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Characterization of industrial dried whey emulsions at different stages of spray-drying

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ABSTRACT

Commercial dried food emulsions, with high fat content (50 g fat /100 g), were prepared at plant scale from whey and palm oil. Five powders were analyzed: powder without fines, taken from the bottom of the spray-dryer chamber; fines 1 and fines 2 respectively collected at the bottom of the first and second cyclones, a mix of fines 1 and fines 2 and the final powder, taken during packing. Scanning electronic and optical microscopy showed only spherical particles and also indicated that fines 2 were roughly twice as smaller as other powder particles. Free fat content was significantly higher in fines than in final powder. Reconstituted emulsions (10 g powder/100 g water) were analyzed by laser light scattering. Aggregation and coalescence indexes were very low, except in reconstituted emulsions made with fines 2. This is consistent with their high free fat content and suggests that this results from processing through the cyclones.

1. Introduction

Many food products are dispersed systems of two immiscible phases: water-in-oil (w/o) emulsions such as butter or oil-in-water (o/w) emulsions such as milk or cream. One phase exists as small dispersed particulates, known as the dispersed phase (Hayati et al., 2007), the other being the continuous phase. Food oil in water emulsions are complex systems that require stabilization of the fat droplets by proteins, small-molecule surfactants (emulsifiers) and, in certain cases, polysaccharides (Dickinson, 2010). Emulsions can undergo different types of instabilities that involve changes with droplet size, such as coalescence and Oswald ripening, or instabilities that involve the spacial rearrangement of the droplets such as flocculation and creaming (Lizarraga et al., 2008). These mechanisms can lead to a destabilization of the system with total phase separation. The presence of an adsorbed protein layer at the surface of droplets is a stabilizing factor through steric and electrostatic mechanisms. Effectiveness of this kind of stabilizing layer depends on how difficult it is to displace it from the interface (Dickinson, 2010).

To increase physical and microbiological stability, and reduce transport and storage costs, liquid emulsions can be transformed into powders by spray-drying (Gharsallaoui et al., 2007; Rattes and Oliveira, 2007; Schuck, 2002). Spray drying is a major process of water removal in milk powder production. The principle is to remove water from the o/w emulsion at the lowest temperature and the shortest time possible in order to minimize heat damage toward the milk solids. This is achieved by spraying the emulsion as very fine droplets by a nozzle or a rotary atomizer into hot dry air steam at 180–220 °C (Gharsallaoui et al., 2007). Drying emulsions can only be successfully achieved if liquid emulsions contained a solid carrier, such as maltodextrins (soluble), or colloidal silica (insoluble) (Christensen et al., 2001a). Indeed, by drying, the aqueous phase is removed, leaving the solid carrier as the bulk matrix able to form the powder particles and protect the oil phase (Christensen et al., 2001b). Milk proteins are widely valued as food ingredients because of their surface-active and colloid-stabilizing properties. Adsorption of milk proteins at the lipid–water interface creates both electrostatic and steric repulsion that protects the particulates against coalescence and thus destabilization of the emulsion (Lizarraga et al., 2008). This stands for most dairy emulsions such as ice cream or dairy foams in which the presence of a thick and negatively charged layer prevents coalescence of lipid droplets (Tomas et al., 1994)). In dried dairy emulsions, the matrix protecting the fat droplets is composed of proteins and carbohydrates such as lactose (Fäldt and Bergenst/aahl, 1996a). Compared to other sugar, lactose exhibits low hydroscopicity and stickiness (Jayasundera et al., 2009). Whey is a dairy ingredient mainly composed of lactose and globular proteins such as β-lactoglobulin and α-lactalbumin, which allow it to be a solid carrier suitable to stabilize dried o/w emulsions (Písecký, 2005). According to Demetriades et al. (1997), whey proteins can help form physically stable food emulsions by forming closely packed monolayer of globular

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proteins at the interface. Moreover, Fäldt and Bergenst/aahl (1996b) demonstrated an interaction between lactose and whey proteins that prevents the emulsion droplets from coalescing during drying and redispersion.

Spray-drying is divided into three stages (Fig. 1). The liquid emulsion enters the spray-dryer chamber by its ceiling and exits at the bottom of the chamber as a powder. A proportion of the created powder is carried out by the outlet warm air because of its lightness. Then, cyclonic separation removes dry products from humid air through vortex separation, *i.e.* rotational effects and gravity. This is done through one or several cyclones placed outside the dryer in order to reduce powder losses in the air (Gharsallaoui et al., 2007). The powder going through the cyclones is called "fines". The final drying and cooling occurs in a fluidized bed where fines and powder from the end of the drying chamber converge.

