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Development of model food systems for thermal pasteurization applications based on Maillard reaction products

Ellen R. Bornhorst, Juming Tang*, Shyam S. Sablani, Gustavo V. Barbosa-Cánovas

Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164-6120, USA

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ABSTRACT

Model food systems with Maillard reaction products have been an effective tool to assess process lethality for microwave-assisted thermal sterilization. However, model food systems used for sterilization temperatures (110–130 °C) are not optimal for pasteurization temperatures (70–100 °C). The purpose of this research was to develop and assess model food systems to quantify process lethality and food quality for pasteurization applications, such as microwave-assisted pasteurization. Chemical marker M-2 (4-hydroxy-5-methyl-3(2H)-furanone) and color reaction kinetics were determined for egg white, mashed potato, and gellan model foods. M-2, L*, and a* value changes followed first order reaction kinetics and were significantly correlated to thermal lethality and cook value. Mashed potato was the optimal model food, in part because it had the greatest range of L* and a* reaction rates at 90 °C. Mashed potato model foods developed in this study could be used in the future to describe safety and quality reactions during pasteurization process evaluation.

1. Introduction

Products of the Maillard reaction have been used as indicators of heat treatment for process lethality evaluation for about 25 years (Kim & Taub, 1993; Kim, Taub, Choi, & Prakash, 1996). Newer thermal processing technologies, such as aseptic with particulates, ohmic heating, and microwave heating, have generated significant interest in the food industry, but it is challenging to use traditional direct temperature measurement methods in developing thermal processes (Kim et al., 1996). Time-temperature integrators (e.g. Maillard reaction products) are an effective alternative developed to quantify the change in a safety or quality attribute due to a variable time-temperature history (Van Loey, Hendrickx, De Cordt, Haentjens, & Tobback, 1996).

Researchers at the United States Army Natick Research Center found three Maillard reaction products that could be used to evaluate process lethality for sterilization of low-acid foods using continuous thermal processing: M-1 (2,3-dihydro-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one), M-2 (4-hydroxy-5-methyl-3(2H)-furanone), and M-3 (5-hydroxymethylfurfural) (Kim & Taub, 1993; Kim et al., 1996). These chemical markers have been evaluated for prediction of process lethality at sterilization temperatures for thermal pulses (Ross, 1993), canned food with particulates (Wnorowski & Yaylayan, 2002), aseptic processing of particulate foods (Kim & Taub, 1993; Ramaswamy, Awuah, Kim, & Choi, 1996), high pressure assisted thermal processing (Gupta, Mikhaylenko, Balasubramaniam, & Tang, 2011), microwave-assisted sterilization (Pandit, Tang, Mikhaylenko, & Liu, 2006; Prakash, Kim, & Taub, 1997; Wang, Lau, Tang, & Mao, 2004; Wang et al., 2009), and microwave-assisted pasteurization (Zhang, Tang, Liu, Bohnet, & Tang, 2014). M-2 was selected as the most applicable for high tempertaure, short time processes, such as microwave heating, because of the faster reaction rate and first order kinetics (Lau et al., 2003; Pandit et al., 2006). Chemical marker (M-2) and brown color formation in model foods systems were utilized for heating pattern visualization, as well as process and simulation validation of a microwave-assisted thermal sterilization (MATS) process, where product temperatures typically reach over 120 °C (Tang, 2015).

A Microwave Assisted Pasteurization System (MAPS) has been developed at Washington State University to thermally pasteurize food (Tang, 2015). For thermal pasteurization of prepackaged chilled food, the European Chilled Food Federation (ECFF) (2006) and United States Food and Drug Administration (FDA) (2011) recommend an equivalent heat treatment of 70 °C for 2 min for a minimum 6 log reduction in *Listeria monocytogenes* or 90 °C for 10 min for a minimum 6 log reduction in the most heat resistant group of nonproteolytic *Clostridium botulinum* spores, e.g. types B and E. The

* Corresponding author.
E-mail address: jtang@wsu.edu (J. Tang).

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MAPS was designed with flexible temperature controls; process schedules can be developed to meet either of these pathogen reduction requirements to achieve pasteurization.

During the development of MAPS, it is essential to be able to visualize the heating pattern and validate computer simulations and proposed process schedules. Similar to validating a MATS process, model food systems with Maillard reaction product formation may be useful for MAPS process development and simulation validation. However, the whey protein gel (Lau et al., 2003) and mashed potato with xanthan gum (Pandit et al., 2006) model food systems used for sterilization are not optimal for pasteurization due to slower Maillard reaction kinetics and high gelation temperatures (80 °C) for whey proteins. There is a need to develop model food systems that are feasible for pasteurization temperatures (70–100 °C) and determine the Maillard reaction kinetics in those systems. In this research, nonproteolytic *C. botulinum* was selected as the target pathogen for pasteurization and therefore, 90 °C was utilized during kinetic studies.

Previous research on M-2 chemical marker formation at pasteurization temperatures is very limited, with one published work by Zhang et al. (2014) on an egg white model food and preliminary tests on a gellan model food (Zhang, 2014). Model food development in all earlier studies for microwave applications was aimed at process lethality determination, not quality optimization. The objectives of this research were to (1) develop model food systems with varying amounts of precursor compounds (ribose and lysine) for use in MAPS process validation and optimization, (2) assess the color and M-2 formation kinetics at 90 °C of the model food systems, and (3) recommend an optimal model food system for future research.

