Food Research International 76 (2015) 587–594

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Effect of temperature abuse on frozen army rations Part 2: Predicting microbial spoilage

J.S. Karthikeyan [a], Kiran M. Desai [a], Deepti Salvi [a], Rieks Bruins [b], Donald W. Schaffner [a], Mukund V. Karwe [a,*]

[a] Department of Food Science, Rutgers University, 65 Dudley Road, New Brunswick, NJ 08901, USA
[b] Rutgers Food Innovation Center — North, 120 New England Avenue, Piscataway, NJ 08854, USA

ARTICLE INFO

Article history:
Received 8 May 2015
Received in revised form 6 July 2015
Accepted 6 July 2015
Available online 14 July 2015

Keywords:
Numerical simulation
Frozen food
Temperature abuse
Microbial spoilage

ABSTRACT

Numerically simulated heat transfer model of frozen US military rations was combined with microbial kinetics to predict the microbial spoilage of the food products, during two possible temperature abuse scenarios. An army breakfast menu box containing five different food items was selected for conducting this research. One of the food item in the menu box, beefsteak, was chosen for detailed microbial study. A microbial predictive tool was used to identify and evaluate the kinetics of the most prone microorganism that can grow in a beefsteak. Numerical predictions suggested that the food items exposed to external temperatures ranging from 20 °C to 40 °C can be allowed to stay at those temperatures for maximum times of 28.7 h to 11.9 h, respectively. The food items can be allowed to stay inside the broken freezer for a maximum time of 186 h, to ensure microbial safety in the case of freezer failure.

1. Introduction

Freezing and storage of food below 0 °C is one of the most successful methods for food preservation as it ensures good retention of food quality over time (Reid, 1990), by suppressing or stopping microbial activity. Freezing also reduces deteriorating chemical reactions by decreasing reaction rates and by lowering water activity. Freezing ensures microbial food safety and quality with minimal changes in appearance, odor, and flavor (Singh & Heldman, 2009; Singh & Wang, 1977). A storage temperature of −18 °C or below is recommended for commercial food products (; Singh & Heldman, 2009; Singh & Wang, 1977). Elevated or fluctuating storage temperatures may have harmful effects on food items by either promoting microbial growth or by increasing chemical reaction rates (Reid, 1990); both may reduce shelf life considerably.

The united group ration-A (UGR-A) is the only US army ration that includes perishable food items that require frozen storage. These rations are manufactured by different US vendors and are frozen at −18 °C, before shipping to US army bases around the world. Cold chain transportation of the frozen US army rations at −18 °C, via road and via sea, can take anywhere between 3 and 5 months. Under ideal conditions, these frozen foods are expected to have a shelf life of 9 months (Natick PAM 30–25, 2012). In actual practice these rations might be exposed to severe unintentional temperature abuse during storage and transportation (e.g. inadvertent extended time out of frozen storage, freezer breakdown etc.), where food items might experience compromised microbial safety and quality loses (Blond & Le Meste, 2004; Moureh & Derens, 2000). Understanding the impact of inadvertent temperature abuse of frozen food items on their safety or microbial quality is an important element in designing effective control techniques. One such technique would be to include a time temperature integrator (TTI) that would measure the temperature risk profile of frozen food items during their storage and transportation. TTIs could provide a visual indication of the suitability of product for consumption at receipt (Nuin et al., 2008).

Meats and meat-based products are more susceptible to microbial spoilage and pathogen growth than many other frozen food items experiencing temperature abuse. Possible microorganisms that can grow in meats include pathogens such as *Listeria* spp., *Salmonella* spp., *Escherichia coli* O157:H7, *Clostridium botulinum*, *Staphylococcus aureus*, *Yersinia enterocolitica* and spoilage microorganisms such as *Pseudomonas* spp. (Bajard, Rosso, Fardel, & Flandrois, 1996; Bollman, Ismond, & Blank, 2001; Dominguez & Schaffner, 2008; Escartin, Lozano, & Garcia, 2000; Silvia, Rui, Margarida, Silva, & Maria, 2009; Trakulchang & Kraft, 1977). Many chemical changes can also occur during temperature abuse of frozen foods. These include: pigment discoloration and oxidative reactions in uncooked meat (Decker & Hutlin, 1992); protein degradation in protein rich seafood (Sarma, Vidya Sagar Reddy, & Srikar, 2000); lipid oxidation in the frozen high fat cooked meat products (Lee, Mei, & Decker, 1997; Rhee, 1988); gluten network damage and

* Corresponding author.
E-mail address: karwe@aesop.rutgers.edu (M.V. Karwe).

http://dx.doi.org/10.1016/j.foodres.2015.07.012
0963-9969/

deterioration of yeast in dough and baked products (Barcenas, Haros, Benedito, & Rosell, 2003; Bhattacharya, Langstaff, & Berzonsky, 2003; Varriano-Marston, Hsu, & Mahdi, 1980); and nutritional loss in fruits and vegetables (Giannakourou & Taoukis, 2003).

