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Thermal pasteurization process evaluation using mashed potato model food with Maillard reaction products

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ABSTRACT

Model foods with Maillard reaction product formation have been utilized to evaluate thermal sterilization processes, but these models are not optimal for pasteurization. Model foods for pasteurization applications have been developed, but studies on temperature sensitivity and validation are limited. The goal of this research was to assess the temperature sensitivity of chemical marker and color formation in mashed potato model foods and conduct validation testing using a microwave-assisted pasteurization system (MAPS) and conventional, hot water methods. Reaction kinetics were determined for chemical marker M-2 (4-hydroxy-5-methyl-3(2H)-furanone) and color formation (L* and a* values). Results showed that the thermal resistance constants (z-values) were 20.6–24.0 °C for M-2, 20.8–28.8 °C for L* value, and 10.3–25.6 °C for a* value. Correlation analysis between M-2, L*, and a* values and thermal lethality and cook value showed that model foods were most relevant for pasteurization process quality evaluation. Thermal treatment equivalent at the cold spot was approximately 11 min at 90 °C for all pasteurization processes. Model foods pasteurized in MAPS had less color change than those from hot water processes, implying the less severe MAPS process yielded better quality. Model foods and image analysis techniques used in this study could be helpful quality evaluation tools for pasteurization processes.

1. Introduction

The Maillard reaction is a type of nonenzymatic browning that occurs between free amino groups and carbonyl compounds (Fayle & Gerrard, 2002). The concentration of generated Maillard reaction products are time and temperature sensitive and can be related to a time-temperature history (Van Loey, Hendrickx, De Cordt, Haentjens, & Tobback, 1996). Maillard reaction products have been used as time-temperature integrators and are an effective alternative method to measure temperature distribution inside a food package and quantify process lethality (Kim, Taub, Choi, & Prakash, 1996; Ramaswamy, Awuah, Kim, & Choi, 1996; Ross, 1993; Wang, Lau, Tang, & Mao, 2004; Wnorowski & Yaylayan, 2002). The use of time-temperature integrators as an alternative method to measure temperature distribution in food products is essential for developing thermal processes using novel technologies (e.g. ohmic heating and microwave heating), where conventional process development and temperature measurement techniques are difficult (Kim et al., 1996).

Chemical marker M-2 (4-hydroxy-5-methyl-3(2H)-furanone) was identified as a relevant Maillard reaction product for evaluating high temperature, short time processes, such as microwave heating (Lau et al., 2003; Pandit, Tang, Mikhaylenko, & Liu, 2006). M-2 is formed as a result of 2,3 enolization of the Amadori compound during the Maillard reaction between D-ribose and an amine (Kim et al., 1996). Products generated from 2,3 enolization are similar to those from sugar degradation without amines, i.e. caramelization, but generation occurs at a different rate because amine and amino acid compounds catalyze sugar degradation during the Maillard reaction (BeMiller & Huber, 2008). M-2 and brown color formation were used conjunctly with model foods and a computer vision system to visualize the heating pattern and validate a microwave-assisted thermal sterilization (MATS) process (Pandit, Tang, Liu, & Pitts, 2007b; Tang, 2015). Homogenous model foods were employed rather than real foods because conducting these experiments with real foods can lead to inaccurate heating pattern results due to their non-homogeneity (Wang et al., 2004). Additionally, the concentration of reactants added to the model food (reducing sugar, amino acid) can be adjusted to change the reaction

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rate of the time-temperature integrators to better match food safety or quality attributes of interest. This validation technique could be employed to validate other thermal processes, such as a Microwave Assisted Pasteurization System (MAPS) that has been recently developed at Washington State University (Tang, 2015).

The patent-pending MAPS design is similar to the MATS set-up without overpressure, as described in Tang (2015). The MAPS design combines traditional hot water heating with microwave heating using 915 MHz microwaves. Microwaves (915 MHz) generated from a magnetron interact with trays of food products in single-mode cavities (Tang, 2015). Briefly, the pilot-scale MAPS set-up includes four sections: preheating, microwave heating, holding, and cooling. This system is able to process 8–20 oz (226.8–567.0 g) trays; belt speed and water temperature are commonly changed to adjust the thermal process severity delivered to the food product. Various food products have been pasteurized with the pilot-scale MAPS and the promising results from these initial tests implied the MAPS can produce safe, high quality food products. Currently, commercial-scale Microwave Assisted Pasteurization Systems for food processing are not available yet to the industry and commercialization is in progress.

The United States Food and Drug Administration (FDA, 2011) and European Chilled Food Federation (ECFF) (2006) have recommended an equivalent heat treatment of 90 °C for 10 min to achieve at least a 6 log reduction in non-proteolytic *Clostridium botulinum* spores (e.g. types B and E) for thermal pasteurization of pre-packaged, chilled food. Less severe treatments are also acceptable in food products with shorter shelf-lives, such as an equivalent heat treatment of 70 °C for 2 min for at least a 6 log reduction in *Listeria monocytogenes* (FDA, 2011; ECFF, 2006). In this study, non-proteolytic *C. botulinum* was the pathogen of interest; MAPS and hot water pasteurization processes were designed to meet the 90 °C for 10 min criteria.

