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Effects of milk heat treatment and solvent composition on physicochemical and selected functional characteristics of milk protein concentrate

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ABSTRACT

Milk protein concentrate (MPC) powders (~81% protein) were made from skim milk that was heat treated at 72°C for 15 s (LHMPC) or 85°C for 30 s (MHMPC). The MPC powder was manufactured by ultrafiltration and diafiltration of skim milk at 50°C followed by spray drying. The MPC dispersions (4.02% true protein) were prepared by reconstituting the LHMPC and MHMPC powders in distilled water ($LHMPC_w$ and $MHMPC_w$, respectively) or milk permeate ($LHMPC_p$ and $MHMPC_p$, respectively). Increasing milk heat treatment increased the level of whey protein denaturation (from ~5 to 47% of total whey protein) and reduced the concentrations of serum protein, serum calcium, and ionic calcium. These changes were paralleled by impaired rennet-induced coagulability of the $MHMPC_w$ and $MHMPC_p$ dispersions and a reduction in the pH of maximum heat stability of $MHMPC_p$ from pH 6.9 to 6.8. For both the LHMPC and MHMPC dispersions, the use of permeate instead of water enhanced ethanol stability at pH 6.6 to 7.0, impaired rennet gelation, and changed the heat coagulation time and pH profile from type A to type B. Increasing the severity of milk heat treatment during MPC manufacture and the use of permeate instead of water led to significant reductions in the viscosity of stirred yogurt prepared by starter-induced acidification of the MPC dispersions. The current study clearly highlights how the functionality of protein dispersions prepared by reconstitution of high-protein MPC powders may be modulated by the heat treatment of the skim milk during manufacture of the MPC and the composition of the solvent used for reconstitution.

Key words: milk protein concentrate, milk heat treatment, solvent composition, functionality

INTRODUCTION

Developments in membrane filtration of milk since the 1970s have led to the availability of a range of high-protein powders, including milk protein concentrates (**MPC**), micellar caseins, whey protein concentrates and isolates, and α-LA. Milk protein concentrates with high protein content (e.g., ≥80%) are prepared by concentration of milk protein (casein and whey protein) using UF and diafiltration (**DF**) of the resultant retentate to dilute out most of the milk serum and its solids components, including lactose, soluble salts, and nonprotein nitrogen (**NPN**). Huppertz and Gazi (2015) reported that the level of denaturation of β-LG in commercial MPC powders varies from approximately 20 to 80% of total, indicating that the milk heat treatment applied during MPC manufacture varies extensively.

Milk protein concentrates are used extensively in food manufacture and formulation, with applications including dairy-based beverages, yogurt, fresh cheese products, recombined milk cheeses, ice cream, coffee whitener, high-protein bars, and alcoholic dairy beverages. During food formulation, MPC is exposed to environments differing substantially in TS content, the types and levels of ingredients, the composition of the solvent phase (e.g., ionic strength, pH, sugar content), and processing conditions (e.g., heat, acidification, rennet gelation, addition of ethanol). Nevertheless, MPC must provide the requisite functionalities or combinations thereof, including emulsification, gelation, foaming, heat stability, or nutritive value (Patel and Patel, 2014; Ikeda, 2015). High-protein MPC powders are more functional than other ingredients, such as skim milk powder or whey protein concentrates, in many applications owing to the combined functionalities of both casein and whey protein, their neutral flavor (e.g., compared with sodium caseinate), and their low lactose content (<3%). Lactose is a nonfunctional ingredient (i.e., inert carbohydrate filler) in many formulations, and high levels increase formulation cost, the risk of crystal formation in products such as ice cream, and browning in products subjected to high-temperature

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conditions during manufacture (e.g., ultra-high-heat treated products) or food service (e.g., formulated foods that are baked or grilled).

Several recent studies have reported the effects of manufacturing conditions on the functionality of high-protein MPC, including heat treatment of the skim milk before UF (Crowley et al., 2015; Gazi and Huppertz, 2015), alteration of calcium (Ca) content by preacidification of the skim milk before UF or DF (Luo et al., 2016; Eshpari et al., 2017), lowering the temperature of the milk during UF (Luo et al., 2015), addition of NaCl (Mao et al., 2012) or calcium-chelating salts to the skim milk (Ramchandran et al., 2017) before UF or the retentate before DF (Bhaskar et al., 2001; Guinee et al., 2009), and high-pressure treatment of the skim milk before UF (Udabage et al., 2012). Increasing the severity of milk heat treatment from 72°C for 15 s to 95°C for 45 s led to denaturation of 65% of total β-LG and 25% of total α-LA (Gazi and Huppertz, 2015) but had little effect on the heat coagulation time (**HCT**) of aqueous dispersions of the MPC (8.5% protein) at 120°C in the pH range 6.3 to 7.1 (Crowley et al., 2015).

