J. Dairy Sci. 99:6983–6994
http://dx.doi.org/10.3168/jds.2016-10968

Effect of tetrasodium pyrophosphate concentration and cooking time on the physicochemical properties of process cheese

N. Shirashoji,*†‡ H. Aoyagi,† J. J. Jaeggi,‡ and J. A. Lucey‡[1]
*Food Research & Development Laboratory, Morinaga Milk Industry Co., Ltd., 1-83, 5-Chome Higashihara, Zama, Kanagawa 228-8583 Japan
†Life Sciences and Bioengineering, Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572 Japan
‡Wisconsin Center for Dairy Research, University of Wisconsin–Madison, 1605 Linden Drive, Madison 53706

ABSTRACT

Tetrasodium pyrophosphate (TSPP) is widely used as an emulsifying salt (ES) in process cheese. Previous reports have indicated that TSPP exhibits some unusual properties, including the gelation of milk proteins at specific ES concentrations. We studied the effect of various concentrations (0.25–2.75%) of TSPP and cooking times (0–20 min) on the rheological, textural, and physical properties of pasteurized process Cheddar cheese using a central composite rotatable experimental design. Cheeses were made with a constant pH value to avoid pH as a confounding factor. Modeling of the textural properties of process cheese made with TSPP exhibited complex behavior, with polynomial models (cubic) giving better predictions (higher coefficient of determination values) than simpler quadratic models. Meltability indices (degree of flow from the UW MeltProfiler (University of Wisconsin–Madison), loss tangent value at 60°C from rheological testing, and Schreiber melt area) initially decreased with increasing TSPP concentrations, but above a critical ES concentration (~1.0%) meltability increased at higher TSPP concentrations. The storage modulus values measured at 70°C for process cheese initially increased with increasing TSPP concentration, but above a concentration of 1% ES, the storage modulus values decreased. Cooking time had little effect on the various melting or rheological properties. With an increase in TSPP concentration, the insoluble Ca and P contents increased, suggesting that TSPP addition resulted in the formation of insoluble calcium pyrophosphate complexes; some of which were likely associated with caseins. A portion of the added TSPP remained in the soluble phase. The acid-base buffering profiles also indicated that calcium pyrophosphate complexes were formed in cheese made with TSPP. In milk systems, low levels of TSPP have been shown to induce protein crosslinking and gelation, whereas at higher TSPP concentrations milk gelation was inhibited due to excessive charge repulsion from these calcium pyrophosphate complexes. We hypothesized that a similar phenomenon was occurring in our process cheese, resulting in the initial reduction in meltability with TSPP addition due to protein crosslinking, but at higher TSPP levels meltability increased due to excessive charge repulsion.
Key words: emulsifying salt, texture, meltability

INTRODUCTION

Process cheese manufacturing involves the heating or shearing of natural cheese in the presence of calcium chelating salts (phosphates and citrates) that are commonly referred to as emulsifying salts (**ES**; Berger et al., 1998; Maurer-Rothmann and Scheurer, 2005). Heating of natural cheese in the absence of ES causes oiling off, which is the separation of fat from the rest of the cheese mass (Lucey et al., 2011). These ES act by disrupting the insoluble Ca-phosphate nanoclusters that are important cross-links for the stability of the caseins (Horne, 1998), thereby dispersing the insoluble casein matrix of natural cheese (Guinee et al., 2004).

Various factors affect the properties of process cheese, including composition (moisture, protein, or fat content), pH, maturity and types of natural cheeses, cooking temperature or time, and cooling rate after cooking (Guinee et al., 2004). The precise effect of the ES used is the least well-understood variable in process cheese manufacturing, and made more complex by the common use of mixtures of different types of ES, in various proprietary ratios. Over the years, studies have focused on the effects of single, or mixtures, of ES on various types of process cheese (Templeton and Sommer, 1930; Gupta et al., 1984; Cavalier-Salou and Cheftel, 1991; Awad et al., 2002; Dimitreli et al., 2005; Sádlíková et al., 2010; Nagyová et al., 2014). However, one significant confounding factor not addressed in most of these studies is that the addition of ES also alters pH, and

Received January 29, 2016.
Accepted May 27, 2016.
[1]Corresponding author: jalucey@facstaff.wisc.edu

the pH value of process cheese has a marked effect on its physical properties (Marchesseau et al., 1997; Mulsow et al., 2007; Lu et al., 2008; Lucey et al., 2011). A couple of studies on ES mixtures did adjust samples to a constant pH (Nagyová et al., 2014; Salek et al., 2015). Consequently, detailed studies where pH is excluded as a possible factor are needed to explore the mechanisms by which the different types of individual ES affect the properties of process cheese.