Dried emulsions have to be easily dispersed when mixed with water. But the drying process can also cause some instability by adversely affecting the properties of the interfacial layer. The surface composition of a spray-dried dairy emulsion is primarily determined by the ingredients, pre-treatment process and spray-drying parameters (Vignolles et al., 2010). Even if the surface is generally dominated by proteins while fat is largely encapsulated within the particles, the types of protein, temperature and pH treatments can influence the surface composition of the powder. Those extrinsic environmental factors can actually modify the percentage of lactose, proteins and oil at the surface of spray-dried powders (Vignolles et al., 2007).

Most of the existing literature examines dairy powders with a low fat content, more particularly their surface composition. For example, Vignolles et al. (2007) reported in whole milk, that the amount of surface fat is significantly higher in the fines coming out from the second cyclone compared to powder from a spray-dryer chamber. Nevertheless, the study of dried emulsions with a high fat content (50% or more) is a topic of interest for its industrial applications. Indeed, products with 50% of fat content or more are used in order to substitute milk or butter in food applications such as cakes, creams, sauces, or even ice cream. Those milk replacers need to be stable in liquid phase and homogeneous. At present, as explained by Martinet et al. (2005), elaboration of such emulsions is still mostly empirical and frequently based on industrial know-how.

The objective of the present study is to determine to what extend can the different stages of spray-drying affect the physic-chemical characteristics and the functionality of commercial whey dried emulsions with a high fat content. This work investigates some physico-chemical properties of final products and powders collected from the spray-drying chamber, the cyclones and after the packing as well as those of the corresponding reconstituted emulsions.

Particle size, structure and free fat content of powders were determined. Reconstituted emulsions made from those powders were characterized in terms of physical stability and size distribution.

2. Materials and methods

2.1. Materials

As in the work of Kim et al. (2002, 2005, 2009), spray-dried whey emulsions were manufactured at a dairy company plant. Liquid whey from different cheese factories with a protein content of *ca.* 8 g ± 1 g per 100 g of dry weight and a lactose content of *ca.* 70 g ± 5 g per 100 g of dry weight was used. Palm oil was used as the dispersed phase. Palm oil, with a melting temperature between 36 and 42 °C, is made up of triglycerides containing mostly two fatty acid residues: palmitic acid (44%) and oleic acid (38%), respectively saturated and unsaturated. Six different batches of production were studied. As in Keowmaneechai and McClements (2002) work, raw materials vary in composition between batches and values should be taken as approximates.

2.2. Industrial process

The powders were made in the industrial-scale as follows. Whey and palm oil were mixed together to provide a final powder-fat content of 50 g/100 g. Homogenization was achieved using a Manton Gaulin type atomiser (homogenization pressure: 10–20 MPa). The liquid emulsion was atomized via a rotary atomizer in a spray-drier with a capacity of at least 3 tonnes of powders per hour (Fig. 1). Palm oil was liquid during all the process. Six different batches of the same formulation were studied right after their production.

For each production, dry emulsions at different stages of manufacture were sampled: the final powder (FP), just before packing (Fig. 1); powder without fines (PWF) collected at the end of the spray-drying chamber; fines 1 (F1), which is powder from the first cyclone; fines 2 (F2), which is powder from the second cyclone and fines 1&2 (F1&2) corresponding to a mix of fines 1 and fines 2, when they joined on a vibrating chute before meeting the PWF in the fluidized bed.

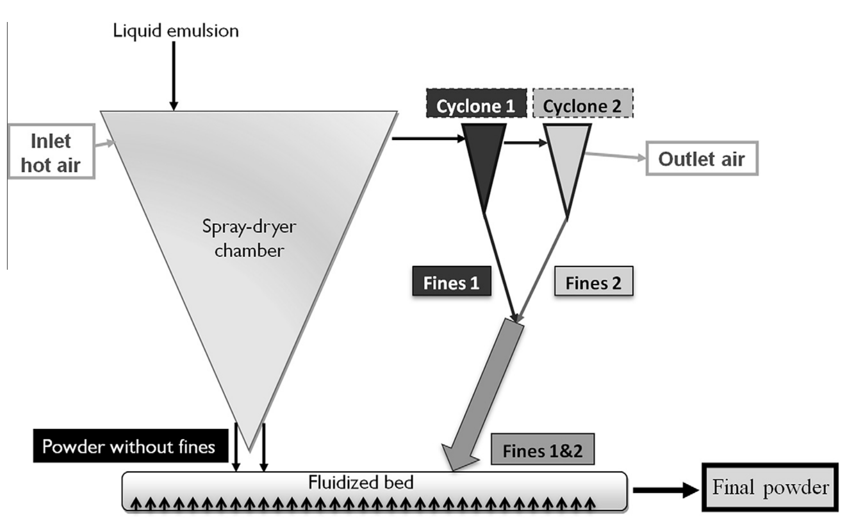

Fig. 1. Sketch of the industrial spray-drying process.