Journal of Food Engineering 124 (2014) 11–18

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Effect of power ultrasound pre-treatment on the physical and functional properties of reconstituted milk protein concentrate

Sun Yanjun [a,b], Chen Jianhang [a], Zhang Shuwen [a], Li Hongjuan [a], Lu Jing [a], Liu Lu [a], H. Uluko [a], Su Yanling [a], Cui Wenming [a], Ge Wupeng [c], Lv Jiaping [a,*]

[a] Institute of Agro-products Processing Science and Technology, Chinese Academy of Agricultural Sciences, Beijing 100193, China
[b] State Key Laboratory of Dairy Biotechnology, Dairy Research Institute, Bright Dairy and Food Co., Ltd., Shanghai 200436, China
[c] Food Science and Engineering, North West Agriculture and Forestry University, Yangling, Shaanxi 712100, China

ARTICLE INFO

Article history:
Received 8 March 2013
Received in revised form 4 September 2013
Accepted 5 September 2013
Available online 18 September 2013

Keywords:
Milk protein concentrate 80
PUS pre-treatment
Physical property
Functionality

ABSTRACT

This work investigated the impact of power ultrasound (PUS) pretreatment on the physical and functional properties of reconstituted milk protein concentrate (MPC) 80. Ultrafiltered/diafiltered (UF/DF) milk protein retentates were treated with PUS (12.50 ± 0.31 W and 50% amplitude) for 0.5, 1, 2, and 5 min prior to spray drying.

Results revealed that the particle size (D50) reduced from 28.45 μm to 0.13 μm after 0.5 min of sonication. Solubility increased significantly from 35.78% to 88.30% after 5 min of PUS pre-treatment. Moreover, the emulsifying activity index (EAI) of MPC samples increased significantly as the time of ultrasonic treatment was prolonged. Additionally, the emulsion stability index (ESI) initially increased after ultrasound treatment for 1 min. Surface hydrophobicity was greatly increased with more hydrophobic groups exposed to the environment. PUS pre-treatment also promoted an increase in the storage modulus (G') of the MPC solutions. Viscosity significantly decreased after PUS pre-treatment. This result was confirmed by the microstructure of the powder, with small particles formed and trapped in dents of large particles. However, sodium-dodecyl sulfate–polyacrylamide gel electrophoresis showed no significant change in protein molecular weight.

1. Introduction

Milk protein products are widely used valuable ingredients in the food and dairy industries; these products made a major contribution in the development of new food products. Traditional milk protein products are produced by acid or rennet precipitation, which involves the application of high heat or pH adjustments that denature the whey protein. Milk protein concentrate (MPC) powders are manufactured through ultrafiltration (UF), diafiltration (DF), and optional evaporation of the retentate prior to spray drying. These processes are relatively moderate without heat treatment and pH adjustment; hence, MPC contains undenatured casein and whey proteins. Compared with skim milk powders, MPCs have less lactose and higher amounts of protein. The casein/whey protein ratio of MPC is similar to that of skim milk powder. MPCs are crucial in the production of cheese, confectionary, yoghurt, and other food products. Generally, the protein powder needs to be dispersed and fully dissolved before it can be utilized. Therefore, prior dissolution of MPC in water must be as rapid as possible at room temperature with moderate agitation to minimize operating costs. However, MPC powders are poorly soluble because of their high protein content (40–90%), which restricts their applications. Several researchers have focused on different ways to improve the solubility of MPC powders in cold water. Examples include the addition of monovalent ions prior to spray drying (Carr et al., 2002), removal of calcium ions using a cation exchanger (Bhaskar et al., 2003; Dybing et al., 2003), acidification to lower pH followed by UF/DF or addition of a calcium chelating agent (Schuck et al., 2002; Bhaskar et al., 2003), and high shear treatment of the milk concentrates prior to spray drying (Augustin et al., 2012).

In contrast to low-intensity ultrasound (typically less than 1 W cm^{-2}, with a frequency range of 5–10 MHz), high-intensity ultrasound (HIUS), which uses much higher power levels (typically in the range of 10–1000 W cm^{-2}, with a frequency range of 20–1000 kHz), causes physical disruption of the material and promotes certain chemical reactions (Mason, 1998). HIUS has been applied in many processes, including homogenization, cutting, drying, and extraction, inactivation of microbes and enzymes, degassing of liquid foods, nucleation, and even preparation of

* Corresponding author at: Institute of Agro-products Processing Science and Technology, Chinese Academy of Agricultural Sciences, Beijing 100193, China. Tel.: +86 15921569362.

E-mail addresses: yanjun1988216@sina.com (S. Yanjun), Lvjp586@gmail.com (L. Jiaping).

0260-8774/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jfoodeng.2013.09.013

submicron emulsions (Bhaskaracharya et al., 2009; Camino et al., 2009; Knorr et al., 2004).

Several studies have focused on the effect of HIUS treatment on whey proteins (Wang et al., 2008; Jambrak et al., 2008; Guzey et al., 2006) and soy proteins (Jambrak et al., 2009). Augustin et al. (2012) examined the effect of various shear treatments (homogenization, microfluidization, or ultrasonication) of UF/DF concentrates on the solubility of MPC. Their work demonstrated that the solubility of MPC powder can be improved by ultrasonication.

To date, systematic studies on the effects of ultrasonication treatment on the functionality of MPCs are lacking. In the present work, skim milk retentate was treated with power ultrasound (PUS) at different durations to evaluate the influence of PUS pre-treatment on the solubility, emulsification, and other functional characteristics of MPC powder.

