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Rehydration characteristics of milk protein concentrate powders

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ABSTRACT

Low-(MPC35, MPC50), medium-(MPC60, MPC70) and high-(MPC80, MPC85, MPC90) protein content milk protein concentrate (MPC) powders, manufactured at pilot-scale, were evaluated for their rehydration characteristics. Optical tensiometry confirmed that water droplets were imbibed more slowly as protein content of the MPCs increased, indicating impaired wetting. Casein micelles comprised only <2% of the particle population by volume in MPC70, MPC80, MPC85 or MPC90 after 90 min of rehydration at 25 °C, as primary particles which had not dispersed fully remained in suspension. The quantity of sediment, measured using analytical centrifugation, increased in the order MPC70 < MPC80 < MPC85 < MPC90 after 90 min of rehydration at 25 °C, with lower protein MPCs forming no sediment. No sediment formation was observed in any of the MPCs after 24 h of rehydration at 25 °C, despite the predominance of primary particles in suspensions of high-protein MPCs. Increasing the temperature of reconstitution from 25 to 50 °C during 90 min of rehydration caused a 41.4% decrease in sediment height for MPC90 in water; however, reductions in sediment height of 89.9% and 99.5% were achieved when MPC90 was rehydrated in milk permeate or 80 mM KCl, respectively. It is evident that low ionic strength (confirmed using conductimetry) has a strong negative effect on the rehydration properties of high-protein MPCs, and that the synergistic effect of increasing ionic strength and temperature can substantially accelerate rehydration.

1. Introduction

Complete rehydration is normally a prerequisite for effective expression of a dried protein ingredient's underlying functionality. Dairy powders which are both high in protein and casein-dominant are difficult to reconstitute fully, even after extended periods of rehydration, due to inhibited transfer of water into powder particles (Schuck et al., 2007) and slow dispersion of a "skin" of casein micelles present at particle surfaces (Mimouni et al., 2009). Milk protein concentrates (MPCs) are one such category of dairy ingredient, the poor reconstitution properties of which require end-users to modify existing unit operations or product formulations so that powder rehydration may be accelerated.

Anema et al. (2006) identified caseins as the primary components in the poorly-dispersible particle population in MPC85. Mimouni et al. (2009) proposed that the rate-limiting step during the rehydration of MPC85 was the dispersion of inter-linked casein micelles predominating at the surface of primary particles, which preceded the subsequent release of colloidal material (i.e., casein micelles and associated minerals). Numerous studies have confirmed that slow dispersion of primary particles is responsible for the extended rehydration times of casein-dominant powders (Gaiani et al., 2005; Fang et al., 2011; Richard et al., 2013), an effect which, perhaps counter intuitively, becomes more pronounced when these powders are agglomerated (Gaiani et al., 2005; Schuck et al., 2007).

According to Mimouni et al. (2010b), the surface of slowly-dispersing primary particles in MPC85 was sufficiently porous to allow water to be imbibed rapidly, with a subsequent fast release of whey proteins, serum-phase minerals and lactose, while the release of casein micelles and associated minerals was retarded. In support of this, the addition of "fast-dissolving" components, such as NaCl (Schuck et al., 2002) or whey proteins (Gaiani et al., 2007), has been shown to improve the rehydration properties of micellar casein isolate (MCI) powders. However, increasing the size and number of pores in MPC powder particles through extrusion-porosification also markedly enhanced rehydration properties (Bouvier et al., 2013). The latter result suggests that, while not being the rate-limiting stage in itself, slow penetration of water into primary particles may contribute strongly to the poor rehydration properties of casein-dominant powders; ultrasound attenuation measurements support this, with Richard et al. (2012) reporting delayed air release from vacuoles within primary particles in MCI powder.

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Table 1
Compositional and physical properties of milk protein concentrate (MPC) powders. All data are presented as the means of duplicate analysis, except for lactose, which was the result of a single analysis.[a]

	Composition				Physical properties	
	Protein (%, w/w)	Lactose (%, w/w)	Ash (%, w/w)	Fat (%, w/w)	d_{50} [b] (μm)	Tapped density (g cm^{-3})
MPC35	35.4	49.6	8.06	0.5	35.3	0.56
MPC50	49.9	35.8	7.75	0.8	43.0	0.59
MPC60	60.8	24.5	7.74	1.5	48.9	0.54
MPC70	68.3	18.0	7.99	1.2	39.6	0.49
MPC80	79.1	6.36	7.69	1.7	27.9	0.30
MPC85	84.0	1.81	7.54	1.2	26.1	0.29
MPC90	85.9	0.37	7.59	1.6	26.8	0.29

[a] Adapted from Crowley et al. (2014a).
[b] Particle size below which 50% of material volume exists – median.

