprod. Process.* 86:53-63.

[4] Walker, C. E., and A. Li. 1993. Impingement oven technology. III. Combining impingement with microwave (hybrid oven). *Technical Bulletin, American Institute of Baking Research Department*. 15(9):1-6.