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Effect of hydrolyzed whey protein on surface morphology, water sorption, and glass transition temperature of a model infant formula

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ABSTRACT

Physical properties of spray-dried dairy powders depend on their composition and physical characteristics. This study investigated the effect of hydrolyzed whey protein on the microstructure and physical stability of dried model infant formula. Model infant formulas were produced containing either intact (DH 0) or hydrolyzed (DH 12) whey protein, where DH = degree of hydrolysis (%). Before spray drying, apparent viscosities of liquid feeds (at 55°C) at a shear rate of 500 s^{-1} were 3.02 and 3.85 mPa·s for intact and hydrolyzed infant formulas, respectively. On reconstitution, powders with hydrolyzed whey protein had a significantly higher fat globule size and lower emulsion stability than intact whey protein powder. Lactose crystallization in powders occurred at higher relative humidity for hydrolyzed formula. The Guggenheim-Anderson-de Boer equation, fitted to sorption isotherms, showed increased monolayer moisture when intact protein was present. As expected, glass transition decreased significantly with increasing water content. Partial hydrolysis of whey protein in model infant formula resulted in altered powder particle surface morphology, lactose crystallization properties, and storage stability.
Key words: hydrolyzed whey, infant formula, sorption isotherms, storage stability, surface morphology

INTRODUCTION

Whey protein hydrolysates (**WPH**) and whey protein isolates (**WPI**) are widely used sources of protein in the food industry, for example, in performance foods and infant milk formula (**IMF**). The IMF industry uses WPI and WPH, the latter being used for ease of digestion in infant comfort foods. Whey protein hydrolysates are used in the nutritional management of individuals unable to digest intact protein, providing complete nutritional requirements with positive health benefits. They have lower molecular mass and less secondary structure than WPI (Chobert et al., 1988).

Proteins play an important role in the stabilization of oil-in-water emulsions in IMF (Damodaran, 2005; McCarthy et al., 2012). Because proteins are incorporated into spray-dried food systems, it is of interest to study the effects of processing on the physical properties of resulting powders, especially in relation to storage stability and rehydration. Physicochemical changes in food powders have been related to their glass transition temperature ($\mathbf{T_g}$; Roos, 1995; McCarthy et al., 2013). For example, powders with low T_g, caused by increased moisture content, may exhibit accelerated deteriorative changes such as stickiness, caking, cohesion, and sugar crystallization.

Lactose, due to its hygroscopic nature, can readily absorb moisture, which may lead to deteriorative reactions (e.g., caking, cohesion, and crystallization) in milk powders. Previous work has explored the effects of milk proteins on the physical behavior of lactose in dairy powders (Haque and Roos, 2004; Hogan and O'Callaghan, 2010; Murphy et al., 2015). It has been shown that, as the protein:lactose ratio increases, there is a concomitant increase in T_g, making high-protein:lactose ratio powders more resistant to stickiness and crystallization (Thomas et al., 2004; McCarthy et al., 2013; Kelly et al., 2015). Netto et al. (1998) reported that the T_g of pure protein hydrolysates depends on the source of protein, for example, casein or whey protein, as well as the degree of hydrolysis (**DH**), and suggested that proteins may be equally as important as sugars in altering T_g. Mounsey et al. (2012) reported that stickiness of hydrolyzed sodium caseinate-lactose mixtures was affected by protein hydrolysis: intact sodium caseinate-lactose mixture was less susceptible to sticking compared with powders with hydrolyzed sodium caseinate-lactose, with the extent of protein hydrolysis having no significant effect on the stickiness behavior.

Hogan and O'Callaghan (2013) studied the effect of varying the DH of whey protein in protein-lactose dispersions and concluded that as DH percentage in-

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creased, hygroscopicity increased and crystallization was delayed. Recently, Murphy et al. (2015) examined the effect of partially and selectively hydrolyzed (in which β-LG was selectively hydrolyzed) proteins within a model infant formula and concluded that selectively hydrolyzed milk proteins may be successfully used to produce IMF powders with good physical characteristics. Protein ingredients require good solubility, emulsification capacity, and thermal stability when used in IMF. Stable emulsions are required to minimize surface free fat during manufacture of IMF and protect against creaming in reconstituted IMF products.