Previous studies have confirmed that a poorly-dispersible casein fraction is responsible for the slow rehydration of MPC powders containing ⩾80% protein, and that this phenomenon is exacerbated during storage, particularly at elevated temperature and/or relative humidity (Mimouni et al., 2010a). MPCs, however, comprise a broad product category, spanning low-, intermediate- and high-protein powders, the entire breadth of which has not been researched extensively. In addition, classical definitions or determinants of solubility, relevant to skim or whole milk powders and whey powders, do not account completely for the rehydration-state of MPCs; thus, there is a need to expand the criteria against which the performances of MPCs during reconstitution are assessed. This study utilised an integrated experimental approach, including measurement of changes in contact angle, conductivity and particle size distribution over time, in addition to measuring sedimentation behaviour using analytical centrifugation, to characterise the rehydration properties (i.e., wetting, mineral release, dispersion) of MPC powders across a range of protein concentrations (from MPC35, close in composition to skim milk powder, to MPC90, effectively a milk protein isolate). The effect of temperature and additives (deionised water, milk permeate, calcium-binder, non-ionic surfactant or monovalent ions, at 25 or 50 °C) on the sedimentation behaviour of MPC90 was also investigated, to develop an understanding of the mechanism dictating its dispersion characteristics and potential strategies to ameliorate same.

2. Materials and methods

2.1. Milk protein concentrate powders: processing, composition and physical properties

The manufacture and composition of the MPC powders used in this study were described in detail by Crowley et al. (2014a, b). Briefly, fresh bovine milk was skimmed and pasteurised followed by ultrafiltration (MPC50, MPC60) or combined ultrafiltration and diafiltration (MPC70, MPC80, MPC85, MPC90) of milk to different protein concentration factors at 50 °C with 10 kDa molecular weight cut-off membranes; MPC35 was not subjected to membrane filtration. MPC35, MPC50, MPC60 and MPC70 were evaporated to increase total solids content of the retentates prior to spray drying, while MPC80, MPC85 and MPC90 were not evaporated. All MPCs were spray-dried in a single-stage drier with nozzle atomisation, an air inlet temperature of 185–190 °C, and an outlet temperature of 85–90 °C. Selected compositional and physical characteristics (based on relevance to rehydration properties) of each MPC powder were analysed as per Crowley et al. (2014a, b) and are shown in adapted form in Table 1. Light microscopy images of particles in MPC powders were also captured at 40× magnification with a light microscope after dispersing powders in paraffin oil.

2.2. Wetting: optical tensiometry

Contact angle (θ) was measured using an optical tensiometer (PocketGoniometer PGX®, Plasmatreat Ltd., Bicester, UK) using the Sessile drop technique and the dynamic measurement option at ~22 °C, with a measurement time of 5 s and a deionised water droplet volume of 5.26 ± 0.43 μL. Measurement of θ was carried out on discs of MPC powder with a diameter of 13 mm, prepared by a Specac® hydraulic compressor (Perkin Elmer, Buckinghamshire, UK), using a fill height of 1 mm and a compression force of 8000 kg. Values of θ were collected every second for 5 s, and images were extracted from the PGX software at 0, 3 and 5 s intervals.

2.3. Powder rehydration

Powders were added to 300 mL of deionised water in 400 mL beakers to attain 1.5% (w/v) protein suspensions. In some analytical centrifugation experiments (see Section 2.6), deionised water was replaced with milk permeate (Carbery, Ballineen, Co. Cork, Ireland), or solutions of KCl, tri-sodium citrate, or polysorbate 80 (Sigma Chemical Co., St Louis, Missouri, MO, USA), all with a theoretical ionic strength of 80 mM. For dynamic analysis of conductivity over 90 min, MPC suspensions were stirred at controlled temperature (25 °C) using an overhead stirrer, with a four-impeller design, and an impeller length of 2 cm, operated at 2025 rpm with no vortex formation in the turbulent regime (Re > 10,000). MPC suspensions rehydrated for 90 min for single-point measurement of particle size distribution (PSD) and sedimentation were stirred magnetically under conditions of controlled temperature (25 °C); the magnetic stirring bar had a length of 2.5 cm, and was operated at 500 rpm with no vortex formation in the turbulent regime (Re > 10,000). MPC suspensions rehydrated over 24 h were first stirred magnetically for 8 h at 25 °C, after which samples were stirred at ambient temperature (22 °C) for the remaining 16 h. Reported stirring rates were selected to achieve a turbulent regime (non-limiting hydrodynamics) without vortex formation (to prevent excessive aeration). Wetted powder adhering to the internal walls of the beaker, when observed, was removed by gentle washing using a Pasteur pipette filled with the solution being studied. Rehydration experiments for each MPC powder were conducted at least in duplicate.

2.4. Mineral release/ionic strength: conductivity

Conductivity was measured using a Titrando autotitrator, equipped with a five-ring conductivity measuring cell and accompanying Tiamo v2.3 software (Metrohm Ireland Ltd, Athy Road, Co. Carlow, Ireland). The probe was calibrated at 25 °C with a KCl solution of known conductivity (12.9 mS cm^{-1}). Sufficient time (1 min)