Studies that combine temperature history with microbial/chemical kinetics to forecast the end safety/quality of food dated back as far as 1944, but prior research has primarily focused on foods with simple geometries (Elvira, Sanz, & Carrasco, 1996; Hicks, 1944; Labuza, 1979; Nunes & Swartzel, 1990; Powers, Lukaszewics, Wheeler, & Dornseifer, 1965; Scott & Heldman, 1990; Zuritz & Singh, 1985). A detailed study involving multiple food products in a complex geometry, including the effects of phase change during freeze thaw cycles on the overall thermal response and food safety and quality, has not been carried out. The aim of this study was to predict the microbial safety of food products experiencing temperature abuse, by combining a complex heat transfer model with microbial kinetics. A typical US army breakfast menu box containing uncooked beefsteak, concentrated orange juice, peppers & onions, French toast, and mini Danishes, was used for this research. The specific objectives were 1) to evaluate the microbial kinetics of the spoilage or pathogenic microorganisms most liable to grow on the most sensitive food item in the menu box, and 2) to combine the evaluated microbial kinetics with a validated heat transfer numerical model of the frozen menu box to predict the microbial safety during two possible temperature abuse scenarios.

Chemical degradation due to temperature abuse was not considered in this study, because chemical degradation takes place at a slower rate in frozen foods compared to microbial spoilage (Singh & Wang, 1977). This was confirmed by our preliminary experiments, wherein we studied the effect of different frozen storage temperatures (−18 °C, −12 °C, and −4 °C) and storage time on the microbial quality (analyzed by total plate count (TPC) method) and chemical degradation (analyzed by quantifying the formation of lipid oxidation byproducts: thiobarbituric acid reactive substances (TBARS)) in beef steak. Considerable increase in microbial growth was observed with increasing storage temperature and time, whereas negligible effect of storage temperature and time on chemical degradation was found. The methodology and results of these experiments were not discussed in this paper, since it is beyond the scope of this research.

2. Materials and methods

A heat transfer numerical model was developed for the army breakfast menu box containing five different food items with the inclusion of their phase change behavior. Detailed descriptions of the food items in the menu box and model development are explained in the Part 1 of this study (Karthikeyan, Desai, Salvi, Bruins, & Karwe, 2015). In brief, thermo-physical properties of each food item were evaluated using their respective component data and a differential scanning calorimeter (DSC). A finite element method (FEM) based commercial computational software, COMSOL Multiphysics® (Version 4.2, COMSOL Inc., Burlington, MA), was used to predict the thermal behavior of food items in the menu box with respect to the external temperature conditions. The three dimensional geometry depicting five different food items inside the cardboard menu box is shown in Fig. 1. The numerical model was experimentally validated with a gel based model food system and a real food system (Karthikeyan, 2013).

2.1. Microbial growth prediction

ComBase Predictor is one of the most commonly used predictive microbiological modeling tools (Baranyi & Tamplin, 2004). Since frozen meat products are most susceptible to microbial spoilage during temperature abuse, uncooked beefsteaks in the menu box were chosen for microbial study. Several microorganisms likely to contaminate uncooked beefsteak were selected. They included pathogenic organisms such as *Escherichia coli* O157:H7, *Salmonella* spp., *Listeria monocytogenes*, *Clostridium botulinum* and the spoilage bacterium *Pseudomonas* spp. (Bajard et al., 1996; Bollman et al., 2001; Juneja, Melendres, Huang, Subbiah, & Thippareddi, 2009; Peck, Goodburn, Betts, & Stringer, 2006; Trakulchang & Kraft, 1977). The maximum allowable growth for pathogens was assumed 1-log, while a 2.5-log increase was allowed for spoilage organisms (Dominguez & Schaffner, 2007; IFT/FDA, 2003; Ingham et al., 2007; NACMCF, 2010; Peck et al., 2006; Uyttendaele, Vankeirsblick, & Debevere, 2001; Zhang et al., 2011). Optimal environmental conditions were assumed for each microbe. Growth rates of the microorganisms in the temperature range of 0 °C to 30 °C were predicted using data obtained from ComBase Predictor. An initial microbial lag phase was assumed to occur prior to growth. Microbial growth below 0 °C was assumed to be negligible. Maximum storage time, i.e., the time until the microbial count reached the allowable limit, was evaluated for each species at different temperatures. The species that exceeded the allowable limit first was used as the representative microorganism for further studies.

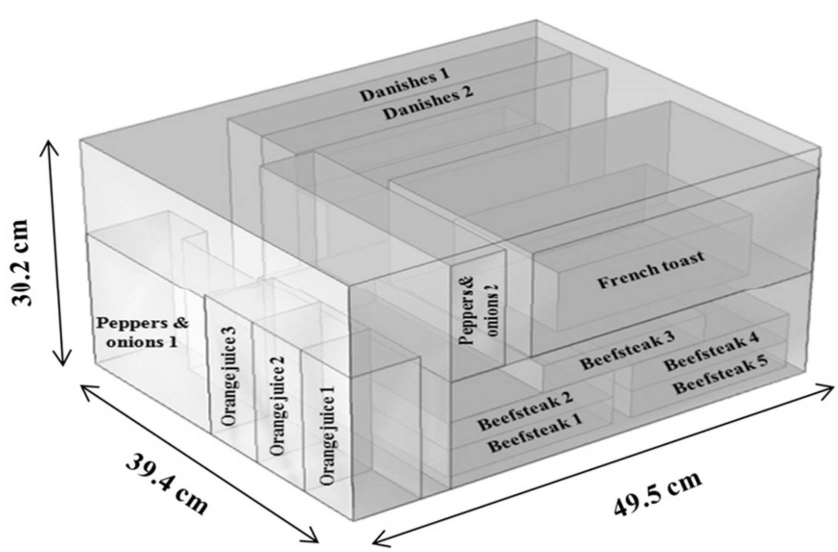

Fig. 1. Three dimensional geometry of menu box containing five food items packed in their specific location and orientation, with their added description, developed using COMSOL Multiphysics® software.