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Manufacture of modified milk protein concentrate utilizing injection of carbon dioxide

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ABSTRACT

Dried milk protein concentrate is produced from skim milk using a combination of processes such as ultrafiltration (UF), evaporation or nanofiltration, and spray drying. It is well established that dried milk protein concentrate (MPC) that contains 80% (MPC80) and greater protein content (relative to dry matter) can lose solubility during storage as a result of protein–protein interactions and formation of insoluble complexes. Previous studies have shown that partial replacement of calcium with sodium improves MPC80 functionality and prevents the loss in solubility during storage. Those studies have used pH adjustment with the addition of acids, addition of monovalent salts, or ion exchange treatment of UF retentate. The objective of this study was to use carbon dioxide to produce MPC80 with improved functionality. In this study, reduced-calcium MPC80 (RCMPC) was produced from skim milk that was subjected to injection of 2,200 ppm of CO_2 before UF, along with additional CO_2 injection at a flow rate of 1.5 to 2 L/min during UF. A control MPC80 (CtrlMPC) was also produced from the same lot of skim milk without injection of CO_2. The above processes were replicated 3 times, using different lots of skim milk for each replication. All the UF retentates were spray dried using a pilot-scale dryer. Skim milk and UF retentates were tested for ζ-potential (net negative charge), particle size, and viscosity. All the MPC were stored at room (22 ± 1°C) and elevated (40°C) temperatures for 6 mo. Solubility was measured by dissolving the dried MPC in water at 22°C and at 10°C (cold solubility). Injection of CO_2 and the resultant solubilization of calcium phosphate had a significant effect on UF performance, resulting in 10 and 20% loss in initial and average flux, respectively. Processing of skim milk with injection of CO_2 also resulted in higher irreversible fouling resistances. Compared with control, the reduced-calcium MPC had 28 and 34% less ash and calcium, respectively. Injection of CO_2 resulted in a significant decrease in ζ-potential and a significant increase in the size of the casein micelle. Moreover, RCMPC had a significantly higher solubility after storage at room temperature and at elevated temperature. This study demonstrates that MPC80 with a reduced calcium and mineral content can be produced with injection of CO_2 before and during UF of skim milk.
Key words: milk protein concentrate, carbon dioxide, ultrafiltration

INTRODUCTION

Ultrafiltration is a membrane separation technology that was introduced in dairy processing in the early 1970s. Ultrafiltration uses a semi-permeable membrane to fractionate components in milk based on their size (Huffman and Harper, 1999; Muthukumarappan and Marella, 2010). It has been extensively used by the dairy industry to produce a variety of dairy ingredients, including protein concentrates from cheese whey (Renner and Abd El-Salam, 1991; Marella, 2009) and milk (Jimenez-Flores and Kosikowski, 1986; Patel et al., 1991), fractionation of cheese whey proteins (Etzel and Chiu, 1997; Muller et al., 2003; Mehra and Kelley, 2004; Marella et al., 2011), and harvesting milk minerals from dairy co-product streams (Vyas and Tong, 2003; Mealy et al., 2013).

In production of milk protein concentrate with 80% protein (**MPC80**), skim milk is subjected to UF and diafiltration (**DF**). This process produces a liquid concentrate that is partially delactosed and high in protein. This liquid concentrate is further concentrated and spray dried to obtain MPC80 powder. During UF, water, lactose, NPN, and some soluble salts pass through the membrane and are collected in the permeate. Higher-molecular-weight constituents such as caseins, whey proteins, and some minerals are concentrated in the retentate stream (Jimenez-Flores and Kosikowski, 1986). The ratio of the volume of the milk to the volume of concentrate obtained during UF is known as volume reduction (**VR**). In a typical UF process, pasteurized skim milk is concentrated to a final volume of one-fifth to one-eighth of the volume of the original skim milk

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(VR of 5–8) to produce MPC that has 65 to 75% protein relative to total solids. For the production of MPC with higher protein content (protein content of 80% and above) relative to solids, DF is used in conjunction with the UF process. Diafiltration is the process of adding water to the product during UF and subsequent removal of it. Diafiltration removes additional lactose and soluble salts, thereby increasing the relative concentration of protein to total solids. As an example, in a typical manufacturing process, MPC with 80% protein relative to total solids is produced with a volume reduction of 5 with a DF level of 20 to 40% (based on volume of skim milk). This process produces a liquid MPC80 with 20 to 22% solids, and a protein:solids ratio of 80. The liquid concentrate obtained is typically further concentrated by nanofiltration before it is spray dried.