The effect of solvent quality on the functionality of dispersions prepared from high-protein MPC has also been investigated. Crowley et al. (2014) evaluated the effect of substituting water with simulated milk ultrafiltrate (**SMUF**) or SMUF with lactose (4.6%) and urea (30 mg/100 g) on the HCT of protein dispersions (3.5%) prepared from low-heat MPC with 80% protein (wt/wt). The HCT of a water-based dispersion of MPC with 80% protein (3.5% protein) at 140°C remained very low (<2 min) at pH 6.3 to 6.9 and then increased as the pH was further increased to 7.2. The use of SMUF or SMUF with lactose instead of water introduced a maximum HCT at pH 6.7 to 6.8. However, cold dialysis of the water-based dispersion against reconstituted skim milk resulted in a type A HCT versus pH profile with a maximum HCT at 6.9 and minimum HCT at pH 7.1. There are 2 types of HCT versus pH profiles for bovine milk: type A, which is the most common and is characterized by a maximum HCT at pH 6.6 to 6.7 and a minimum HCT at pH 6.8 to 7.0, and type B, for which HCT increases progressively with pH increases in the range of 6.2 to 7.2 (O'Connell and Fox, 2003). Eshpari et al. (2015, 2017) altered the solvent composition of protein dispersions (3.2% protein) prepared from standard- or reduced-Ca MPC with protein content ≥80% by overnight dialysis against skim milk at 4°C. The pH of the nondialyzed standard-Ca and reduced-Ca samples was 7.1 and 6.68, respectively, whereas that of the corresponding dialyzed standard-Ca and reduced-Ca samples was 6.65 and 6.65, respectively. Dialysis increased the concentrations of nonsedimentable protein and Ca of both the standard-Ca and reduced-Ca dispersions, the HCT of the reduced-Ca dispersion, and the storage modulus (**G′**) of the rennet-treated standard-Ca dispersion. Meletharayil et al. (2016) studied the effects of increasing lactose content (~0.3, 5.6, and 11.2%, wt/wt) on the glucono-δ-lactone-induced gelation of 4% protein dispersions prepared from low-heat MPC with 80% protein. Increasing lactose content from 0.3 to 11.2% coincided with increases in the pH at onset of gelation (from pH ~5.35 to 5.55) and G′ at pH 4.6 (from ~340 to 460 Pa) and a reduction in the level of expressible serum (whey) on centrifugation at 3,000 × *g* (from 67 to 36 g/100 g).

To our knowledge, there is no comprehensive study on the combined effects of milk heat treatment and solvent composition on the functionality of MPC dispersions. The objectives of the current study were to investigate the effects of milk heat treatment (72°C for 15 s or 85°C for 30 s) during the manufacture of MPC powder and the solvent (water or milk permeate) used for reconstitution of the MPC powder on the composition, physicochemical, and key functional characteristics of the resultant MPC protein dispersions (4% true protein). Commercially, water and milk permeate are commonly used solvents in formulated food products.

MATERIALS AND METHODS

Manufacture of Low- and Medium-Heat MPC

The MPC was produced in the Bio Functional Food Engineering pilot plant unit of Moorepark Technology Limited (Teagasc, Moorepark, Fermoy, Co. Cork). Milk was separated at 55°C (Westfalia model MM1254 separator, Westphalia, Germany). Skim milk (~800 L) was split into 2 portions (~400 L); one was used for the manufacture of low-heat MPC (**LHMPC**), and the other for the manufacture of medium-heat MPC (**MHMPC**). Milk was pasteurized at 72°C for 15 s using a plate heat exchanger (APV Pasilac SSP pilot plant, APV DK 8600, Silkeborg, Denmark) for LHMPC or at 85°C for 30 s using a pilot-scale tubular heat exchanger (MicroThermics, Raleigh, NC) for MHMPC.

The pasteurized skim milk was UF at 50°C (10 kDa; total membrane area: 27 m^2; ST28 3838 UF membrane; Synder Filtration, Vacaville, CA) to 21% TS. The resultant retentate was diluted with deionized water (50°C) at a retentate:water weight ratio of 1:1, diafiltered to 21% TS using UF at 50°C, and spray dried (Anhydro spray dryer, SPX Flow Technology Danmark A/S, Soeborg, Denmark) using nozzle atomization at inlet and outlet air temperatures of 180 and 85°C, respectively. The LHMPC and MHMPC powders (~4 kg of each type) were packed in silver aluminum bags and stored at 15°C until they were used for analysis. Both LHMPC