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Comparative thermal impact of two UHT technologies, continuous ohmic heating and direct steam injection, on the nutritional properties of liquid infant formula

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A continuous pilot plant for liquid sterilization was used to compare ohmic heating and steam injection on liquid infant formula under the same conditions of pre-heating and holding. Samples were collected at different holding times and temperatures and analyzed for reactions of thermal degradation. Two substrates were measured: soluble proteins and vitamin C and different intermediate or advanced products of Maillard reaction were monitored: furosine, carboxymethyllysine (CML), FAST index (Fluorescence of Advanced Maillard products and Soluble Tryptophan) and color (ΔL^*, Δa^* and Δb^*). Pseudo-zero order kinetics was established for the Maillard products or global markers and Arrhenius parameters could be calculated. Equivalent markers contents were obtained after ohmic heating and steam injection showing equivalent quality of the infant formula for both sterilization technologies.

1. Introduction

Milk based infant formulas (IF) which composition is close to mature human milk, are designed to cover the nutritional needs of healthy infants. Product stability and microbiological safety are usually achieved by atomization or heat sterilization. However, severe heat treatments have deleterious effects on the sensory, biophysical and nutritional properties of milk products (Finot et al., 1981). Major changes are detected in thermally treated milks like protein denaturation and aggregation (Oldfield et al., 1998, 2000), lipid-protein and protein–protein interactions (Fenaille et al., 2006), sugar isomerization (Berg and Van Boekel, 1994) and a wide range of chemical reactions, the Maillard reaction being the main involved (Hiller and Lorenzen, 2010; Pellegrino et al., 1995; van Boekel, 1998). It is a complex series of reactions in which, in milk, a condensation reaction first occurs between the carbonyl group of lactose and the ε-amino group of lysine. The new compounds produced by Maillard reaction are likely to affect the quality, nutritional value and safety of the product (Birlouez-Aragon et al., 2006).

Two classical modes of high temperature short time (HTST) heating - indirect and direct UHT - are commonly used for sterilization of milk and milk products. In the indirect mode, the milk is separated from the heating fluid (steam or warm water under pressure) by a wall while in the second case it is mixed with the warming fluid (steam). Some of the steam is condensed, giving up its latent heat of vaporization to the product and giving a much more rapid rate of heating than is available with any indirect system. After holding at the sterilizing temperature, the product is expanded in a cooling vessel, where the pressure is at a level below atmospheric. It immediately boils and gives up water in the form of water vapor which is removed from the vessel and condensed. Steam injection (SI) has been observed to be the best technology to limit thermal damage of milks (Birlouez-Aragon et al., 1998; van Asselt et al., 2008). Although it is a very efficient heating method,

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where the product can reach temperatures above 150 °C in less than a second, the main disadvantage of SI relies on increased complexity and costs (Burton, 1994). Firstly, the water used for vapor production needs to be of "culinary" grade: it fulfills very strict hygiene standards and the use of chemical sterilizing agents that might end in the food product is a critical point. Boilers and steam generation equipment have to be operated in a way to prevent foaming, priming, carryover and excessive entrainment of boiling water into the steam (Canadian Food Inspection Agency, 2014). Secondly, the dilution of the product caused by steam condensation (up to 11% of the product) needs to be compensated by a vaporization step to recover the exact initial solid content of the milk; the recovered vapor requires expensive devices to be recycled in comparison with an indirect heat exchanger allowing 80–90% heat recovery (Burton, 1994). Thirdly, elevated costs of heat and water are involved in direct UHT: the steam distribution through a network of pipes down to the injector comes along with heat losses and large amounts of water are required for the operating of the condenser. Furthermore, the residence time distribution can be quite dispersed within the steam nozzle causing thermal heterogeneity. Finally, fouling in the downstream area of the SI heater is an important operating problem, threatening the quality of product and affecting plant operation (Truong et al., 2002).

Another direct way of warming up a food product is ohmic heating. It is based on a simple mechanism – the Joule effect – which consists of raising the product temperature by passing an electrical current directly through the food when placed between two electrodes. Ohmic heating (OH) offers the big advantage over conventional indirect heating methods, of being based on pure-volume heating: the heat is directly dissipated in the product which behaves as a resistance thanks to the presence of free ions, resulting in fast and uniform heating. Even though it is based on the use of electricity which is less and less appreciated today, the electrical conversion into heat energy is close to 100% (Ghnimi et al., 2007) and the very low thermal inertia makes possible fast and precise regulation. Heat transfer is a function of the electrical and thermal parameters of the product and equipment which makes the process easy-to-drive (Goullieux and Pain, 2014; Roux et al., 2010). However, fouling on electrode surfaces constitutes one of the main problems of OH (Ayadi et al., 2004, 2005; Fillaudeau et al., 2007; Stancl and Zitny, 2010). Besides production shut down for cleaning, fouling induces quality losses of the product and presence of electric arcs. Two big ways have been explored to limit fouling in OH: the one goes through cooling the walls of the ohmic reactor (Pain et al., 2013); and the second is based on the use of a fluid jet subjected to the electric field (Ghnimi et al., 2008). The first approach was used in this study to limit fouling problems during sterilization of the liquid infant formula.

