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Optimizing the use of power ultrasound to decrease turbidity in whey protein suspensions

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ABSTRACT

This research employed power ultrasound (US) to decrease the turbidity of whey suspensions. US was applied using a 20 kHz generator and different power levels (3 and 15 W) for different application times (5 and 15 min) at different temperatures (20, 60 °C, and no temperature control [NTC]) to whey suspensions obtained at 4 different steps in a commercial process. The whey suspensions varied from 6.9 to 30.2% solids and 13.5 to 88% protein. This research shows an approximately 90% decrease in turbidity when US was applied to a whey suspension of 28.2% of solids containing 35.6% of protein on a dry basis. The greatest decrease in turbidity was observed when US was applied for 15 min using 15 W of electrical power at 60 °C and NTC conditions. Surprisingly, when US was used in whey suspensions containing 88.0% protein an increase in turbidity of samples was observed.

1. Introduction

In the food industry, ultrasound has been used to monitor (Saggin & Coupland, 2004; McClements & Povey, 1992, McClements, Povey, Jury, & Betsanis, 1990; Martini, Herrera, & Marangoni, 2005; Martini, Bertoli, Herrera, Neeson, & Marangoni, 2005a,b: Ueno, Sakata, Takeuchi, & Sato, 2002; Ueno, Ristic, Higaki, & Sato, 2003) and induce (Higaki, Ueno, Koyano, & Sato, 2001; Martini, Suzuki, & Hartel, 2008) lipid crystallization, to induce the crystallization of sugars and ice (Chow, Blindt, Chivers, & Povey, 2003;2005), to evaluate the rheology of food materials (Mert & Campanella, 2007; Maleky, Campos, & Marangoni, 2007), and to reduce the size of polysaccharide molecules (Wu, Zivanovic, Hayes, & Weiss, 2008; Kasaai, Arul, & Charlet, 2008; Kjartansson, Zivanovic, Kristbergsson, & Weiss, 2006; Baxter, Zivanovic, & Weiss, 2005). Other potential food applications of US include pasteurization, emulsification, de-foaming, and de-gassing of soft food materials. US techniques use sound waves of frequencies higher than those perceived by human hearing (>18 kHz). Acoustic waves can be applied to materials in the form of low intensity waves to passively monitor physical changes in the material caused by non-acoustic sources; or as high intensity waves (power ultrasound [US]) where disruption of molecular entities or changes in the physicochemical characteristics of the materials are originated by the acoustic waves. In particular, US has been commercially used in different food science applications such as emulsification, dispersion of solids, crystallization, de-gassing, and extraction. The advantages of using low intensity ultrasound techniques over other technologies are: i) low cost, ii) reproducibility and reliability, iii) capability of measuring in a continuous process (in-line, real-time measurements), iv) non invasive, v) and ability to measure material properties through opaque media such as cheese and shortenings (Patist & Bates, 2008).

Whey protein solubility is influenced by pH, temperature, and concentration. In general, whey proteins are the least soluble at pH 4.5–5.2 with an increase in solubility at acidic and alkaline pH values. In addition, there is usually a decrease in whey protein solubility with an increase in temperature. Previous research has shown that at neutral pH, there is a 22% decrease in solubility at 60 °C compared to 40 °C (Pelegrine & Gasparetto, 2005; Beecher, Drake, Luck, & Foegeding, 2008). Whey protein-containing beverages are generally formulated at acidic pH values because this results in a clear solution. A disadvantage to acidic beverages is that astringency is more pronounced necessitating the use of more sugar to offset the astringency. Beverages produced at neutral pH are generally opaque or turbid, even at just 2.5% protein, and less astringent, but require higher thermal processing temperatures than acidic beverages (Beecher et al., 2008; LaClair & Etzel, 2009). Therefore, increasing the clarity of whey protein solutions at neutral pH values is of industrial importance.

Several studies showed that US can change the functional properties of whey proteins. Recently, Ashokkumar et al. (Ashokkumar et al., 2009) showed that whey proteins (6% protein) sonicated after heat treatment had reduced viscosity and reduced heat-induced protein aggregates. Kresic et al. (Kresic, Lelas, Jambrak, Herceg, &

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Nomenclature

α-LB	α-lactalbumin
β-LG	β-lactoglobulin
BSA	Bovine serum albumin
C_p	Specific heat capacity of the medium at constant pressure, expressed in J g^{-1} K^{-1}
Δ $\%T_{600nm}$	Change in transmittance
DSC	Differential scanning calorimeter
ΔH	Enthalpy, J/g
dT/dt	Increase in temperature during HIU expressed in K/min
NTC	No temperature control
M	Mass, g
P	Acoustic power, W
US	Power ultrasound
$\%T_{600nm}$	Percentage of transmittance
T_{on}	Onset temperatures, °C
T_p	Peak temperatures, °C
Y	Heat flow, W/g

