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Novel methods to study the effect of protein content and dissolution temperature on the solubility of milk protein concentrate: Focused beam reflectance and ultrasonic flaw detector-based methods

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ABSTRACT

Processing, storage, dissolution conditions, and the composition of milk protein concentrates (MPC) affect the solubility of high-protein dairy powders. Increasing the storage temperature and time decrease the solubility of MPC and milk protein isolates (MPI). The MPC and MPI are popular ingredients in high-protein food products and have a variety of protein contents. In addition, the dissolution temperature has been shown to affect the solubility of the powders. This study focused on determining how protein content and dissolution temperature affect the solubility of MPC and MPI. For this study, 11 powders were obtained from a commercial manufacturer. The powders were classified as A, B, C, and D, and they had a mean protein content of 85, 87, 88, and 90%, respectively. A 5% (wt/wt) concentration of powder was dissolved in water at 40 and 48°C. The solubility of the MPC and MPI samples were characterized using an ultrasonic flaw detector (UFD) and focused beam reflectance measurement (FBRM). The UFD and FBRM data were collected every 15 and 10 s, respectively, for 1,800 s. At both dissolution temperatures, the UFD and FBRM data showed that the solubility decreased as the protein content increased. Powders A and B were found to be more soluble because they had a lower relative velocity standard deviation, high area under the attenuation curve, high peak height, and low peak time. With the FBRM, the fine and medium particle count decreased and large particle count increased as the protein content increased. Powders dissolved at 48°C typically had a lower relative velocity standard deviation, higher area under the attenuation curve, higher peak height, and lower peak time than the powders dissolved at 40°C. The FBRM showed that powders dissolved at 48°C reached a stable counts before the powders dissolved at 40°C. Overall, the study showed that increasing the protein content led to a reduction in solubility and increasing the dissolution temperature improved the solubility of the powders.

Key words: milk protein concentrate, dissolution behavior, focused beam reflectance measurement, flaw detector

INTRODUCTION

High-protein dairy powders such as milk protein concentrates (**MPC**) and milk protein isolates (**MPI**) are added to a variety of dairy and food products to improve the nutritional, sensory, and functional properties. The protein content of MPC and MPI ranges from 40 to 90%. Generally, powders with a protein content of 80% or above are added to high-protein nutrition bars, meal replacement beverages, and medical nutrition products (Agarwal et al., 2015). The MPC and MPI must be soluble to give the products the desired characteristics. However, various factors such as processing conditions, composition of the powder, storage conditions, and dissolution conditions affect the overall solubility of MPC and MPI.

Lactose, minerals, and water are removed from skim milk during ultrafiltration and diafiltration to concentrate the proteins in their native form (Chandan and Kilara, 2011). However, subsequent processing steps such as evaporation and spray drying partially denature the protein, which leads to a reduction in solubility of the finished product (Augustin et al., 2012; Fang et al., 2012). Various techniques have been proposed to improve the solubility of high-protein dairy powders. Mao et al. (2012) reported that the MPC80 powder obtained by addition of 150 m*M* NaCl during diafiltration showed highest solubility during reconstitution. The addition of a sodium solution to the retentate before spray drying has been shown to improve the solubility (Schuck et al., 2007). In a study conducted by Augustin et al. (2012), the addition of a high shear treatment such as homogenization, microfiltration, and ultrasoni-

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cation improved the solubility of the powder even after 6 mo of storage.

The major and minor components of MPC and MPI such as protein, lactose, and mineral influence the solubility. A reduction in rehydration time was observed for powders with a higher lactose and whey protein concentration (Gaiani et al., 2006, 2007). In a study reported by Sikand et al. (2011), MPC40 samples were appear to be more soluble compared with MPC80 and MPI samples, with a couple of exceptions. The exceptionally high solubility of MPI samples was attributed to low calcium and phosphorus contents when compared with the other samples tested. The MPC powders have the best solubility immediately after production and the solubility decreases as the storage time and temperature increases. (Anema et al., 2006; Fang et al., 2011; Gazi and Huppertz, 2015).