Several researchers have conducted extensive studies on the solubility of commercially available MPC powders and have reported poor solubility for MPC80 powders after extended storage (de Castro-Morel and Harper, 2002; Sikand et al., 2011; Udabage et al., 2012). Poor solubility of MPC80 can lead to nugget formation during cheese making (Bhaskar et al., 2007), bar hardening in high-protein bars (Imtiaz et al., 2012), and settling of insoluble material when used in drink mixes (personal communications with MPC80 customers). Previous research has demonstrated that processing and storage conditions affect physicochemical interactions among the proteins, salts, and sugars, and can affect the solubility of MPC80. The physicochemical interactions that have been shown to affect the functional properties of MPCs include casein–casein and casein–whey protein interactions (McKenna, 2000; Anema et al., 2006; Havea, 2006); hydrophobic association of casein micelles (Havea, 2006); formation of disulfide-linked β-LG and casein complexes (Kameswaran and Smith, 1999; Anema et al., 2006); sulfhydryl–disulfide interchange reactions, and hydrophobic interactions among the proteins (Mao et al., 2012); lactosylation, deamidation, and protein cross-linking (Le et al., 2012); and formation of a thin crust of fused casein micelles on the surface of powder particles (Fyfe et al., 2011). Several of these studies have shown a strong correlation between solubility of MPC80 and their Ca content (Bhaskar et al., 2007; Sikand et al., 2011, 2013; Ye, 2011) and it is theorized that Ca present in MPC may be promoting protein–protein interactions during processing as well as storage.

To improve the functionality of MPC80, several researchers have developed new manufacturing processes that have focused on (1) application of physical treatments to the liquid concentrate before spray drying or to final dried MPC; or (2) process modifications that produce MPC with a modified mineral profile. Banach et al. (2013) studied the effect of low- and high-shear extrusion and low-temperature toasting of MPC80 powders on the functional properties of the resultant modified MPC. Both of these treatments result in a decrease in solubility, hydrophobicity, and water-holding capacity. High-pressure homogenization (Augustin et al., 2012; Udabage et al., 2012), extrusion-porosification (Bouvier et al., 2013), microfluidization, and ultrasonication (Augustin et al., 2012) of liquid concentrates before spray drying have been reported to improve the solubility of MPC. Partial disintegration of casein micelle due to these high shear treatments and the resultant high level of nonmicellar casein is thought to cause the improved solubility (Udabage et al., 2012). Mao et al. (2012) and Sikand et al. (2013) developed a novel process to produce mineral modified MPC80 utilizing DF with different levels of monovalent salts added to the DF water. The mineral modified MPC80 produced from this process exhibited modified functionality with higher solubility compared with conventionally produced MPC80. Dybing et al. (2007) and Bhaskar et al. (2007) used a cation-exchange process to replace divalent ions, especially calcium, and reported improved functional properties for the resultant calcium-depleted MPC.

The modified functionality resulting from partial demineralization of MPC may be a result of protein disaggregation that occurs when calcium phosphate is removed from the casein micelle. A new approach that may be applicable for production of partially demineralized MPC is the injection of CO_2 before and during UF. Injection of CO_2 into milk has been extensively studied, and it is widely used to increase the shelf life of raw milk (King and Mabbitt, 1982; Law and Mabbitt, 1983; Werner and Hotchkiss, 2006) and pasteurized milk (Ma and Barbano, 2003; Hotchkiss et al., 2006). Previous research has demonstrated that CO_2 injection of cheese milk before rennet coagulation can be used to reduce the pH of milk and solubilize micellar calcium phosphate, which modifies the mineral profile of cheese produced from concentrated milk (Nelson et al., 2004). In a similar fashion, CO_2 injection could be used to reduce the pH of milk and solubilize micellar calcium and phosphate before and during UF to produce MPC with reduced calcium and mineral content. Additionally, when CO_2 is used as an acidulant, residual CO_2 can easily be removed by heating or applying vacuum, whereas other acidulants such as organic acids cannot easily be removed.

The overall objective of this research was to use injection of CO_2 before and during UF of skim milk and to determine the effect of CO_2 injection on the mineral content, casein particle size, ζ-potential, membrane performance, and solubility of MPC80.