The question of quantifying the healthiness of a product, which is crucial for infant formulas, and the possibility of optimizing food processing with respect to health aspects were addressed by van Boekel and Jongen (1997) who observed among others, the (anti) mutagenicity of Maillard products in heated milk. Different authors have used various markers of heat damage in milk and infant formulas in order to evaluate the effect of a given technology on the product quality: the combination of furosine and lactulose values was used by Pellegrino et al. to build information about the thermal history of sterilized milk (Hiller and Lorenzen, 2010). Rufián-Henares et al. (2004) monitored the extent of Maillard reaction by measuring furosine and color in model infant formula mixed and heated at lab scale. In addition to furosine, hydroxymethylfurfural (HMF) and pyrraline were studied by Contreras-Calderon et al. (2008) as indicators of thermal damage together with available lysine as nutritional indicator, to evaluate heat damage to ingredients used in commercial infant formulas. Morales et al. (2004) proposed to use the ratio of maltose to maltulose and furosine as quality parameters for infant formula. Rapid fluorimetric methods were investigated to assess the quality of heat-treated food products: the FAST index (Fluorescence of Advanced Maillard products and Soluble Tryptophan) was first designed for liquid milk products (Birlouez-Aragon et al., 1998) and extended to liquid infant formulas (Birlouez-Aragon et al., 2004; Damjanovic Desic and Birlouez-Aragon, 2011); it is based on the fluorescence of Maillard products observed in the soluble extract of the food and corrected for the protein concentration of the obtained solution. Front face fluorescence finger prints were used as rapid predictor of the nutritional quality of a bigger range of food products, by correlating the fluorescence response to the concentration of specific Maillard products like carboxymethyllysine (CML) in IF (Birlouez-Aragon et al., 2005), HMF in milk (Schamberger and Labuza, 2006), or the concentration of vitamin C, protein denaturation and accumulation of Maillard products in IF (Diez et al., 2008). Finally, Feinberg et al. (2006) demonstrated that no tracer can universally discriminate pasteurization from high pasteurization, direct UHT, indirect UHT, and sterilization of commercial milks. He recommended a multivariate approach by combining at least five tracers, the most discriminative ones being those which globally measure the structural modifications of the milk protein rather than those which specifically quantify the metabolites of the Maillard reaction.

In this study two types of continuous direct UHT treatments were applied to sterilize a model infant formula. The first objective was to compare the performances of OH to SI which is considered the best technology for UHT treatments of milk and milk products. Both technologies were applied at pilot scale, switching from one to another on the same pilot plant to generate identical time-temperature histories of the sterilized IF. They were compared on the basis of thermal degradation of proteins or vitamin C and production of Maillard products. The second objective was to generate kinetic data under real HTST processing conditions, including heating, holding and cooling phase, by modulating the holding time and temperature.

2. Materials and methods

2.1. Liquid infant formula

The liquid infant formula was specially designed for these experiments by industrial partners of ICARE project. It was produced at industrial scale using microfiltrated skim milk supplemented with various other ingredients in order to fulfill the nutritional target of the designed product (Table 1). The liquid product was packed into vacuum bags of 1 ton (2 units, one for each trial), transported and stored at 4 °C for 4 days.

2.2. Analytical methods

2.2.1. FAST method

The analytical method used to monitor the Fluorescence of Advanced Maillard products and Soluble Tryptophan (FAST) was the one previously developed and patented (Birlouez-Aragon, 2002; Birlouez-Aragon et al., 2002): first, a soluble extract of the IF was produced by bringing 1 mL sample to pH 4.6 using 50 mL of sodium acetate buffer (0.1 M, pH 4.6). 4 mL of supernatant were then filtered through a 0.45 μm nylon filter (VWR, France) and placed in a disposable 4 faces acryl cuve (Sarstedt, France). The fluorescence of two complementary indicators was measured in the same sample, using a spectrofluorimeter (CaryEclipse Varian, France): at excitation/emission wavelengths of 290/340 nm,