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Shelf-life modeling of microwave-assisted thermal sterilized mashed potato in polymeric pouches of different gas barrier properties

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ABSTRACT

This study investigated how the shelf-life of foods processed with microwave-assisted thermal sterilization (MATS) is affected by temperature and package gas barrier properties. We conducted accelerated shelf life testing of a mashed potato-based model food processed with MATS. The model food was processed to a lethality of $F_0 = 9.0$ min, packaged in four pouch materials with different oxygen transmission rate (OTR) and water vapor transmission rate (WVTR), and then stored at 23 °C, 37 °C and 50 °C for up to 12, 6, and 2.8 months, respectively. Findings showed that there were significant temperature effects and the combined effects of OTR and WVTR on the food color (ΔE). Moisture loss and lipid oxidation were also affected by package over the storage periods. Shelf-life predictions were based on the model at different temperatures and OTRs (23 °C storage) using $\Delta E = 12$ as the end point for acceptable quality, with Q_{10} values ranged from 2.85 to 3.15. The results provide valuable information for selecting packaging materials for MATS and other thermally processed foods.

1. Introduction

Microwave-assisted thermal sterilization (MATS) has the potential to produce food with a higher quality and longer shelf-life. Fast volumetric heating created by microwave reduces the time for the product to reach desired processing temperature and the overall processing time (Guan et al., 2003). Process validation has been conducted using a 10-kW 915-MHz microwave sterilization system and single-mode cavity for 7-oz to 13-oz food trays or 8-oz pouches (Tang et al., 2006). Subsequently, the MATS has been accepted by the Food and Drug Administration (FDA) for prepackaged commercial sterilization of homogeneous and non-homogeneous foods (Tang, 2015). MATS has also received a non-objection notification from the Food Safety and Inspection Service (FSIS) of the USDA for production of shelf stable foods (Tang, 2015).

Several studies on system design and validation studies show that MATS can produce safe shelf stable food. Early studies focused on how quality was influenced by MATS vs. retort processing under the same lethality conditions (Sun et al., 2007; Guan et al., 2002). More extensive work had been conducted to obtain kinetic information through isothermal treatment conditions for various food products: salmon (Kong et al., 2007a, 2007b), green asparagus (Lau et al., 2000), carrots (Peng et al., 2014), blue mussels (Ovissipour et al., 2013), and spinach (Aamir et al., 2014). These studies showed that shorter processing times resulted in higher quality, which were primarily judged based on reduced shrinkage, less loss of texture and greater retention of fresh-like appearance. However, research is needed to determine how long-term storage affects food quality (Tang, 2015). A shelf-life study has been conducted by the U.S. Army Natick Soldier Center compared MATS-treated chicken breast in 10.5-oz EVOH based trays to chicken retort processed at the same lethality as the control in the aluminum pouch. Results of the sensory study revealed that the MATS-sterilized product had an overall higher quality and flavor than the retort control before and after storage at 100 °F (37.8 °C) over 6 months. In a recent study on commercially sterile chicken and dumplings in 8-oz polymer pouches, storage at 120 °F (48.9 °C) for 4 weeks was conducted to simulate storage of 3 years in 80 °F (26.7 °C). Sensory scores of MATS-processed chicken and dumplings showed a slight decrease in overall quality, but a higher score than the retort control (Tang, 2015). However, only sensory attributes were evaluated, no instrumental quality data was collected that can be used to predict shelf-life.

Packaging is an important factor determining the shelf-life of

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thermally processed foods. Polymer materials are suitable choices for MATS, providing advantages of flexibility, transparency (in some cases), heating efficiency, and most importantly, microwave penetrability (Zhang et al., 2016). But high gas barrier properties in polymer packages may deteriorate after undergoing high temperature and moisture processes. Our previous work has reported the effect of MATS on oxygen transmission rates (OTR) and water vapor transmission rates (WVTR) for selected polyethylene terephthalate (PET) and ethylene vinyl alcohol (EVOH) package films (Mokwena et al., 2009; Dhawan et al., 2014). The performance of polymer packages requires validation during shelf life studies of MATS foods. Recently, the Advanced Food Technology (AFT) Project of the National Aeronautics and Space Administration (NASA) evaluated the stability of 13 representative retort processed foods in pouches for use on space flights. Findings showed that the main mechanisms of quality loss were color and flavor changes via Maillard reactions, as well as texture changes via moisture migration (Catauro and Perchonok, 2012). Lipid oxidation can also alter original food color and flavor in storage, especially for high lipid meats or seafoods (Zhang et al., 2016). Consequently, it is important to optimize packaging for MATS processing, especially in terms of the barrier properties, to achieve the required shelf life of 1 year for the retail market, 3 years for U.S. Army ready-to-eat meals and 5 years for NASA space missions at room temperature (Tang, 2015).