Cooking time is well known to affect the properties of process cheese (Rayan et al., 1980). Heat and shearing during cooking could also act synergistically with ES to better disperse the caseins during process cheese manufacturing (Mulsow et al., 2007). It has also been reported that with longer cooking times, for some types of ES, a thickening or increase in viscosity, commonly referred to as creaming, can be observed (Meyer, 1973; Berger et al., 1998; Kawasaki, 2008).

Tetrasodium pyrophosphate (**TSPP**) is a well-known Ca chelating agent and is commonly used in the food industry as a binding agent for meats, a tartar control agent in toothpaste, and an emulsifier for process cheese. Several studies have reported on the characteristics of TSPP such as its buffering ability (Guinee et al., 2004; Maurer-Rothmann and Scheurer, 2005; Lu et al., 2008), Ca-sequestering ability (Carić et al., 1985; Guinee et al., 2004), and ability to disperse casein (Dimitreli et al., 2005; Cunha and Viotto, 2010). Lucey et al. (2011) indicated that TSPP is an ES with strong buffering and creaming ability, and moderately strong Ca-binding ability. Various studies (Gupta et al., 1984; Cavalier-Salou and Cheftel, 1991; Dimitreli et al., 2005) also reported that addition of TSPP to cheese analog, or process cheese, resulted in higher pH values. Mizuno and Lucey (2007) investigated the influence of TSPP on some physical properties of caseins using a reconstituted milk protein concentrate solution adjusted to pH 5.8. Mizuno and Lucey (2007) reported that low concentrations of TSPP effectively dispersed caseins, whereas at some critical concentrations of TSPP gelation of caseins was observed in solution during storage at room temperature. Addition of high concentrations of TSPP to the milk protein solutions dispersed caseins, but no gels were observed during storage due to excessive electrostatic repulsion (Mizuno and Lucey, 2007). To our knowledge, no studies exist on the effect of TSPP addition on the state of Ca in process cheese. The objectives of the current study were to investigate the effect of TSPP concentrations and cooking time on the rheological and textural properties of pasteurized process Cheddar cheese. Another objective was to determine the state of Ca on process cheese made with TSPP that were adjusted to a constant pH to avoid the confounding effect of differences in pH values.

MATERIALS AND METHODS

In the current study, we used similar materials and methods as applied by our group in previous single ES studies; that is, where the effect of the trisodium citrate and sodium hexametaphosphate on properties of process cheese was studied (Shirashoji et al., 2006, 2010).

Materials

Four-month-old Cheddar cheese was obtained from Alto Dairy Cooperative. Cheeses used for this research had the following composition: moisture, 37%; fat, 34%; protein 26%; 669 mg of Ca/100 g of cheese. The ES used was TSPP (ICL Performance Products LP, St. Louis, MO). The pH modifiers used were 50% sodium hydroxide (Fisher Scientific, Pittsburgh, PA) or 88% lactic acid (Brenntag Great Lakes LLC, Wauwatosa, WI).

Process Cheese Manufacture

Process cheeses were manufactured with a Blentech twinscrew cooker (Blentech Corp., Rohnert Park, CA) as described by Shirashoji et al. (2006, 2010). Cheddar cheese was grated by a meat grinder (Biro Manufacturing, Marblehead, OH). The TSPP (0.25–2.75%) were added into grated cheese, mixed with water, and added to the cooker to avoid lumps of TSPP. Mixing was at 50 rpm for 40 s, then stirred at 100 rpm, and heated by direct steam injection (87 kPa) for 200 s; indirect steam was used to finish heating. The pH of the final products was adjusted by adding 50% sodium hydroxide or 88% lactic acid during premixing, but water addition was adjusted in those pH-adjusted samples to maintain constant cheese moisture concentrations. After cooking to 80°C, melted cheese was poured into 0.9-kg pouches. The cheese blocks were vacuum sealed after cooling, then stored at 5°C. All analyses were determined 7 d after manufacture.

Rheological and Meltability Measurements

Rheological properties of pasteurized process cheese were measured by dynamic small amplitude oscillatory rheology as described by Shirashoji et al. (2006, 2010). The storage modulus (**G′**) and loss tangent (**LT**) were determined by dynamic temperature ramp test. The cheese disks were heated from 5 to 85°C at the rate of 1°C/min with an applied strain of 0.5% and a frequency of 0.08 Hz. Three replicates were measured for each cheese sample.

Texture profile analysis (**TPA**) was performed using a TA.XT2 Texture Analyzer (Texture Technologies