2. Materials and methods

2.1. Materials

Raw cow's milk was obtained from the dairy farm of the China Agriculture University. The raw milk was composed of 3.4% (w/w) protein, 4.5% (w/w) lactose, and 4.0% (w/w) fat (data collected from Beijing Dairy Cattle Center). The raw milk was kept at 4 °C until use.

2.2. Sample preparation

The fat content of the raw milk was removed by a disc bowl centrifuge (FT15, Armfield Company, UK). MPC was manufactured through UF of skim milk with DF. Pasteurized skim milk (60 kg) was heated to 50 °C and ultrafiltered to approximately 3:1 volumetric concentration ratio (VCR) in a pilot plant unit equipped with a stainless steel membrane tube (Hyflux L400, Hyflux Ferro-Cep, Singapore) with a pore size of 20 nm. For the first DF, 40 kg of deionized water at 50 °C was added to the 3:l UF milk to commence DF. The water-diluted concentrate was ultrafiltered again to 3:1 VCR (20 kg retentate and 40 kg permeate). DF was conducted three times. The VCR after the final DF was 6:1 (10 kg retentate and 50 kg permeate), producing ultrafiltered milk with 15.55% solid content. Membrane inlet pressure of 1.7 bar and outlet pressure of 1.05 bar were maintained throughout the operation.

2.3. Ultrasound treatment

The rententate was sonicated in a glass vessel equipped with a cooling jacket using an ultrasonic horn (CTXNW-10B, Hongxianglong Bictechnology Co. Ltd., Beijing, China) with a maximum net output power of 600 W at a frequency of 20 kHz and an amplitude of 50% (maximum amplitude, 100%). A fully immersed high-grade titanium alloy probe (14.5 cm × 5 cm diameter) was used to sonicate 750 mL of solution. The treatment times were 0, 0.5, 1, 2, and 5 min in 5 s: 3 s work/rest cycles. During sonication, cooled water was continuously circulated through the cooling jacket to maintain the sample temperature below 50 °C. The PUS pre-treatment samples were then spray-dried in a single stage dryer (GEA Process Engineering Inc., Dusseldorf, Germany) using inlet and outlet temperatures of 130 and 65 °C, respectively. The experimental scheme used is depicted in Fig. 1. The powders were packed in bags for further experiments.

2.4. Chemical composition of powdered MPC

The chemical composition of MPC used in this study was analyzed by the methods described in Standards Australia (1995). This

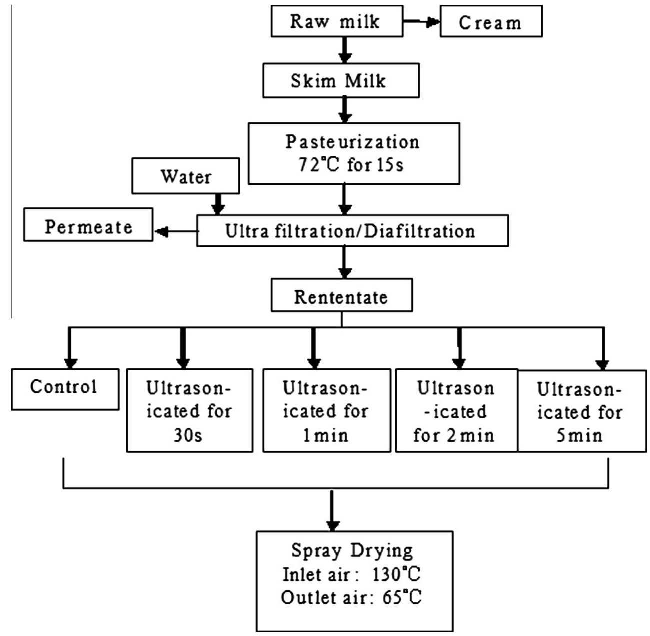

Fig. 1. MPC powder production. After ultrafiltration and diafiltration, the rententes were treated for different HIUS time.

MPC primarily contains milk proteins (80% w/w) with the same proportion of casein and whey proteins as in the milk used for the powder manufacture, lactose (4.1% w/w), ash (7.4% w/w), and fat (1.8% w/w).

MPC powders were reconstituted in distilled water at room temperature to obtain 5% w/w solutions. Sodium azide (0.02% w/w) was added to prevent microbial growth. All protein solutions were stirred for 1 h and then allowed to stand overnight at 4 °C. They were equilibrated at room temperature before further analysis.

2.5. Acoustic energy determination

Ultrasonic power is partly lost in the form of heat when ultrasound passes though the medium. The dissipated acoustic power in the liquid (power output) was calculated according to Raso et al. (1999). The temperature rise was estimated from the slope of the straight portion of the line that was obtained during the first 30 s of the experiment. The power output was calculated as follows:

$$P = mC_p\,dT/dt$$

where m is the mass of solvent used (in g) and C_p is the heat capacity of the solvent (in J g^{-1} °C^{-1}). The power output is expressed in watts per unit volume of the sonicated solution (W cm^{-3}).

The determined dissipated acoustic power in the liquid was 12.50 ± 0.31 W.

2.6. pH and conductivity determination

The pH and conductivity of each sample were measured. The pH was measured by a pH meter (FE20K, Mettler, Switzerland) at room temperature. Possible changes in electrical conductivity were determined at 25 °C using a conductimeter (DDS 307, Precision Scientific Instrument Co., Ltd., Shanghai, China).

2.7. Particle size distribution

The particle sizes of the dry MPC powder were determined using a particle size analyzer (S3500, Microtrac Company, USA).