This study investigated quality changes in a mashed potato model food processed by MATS during storage at different temperatures. We evaluated the kinetics of color, moisture loss, and lipid oxidation, and characterized the effects of packaging barrier properties on quality changes. Findings can be used to predict the shelf-life of MATS foods or other thermally-processed foods. These results can also be used to inform necessary improvements to food packaging.

2. Materials and methods

2.1. Chemicals

Trichloroacetic acid (TCA) and 2-Thiobarbituric acid (TBA) were purchased from Avantor Performance Materials, Inc. (Center Valley, PA), butylated hydroxyanisole (BHT) was purchased from Fisher Scientific USA (Pittsburgh, PA), and malondialdehyde (MDA) standard was purchased from Enzo Life Science (Farmingdale, NY). Hexanal standard (GC level, purity > 95%) was obtained from TCI Chemical (Portland, OR).

2.2. Packaging

The structures and thickness of selected three polymer pouches used as model food packages, named as MFA, MFB and MFC and the foil pouch (named as MF0) were listed in Table 1. All polymer pouches were tailored to the same dimensions (181 mm × 133 mm) before processing. The MF0 pouch (230 mm × 190 mm) was used to double-seal the MFA pouches after processing, and served as the control. The oxygen transmission rates (OTR) and water vapor transmission rates (WVTR) of these pouches were measured with a Mocon Ox-Tran 2/21 MH and a Mocon Permatran 3/33 permeability instrument, following the method of Dhawan et al. (2014). After MATS processing, the OTRs (23 °C, 65% RH, 1 atm) and The WVTRs (38 °C, 100% RH, 1 atm) were also listed in Table 1, they were used as barrier properties during storage.

2.3. Model food preparation

Mashed potato model food was prepared fresh for each experiment. The following ingredients were added to each 100 g of mashed potato model food: 11 g potato flakes (Oregon Potato Company, Pasco, WA), 4.3 g vegetable oil (flaxseed oil: olive oil = 1:1), 4.7 g whey protein, 1.3 g glucose, and 0.5 g salt, in this order, into 78.2 ml of hot water (70 °C). The model food was designed with a simple, homogeneous formulation that is sensitive to color changes according to our former study (Zhang et al., 2016). Air was removed from the mixture by vacuum-treatment using a UV 250 sealing machine (KOCH Equipment, Kansas City, MO, USA). Next, 230 g of mashed potato was added to each pouch and sealed at a vacuum pressure of 0.8 bar. The control pouch (MF0) was made by sealing the processed MFA pouch inside it with a pressure of 1.0 bar to reach a complete vacuum.

2.4. MATS processing and accelerated storage

Processing of the packaged foods was conducted with a single-mode microwave-assisted thermal sterilization pilot system (10 kW, 915-MHz). A description of this system can be found in Tang et al. (2006). The general processing procedure general followed that of Dhawan et al. (2014). To ensure sufficient lethality, the $F_0 = 9$ min for MFA pouch was adopted. The process protocol was established for pouches of the same shape and dimensions. The processing time was set to 26 min for preheating at 61 °C, 7.4 min for microwave heating, and then 4 min for holding at 124 °C, with a final step of 4 min cooling in tap water (around 20 °C). After processing, pouches were randomly divided into three groups to be stored at different temperatures: 50 °C, 37 °C, and 23 °C for 12 weeks (2.8 months), 6 months, and 12 months, respectively. Duplicate pouches were taken out at each time interval, with at least 5 measurements conducted for each treatment.

2.5. Moisture loss

Moisture loss was calculated as the percentage weight loss divided by the filled pouch weight to show the quantity of water migration from the inside to the outside of the pouch. Triplicate pouches (n = 3) were measured at each interval during the storage period.

Table 1
Parameters of the pouch materials used as model food packages.

Pouch[a]	Material structure[b]	Thickness (μm, n = 5)	OTR[c] (cc/m^2·day)	WVTR[d] (g/m^2·day)
MFA	CNC 1 μm/PET 12 μm/CNC 1 μm/Nylon/PP	96.4 ± 1.8	0.20 ± 0.03	8.73 ± 0.01
MFB	Nylon 15 μm/27% EVOH 15 μm/CPP 60 μm	91.8 ± 2.2	2.11 ± 0.09	4.48 ± 0.26
MFC	HB-PET 12 μm/Nylon 15 μm/CPP 70 μm	107.6 ± 0.9	0.07 ± 0.01	0.70 ± 0.13
MF0	PET12 μm/Al 9 μm/BOPA 15 μm/RCPP 80 μm	114.8 ± 1.8	–	–

[a] Pouch names stand for model food pouch A, B, C and 0.
[b] BOPA: biaxially oriented nylon; CNC: composite nano coating; CPP: cast polypropylene; HB-PET: hyper-branched polyester; PP: polypropylene; RCPP: retort cast polypropylene.
[c] Oxygen transmission rate.
[d] Water vapor transmission rate.