Studies have shown that increasing the stirring speed and temperature decreased the rehydration time. Jeantet et al. (2010) reported that increasing the dissolution temperature from 26 to 30°C was more effective than doubling the stirring speed in increasing the solubility and concluded that temperature has a major effect on rehydration behavior of micellar casein powder. Fang et al. (2011) noticed that a higher dissolution temperature improved the ability to detect solubility differences between fresh and aged powders. However, a dissolution temperature at or above 60°C led to a reduction in solubility due to protein denaturation and aggregation (Fang et al., 2010).

Baldwin (2010) highlighted the need for information on instrumental measurements and solubility measurements of powders to probe insolubility phenomenon in milk powder products. Ji et al. (2016) also recognized the need for more reliable techniques tailored for dairy powders and evaluated methods including light scattering, light transmission, and conductivity of suspension, to characterize milk protein-based powders. With this background, still there is a need to quantitatively determine the effect of protein content and dissolution temperature on the dissolution characteristics of high-protein dairy powders. For this study, the objective was to determine the effect of protein content and dissolution temperature on the dissolution characteristics of MPC and MPI as measured by an ultrasonic flaw detector (**UFD**) and focused beam reflectance measurement (**FBRM**).

MATERIALS AND METHODS

Experimental Design

From a commercial manufacturer within the United States, 11 MPC powder samples were obtained and the dissolution characteristics of powders were evaluated at 40 and 48°C using the UFD-based method and FBRM. Based on the protein content, the powders were divided into 4 categories: A, B, C, and D. As per the certificate of analysis provided by the manufacturer, Powders A, B, C, and D had a protein content of 85, 87, 88, and 90%, respectively. Powders A and B both contained 3 lots and powders C and D contained 4 lots and 1 lot, respectively. Each of the samples was analyzed using the UFD-based method and FBRM in triplicate ($n = 3$).

Experimental Setup

Experimental setup as described by Hauser and Amamcharla (2016) was used to acquire dissolution characteristics of powders. Briefly, the setup consisted of a UFD (Epoch LTC, Olympus Scientific Solutions, Waltham, MA), connected to an immersion transducer (V303-SU, Olympus Scientific Solutions) in a holder, and a 4-bladed overhead stirrer (Caframo, Georgian Bluffs, Ontario, Canada) that was placed 10 mm from the bottom of the beaker. The experimental setup was also fitted with a FBRM (Particle Track E25, Mettler Toledo, Columbus, OH) probe. A temperature-controlled water bath (Fisher Scientific, Pittsburgh, PA) was used to maintain the powder dissolution temperature at 40 and 48°C.

UFD. A UFD in pulse-echo mode was connected to a 1-MHz immersion transducer. The ultrasound path length was kept constant at 18 ± 0.5 mm with a stainless steel holder. A detailed description of the design of the holder was provided in Hauser and Amamcharla (2016).

Deriving Parameters from UFD. The method for exporting the ultrasound data and calculating the ultrasound velocity, relative ultrasound velocity, and ultrasound attenuation can be found in Hauser and Amamcharla (2016). Relative ultrasound velocity and ultrasound attenuation were plotted against powder dissolution time. From these curves, the standard deviation of relative ultrasound velocity from 900 to 1,800 s, ultrasound attenuation peak height (maximum attenuation), attenuation peak time (time to reach maximum attenuation), and area under the attenuation curve were extracted to characterize powder dissolution. The area under the attenuation curve was calculated using the trapezoidal rule (Potter and Goldberg, 1987). The derived ultrasound parameters were used as a tool to understand the effect of protein content on the solubility of MPC and MPI.

FBRM. A FBRM was also used to monitor and evaluate the dissolution behavior of the powders. The FBRM was installed at an angle of 30° and 20 mm from