The majority of studies on hydrolyzed proteins in IMF have focused on nutritional and allergenic aspects rather than functional characteristics such as emulsification and viscosity. The significance of protein content on IMF emulsion stability has recently been reported (McCarthy et al., 2012, 2013; Murphy et al., 2015).

The objective of the present study was to compare the effects of hydrolyzed whey (12% DH) compared with intact whey on the stability of model infant milk formula emulsions during processing, and also on physicochemical properties in the resultant powders. To determine emulsion stability, emulsion fat globule size (**FGS**) and viscosity were evaluated systematically throughout processing and reconstitution (i.e., post-homogenization, spray drying, and reconstitution). Stability of spray-dried powder was examined in relation to relative humidity (**RH**).

MATERIALS AND METHODS

Materials

Intact whey protein concentrate (80% protein by weight) and hydrolyzed whey protein concentrate (80% protein by weight) with a DH value of 12% were purchased from Carbery Ingredients Ltd. (Ballineen, Co. Cork, Ireland). According to the supplier, the WPH had an average molecular weight of 5.84 kDa, with more than 70% being >5 kDa. Edible-grade α-lactose monohydrate was obtained from Glanbia Ingredients (Ballyraggett, Co. Kilkenny, Ireland), sunflower oil was purchased from Trilby Trading (Drogheda, Co. Louth, Ireland), and skim milk powder (**SMP**; consisting of intact casein and whey protein, 80:20 ratio) was purchased from Dairygold Food Ingredients (Mitchelstown, Co. Cork, Ireland).

Preparation of IMF Powders

Emulsions consisting of 11.8% (wt/wt) lactose, 2.5% (wt/wt) protein (whey:casein 60:40), and 5.7% (wt/wt) oil were prepared (20% wt/wt total solids). Batches (15 kg) were produced as follows. Lactose powder was dissolved in preheated water (~70°C), using a Silverson L4RT (Silverson Machines Ltd., Waterside, Chesham, UK) mixer to aid reconstitution. Approximately 10% of the total fat was added to the batch to reduce foaming before addition of protein. The SMP was then added slowly, followed by whey protein, before addition of the remaining fat. The batches were tempered at 60°C and adjusted to pH 6.9 by adding 2 *M* KOH and kept under high shear for 30 min to ensure complete hydration of the protein. The feed was subjected to heat treatment (100°C × 30 s) using a Microthermics tubular heat exchanger (model 25HV; Raleigh, NC). The coarse emulsion was then homogenized using a LAB 60 homogenizer (APV, Lübeck, Germany) using a first-stage pressure of 13.6 MPa and a second-stage pressure of 3.4 MPa. It was subsequently spray-dried in a pilot-scale Anhydro spray dryer (model Plant No. 3 type I KA, Copenhagen, Denmark), equipped with a 2-fluid nozzle atomization system (Type 1/8 JAC 316ss) and counter-flow drying. Dryer inlet temperature was held constant at 185°C and outlet temperature was 80°C.

Emulsion FGS and Powder Particle Size

Emulsion FGS was measured after homogenization and after reconstitution of powder using dynamic light scattering (Mastersizer 3000, Malvern Instruments Ltd., Malvern, UK). The optical parameters used were refractive indices of 1.46 and 1.33 for sample and dispersant, respectively, and particle absorbance of 0.001. Product was reconstituted (12.5 g/100 g) at ~40°C. The following fat globule size parameters are presented: cumulative volume diameters, $D(_V,0.1)$ and $D(_V,0.9)$, such that all globules below that size amount to 10 and 90%, respectively, of total volume of fat globules, and volume mean diameter, D[4,3], also known as the volume moment mean, determined as

$$D[4,3] = \frac{\sum d^4}{\sum d^3}.$$

Powder particle size was determined by laser light scattering using a Malvern Mastersizer 3000 with the Aero S dry powder feeder unit. The powder sample was added to the standard venturi disperser with a hopper gap of 4 mm and then fed into the dispersion system at a feed rate of 18 to 25% to keep the laser obscuration level at 1 to 6%. Compressed air at 50 kPa was used to transport and suspend the powder particles through the optical cell and a measurement time of 10 s was