Model food systems with Maillard reaction products developed for sterilization (110–130 °C) applications (Lau et al., 2003; Pandit et al., 2006; Ramaswamy et al., 1996; Ross, 1993; Wang et al., 2009) are not ideal for pasteurization (70–100 °C) applications, especially due to the slower reaction kinetics at the lower temperatures used in pasteurization. Several model foods with Maillard reaction products have been developed for pasteurization applications, including egg white model food (Bornhorst, Tang, Sablani, & Barbosa-Cánovas, 2017; Zhang, Tang, Liu, Bohnet, & Tang, 2014), gellan model food (Bornhorst et al., 2017; Zhang et al., 2015), and mashed potato model food (Bornhorst et al., 2017). Bornhorst et al. (2017) compared the performance and reaction kinetics at 90 °C for all three model foods: egg white, gellan, and mashed potato. They concluded that the optimal model food for future research was mashed potato, which is why this study utilized mashed potato model food.

Previous work by Bornhorst et al. (2017) on mashed potato model food for pasteurization applications determined the chemical marker (M-2) and brown color formation kinetics at only one temperature (90 °C). The temperature sensitivity in the pasteurization temperature range of the chemical marker and brown color formation in the mashed potato model is unknown. This missing information is critical in order to utilize the model food systems to compare pasteurization processes with various processing temperatures and differing time-temperature histories. Additionally, previous research on model foods for pasteurization was focused on formula development and reaction kinetic studies with very limited work on validation of the models in food processing applications. Therefore, the objectives of this research were to (1) Determine the temperature dependence of M-2 and color formation in the mashed potato model food and (2) Perform a validation by pasteurizing the mashed potato model food using MAPS and hot water methods.

2. Materials and methods

2.1. Sample preparation

The model food (100 g) was prepared with 15 g instant mashed potato flakes (Oregon Potato Co. Boardman, OR), 0.5 g low acyl gellan gum (Kelcogel® F Food grade gellan gum, supplied by CP Kelco Inc. Atlanta, GA), 0.13 g calcium chloride ($CaCl_2 \cdot {}_2H_20$, J.T. Baker, Avantor Performance Materials, Inc. Center Valley, PA), 1–2 g D-ribose (Sigma-Aldrich Co. LLC, St. Louis, MO), 0.5–2 g L-lysine (Sigma-Aldrich Co. LLC, St. Louis, MO), and deionized and distilled water (80.37–84.37 g), as described in Bornhorst et al. (2017). Different quantities of D-ribose and L-lysine, the chemical marker precursors, were added to alter the reaction rates. The models used in this study included 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 in the paper as 1_R, 0.5_L, 1_R, 1_L, and 2_R, 2_L. Calcium chloride was added to the model food systems in order to facilitate the gel setting to form a strong, brittle, and heat stable gel (Morris, Nishinari, & Rinaudo, 2012; Tang, Tung, & Zeng, 1996, Tang, Tung, & Zeng, 1997). Calcium chloride also affects the rate of Maillard browning (Kocadağli & Gökmen, 2016); for this reason, the amount calcium chloride added to each formula was kept constant to maintain consistency.

The preparation protocol for the mashed potato model foods was adapted from Bornhorst et al. (2017). Briefly, gellan gum and mashed potato flakes were mixed with deionized and distilled water and heated to 90 °C, followed by the addition of calcium chloride and holding at 90 °C for 1 min. The mixture was cooled to 60 °C and D-ribose and L-lysine were thoroughly mixed into the model food. A firm gel was formed upon cooling to ambient conditions (22 °C).

2.2. Temperature kinetic study

Mashed potato model foods were exposed to heat, followed by chemical marker (M-2) and color quantification. Model foods were heated inside 1 mL cylindrical, aluminum test cells (Chung, Birla, & Tang, 2008) with a water bath (80 °C) and ethylene glycol bath (100 °C) (HAAKE DC 30, Thermo Fisher Scientific Inc. Newington, NH) and cooled in ice water (0 °C). The time for the coldest spot in the kinetic cell to reach within 0.5 °C of the set point temperature (come-up time, CUT) was 1.75 min, as measured by calibrated type-T thermocouples. Model food samples were heated at 80 °C from 5 to 240 min (excluding CUT) and 100 °C from 5 to 150 min (excluding CUT) in triplicate. These time-temperature combinations were selected to be relevant to pasteurization with MAPS and conventional methods; longer heating times were needed to find the saturation of M-2 and color (Lau et al., 2003; Pandit et al., 2006). Model food samples for the three replicates of each time point came from three separate experimental batches. The results from this study at 80 and 100 °C were combined with findings from Bornhorst et al. (2017) at 90 °C to facilitate the determination of the temperature sensitivity of the chemical marker and color change of each model food.

Chemical marker, M-2 (4-hydroxy-5-methyl-3(2H)-furanone) concentration was quantified using high performance liquid chromatography (HPLC) with an adapted method from Bornhorst et al. (2017) and Zhang et al. (2014). Briefly, mashed potato samples were homogenized in 10 mmol/L H_2SO_4 extraction buffer, followed by centrifugation and filtration. An Agilent 1100 HPLC system (Agilent Technologies, Santa Clara, CA) was set up with a diode array detector and a 100 × 7.8 mm fast acid analysis column (Bio-Rad