Brncic, 2008) showed an increase in water solubility of whey proteins treated with US. They suggested that US enhanced protein solubility by changing protein conformation. Jambrak et al. (Jambrak, Mason, Lelas, Herceg, & Herceg, 2008) evaluated the effect of US on the solubility and foaming properties of whey protein suspensions. They found that both functional properties were improved when US was used and that these effects were dependant on the acoustic frequency used: higher frequencies (40 kHz) were not as efficient as lower ones (20 kHz). Stathopulos et al. (Stathopulos et al., 2004), Villamiel and de Jong (2000), and Karki et al. (Karki et al., 2009) reported conformational changes in US treated proteins. The first group of researchers reported the formation of aggregates with high beta sheet content in non-dairy proteins such as myoglobin and lysozyme. The second group of researchers found denaturation of whey proteins when US, in combination with heat, was applied to milk. The third group of researchers found that US resulted in slight negative changes in soy protein functionality which they attributed to changes in the native state of the major proteins.

Most of the research described above was performed in model systems consisting of whey protein suspensions prepared from a whey protein isolate and/or concentrate. The objective of this research was to evaluate the effect of US on the turbidity of whey suspensions taken at different points along a whey production line. The influence of power level (0, 3 and 15 W) as well as temperature (20 °C, 60 °C and no temperature control) on the turbidity of whey samples at four different points compared to non-treated samples was determined. In addition differential scanning calorimetry (DSC) and SDS-PAGE were conducted to add further information on the effects of US on whey solutions.

2. Materials and methods

2.1. Samples

Liquid whey samples from a whey production line were obtained from Glanbia Foods Inc. (Twin Falls, ID). Four liquid whey samples (A, B, C, and D) were collected from the whey stream as shown in Fig. 1. Samples differed in their solid (6.9, 20.1, 28.2 and 30.2%) and protein content (13.5, 15.0, 35.6, and 88.0, respectively). Samples were transported refrigerated to Utah State University and immediately frozen upon arrival. Solid and protein contents of the samples were determined as described below.

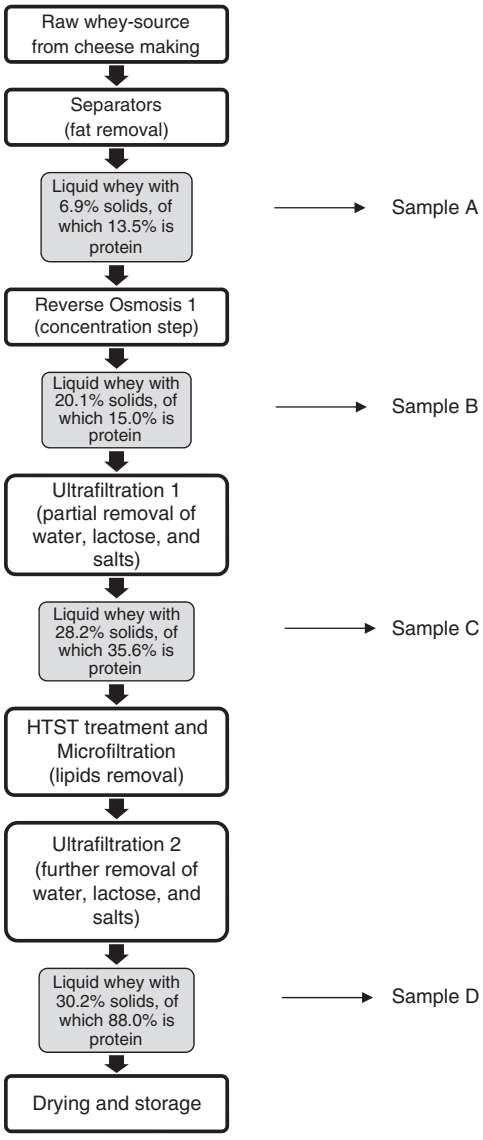

Fig. 1. Schematic flow diagram of a liquid when production line that indicate where the samples (A, B, C, and D) were taken from.

2.2. Solid and protein content

For solid content determination, 1 ml of each sample (A, B, C, and D) was measured into a weighing pan, and heated in a 68 °C oven for 3 days. Weight measurements were taken at 48 and 72 h to ensure that samples were dry, as evidenced by no change in weight between these two time points. Protein content was determined using a Thermo Scientific Modified Lowry Protein Assay Kit (Waltham, MA) with bovine serum albumin (BSA) as the standard. One percent solid matter suspensions were prepared using deionized water (pH 7.0). Samples were vortexed to ensure a homogenous suspension and were further diluted with water to the mg/ml range. Diluted samples were used to determine protein content based on the BSA standard curve according the manufacturer's protocol.

2.3. Ultrasound treatment

Fifty milliliters of each sample was used for the US treatment. A 3.2 mm titanium microtip was used for US application using a Misonix Sonicator 3000 (Misonix Inc., NY) with a maximum output power of 600 W. Three power treatments were used on each sample: no power