2. Materials and methods

2.1. Sample preparation

Three model foods were selected for analysis: egg white, gellan, and mashed potato with added gellan gum. Four formulas were used for all model food systems with varying amounts of chemical marker precursors (D-ribose and L-lysine): 0 g/100 g D-ribose and 0 g/100 g L-lysine, 1 g/100 g D-ribose and 0.5 g/100 g L-lysine, 1 g/100 g D-ribose and 1 g/100 g L-lysine, and 2 g/100 g D-ribose and 2 g/100 g L-lysine, abbreviated throughout the paper as 0_R, 0_L, 1_R, 0.5_L, 1_R, 1_L, and 2_R, 2_L, respectively. The formula with the lowest amount of added precursors, 1_R, 0.5_L was selected based on Zhang et al. (2014). Formulas with greater amounts of Maillard browning precursors (1_R, 1_L and 2_R, 2_L) were selected based on the hypothesis that these formulas would have faster reaction rates.

Egg white model food was selected due to promising initial results in heating pattern analysis at pasteurization temperatures (75–100 °C) (Zhang et al., 2014). The egg white model food formula was modified from Zhang et al. (2014) and 100 g of the model food contained 25 g stabilized, glucose reduced powdered egg whites (JustWhites®, Deb-El Food, Elizabeth, NJ), 0–2 g D-ribose (Sigma-Aldrich Co. LLC, St. Louis, MO), 0–2 g L-lysine (Sigma-Aldrich Co. LLC, St. Louis, MO), and the remaining amount double deionized (DDI) water (71–75 g). The powdered egg whites were mixed with 35 °C DDI water for 10 min and the mixture was heated at 35 °C for 20 min to further rehydrate the egg whites. Chemical marker precursors (D-ribose and L-lysine) were added and mixed for 30 min. The solution was placed into a custom designed aluminum test cell with a diameter of 18 mm and height of 4 mm (Chung, Birla, & Tang, 2008). The egg white solution inside the test cells was heated for 30 min at 70 °C and cooled in ice water to form a firm gel (Zhang et al., 2014).

Gellan model food (Zhang, 2014; Zhang et al., 2015) showed promising initial results, but the model was translucent, which is a limitation because a translucent model food can obscure color and heating pattern analysis. The gellan model food formula in this study was modified from Zhang (2014) to be opaque by adding titanium dioxide. 100 g of the gellan model food consisted of 1 g low acyl gellan gum (Kelcogel® F Food grade gellan gum, supplied by CP Kelco Inc., Atlanta, GA), 0.5 g titanium dioxide dispersed in glycerin and water (white-white icing color, Wilton Industries Inc., Woodridge, IL), 0.26 g calcium chloride ($CaCl_2 \cdot {}_2H_20$, J.T. Baker, Avantor Performance Materials, Inc., Center Valley, PA), 0–2 g D-ribose, 0–2 g L-lysine, and the remaining amount DDI water (84.24–98.24 g). The titanium dioxide was mixed with 22 °C DDI water for 5 min, followed by the addition of the gellan gum powder, mixed for an additional 5 min. While stirring, the mixture was heated to 90 °C, the calcium chloride was added, and the mixture was held at 90 °C for 1 min. Chemical marker precursors were added once the solution was cooled to 65 °C and were mixed for 3 min. The solution was poured into the custom designed test cells and cooled to 22 °C to form a firm gel.

Mashed potato with added xanthan gum was a successful model in microwave sterilization work (Pandit et al., 2006), but did not form a firm gel at pasteurization temperatures. Mashed potato was selected for this study, but the formula was modified to include gellan gum instead of xanthan gum to obtain a firm gel. Low acyl gellan was selected over alternative gelling agents because it forms a strong, brittle gel in the presence of cations and has a low enough gelation temperature to be used in pasteurization applications (Morris, Nishinari, & Rinaudo, 2012; Tang, Lelievre, Tung, & Zeng, 1994; Tang, Tung, & Zeng, 1997). The mashed potato model food formula was modified from Pandit et al. (2006) and 100 g of the model food contained 15 g instant mashed potato flakes (Oregon Potato Co., Boardman, OR), 0.5 g low acyl gellan gum, 0.13 g calcium chloride, 0–2 g D-ribose, 0–2 g L-lysine, and the remaining amount DDI water (80.37–84.37 g). The gellan gum powder was mixed with 22 °C DDI water for 5 min, followed by the addition of the potato flakes to the solution. Similar to the gellan model, the mashed potato model solution was heated to 90 °C, the calcium chloride was added, and the mixture was held at 90 °C for 1 min. Chemical marker precursors (D-ribose and L-lysine) were added once the solution was cooled to 60 °C and were mixed for 5 min to obtain a uniform distribution of the chemical marker precursors. Mashed potato model food was placed into the test cell and cooled to ambient temperature (22 °C) to form a firm gel.

2.2. Thermal treatment

Model foods were exposed to thermal treatments by heating the samples inside custom designed, cylindrical, aluminum test cells with a diameter of 18 mm and height of 4 mm (Chung et al., 2008) using an ethylene glycol bath (Haake DC 30, Thermo Fisher Scientific Inc., Newington, NH). The average come-up time (CUT), defined as the time for the coldest spot in the sample to reach within 0.5 K of the target, was measured to be 1.75 min using a calibrated type-T thermocouple. All three model foods were heated at 90 °C from 5 to 180 min (excluding CUT), followed by cooling in ice water (0 °C). Kinetic experiments were conducted in triplicates.

2.3. Chemical marker quantification

The average concentration of chemical marker, M-2 (4-hydroxy-5-methyl-3(2H)-furanone) in each sample was determined using an adapted method from Zhang et al. (2014) with high performance liquid chromatography (HPLC). Briefly, sample preparation involved grinding each 0.8 g sample in 8 mL of 10 mmol/L H_2SO_4