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Functionality of milk protein concentrate: Effect of spray drying temperature☆

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ABSTRACT

This study investigated the effect of spray-drying conditions on the resulting functionality of milk protein concentrate (MPC), utilizing specially produced mono-dispersed MPC particles. The particles were generated from a pilot microfluidic spray dryer at selected inlet air temperatures (77 °C, 107 °C, 155 °C and 178 °C). The solubility and extent of protein denaturation were characterized using focused beam reflectance measurement and polyacrylamide gel electrophoresis. Due to the controlled drying conditions and well-defined properties of the particles, a direct relationship between spray drying temperatures and the resultant particle functionality could be identified. The particle morphologies obtained from lower inlet air temperature appeared spherical whereas the one from higher inlet air temperature appeared deflated. The FBRM results indicated that the solubility of MPC particles deteriorated with increasing inlet air temperature with increasing protein denaturation. SDS-PAGE results suggested that the insoluble material were primarily casein rather than heat sensitive whey protein. These findings could be used to establish a better understanding of the relationship between drying conditions and MPC microstructures, and the corresponding influence on the functionality for non-traditional powder types.

1. Introduction

Recent developments of membrane filtration technology have made it possible to make specific use of different milk components [1–3]. Protein is one of the major components as well as being the most valuable of the dairy products. As such, milk products rich in protein has been customized to meet the specific requirements on nutritional and functional properties, for instance in bakery products, formulated food, ice-cream, beverages, energy drinks, and others [3–5]. Protein is a heat-sensitive material and during the spray drying process, structural and physical changes due to denaturation, aggregation of whey protein, formation of protein complexes between whey protein and caseins, could occur [6–9]. Particularly, whey protein is known to denatured easily upon heating, and is irreversible [10]. Upon heating to a high enough temperature and duration, whey protein starts to unfold, exposing the hydrophobic amino acid residues that are usually hidden deep within the proteins. These hydrophobic residues will associate with the hydrophilic environment, such as κ-casein on the micelle surface, forming aggregates [6,7,11–15]. It has been identified that there is a direct interaction between whey protein (mainly β-lactoglobulin) and casein micelles *via* the κ-casein on the micelle [6]. It has been reported that the surface of spray dried dairy particle are dominated by proteins [9,16,17] which is more pronounced when the powders are spray dried at a lower temperature [18]. Therefore, the condition of proteins on the particle surface could affect the functional behaviors such as dissolution. There is therefore a need to develop a better understanding of formation of insoluble protein as a result of different processing conditions such as drying, storage and testing conditions.

To understand the effects of storage conditions on protein interactions, McKenna conducted an intensive investigation on the formation of the insolubility material in milk protein concentrates (MPC) with different protein contents subjected to different storage durations and temperature treatments [19]. It was found that casein micelles appeared to be fused together and formed an insoluble material in a direct correlation with increasing storage duration and temperature. Protein content was also a determinant in this degradation process, with a higher protein content leading to formation of more insoluble material within shorter storage duration. Havea conducted an experiment on a batch of MPC subjected to different storage durations and investigated the protein interactions using polyacrylamide gel electrophoresis (PAGE) and transmission electron microscopy (TEM) [20]. It was observed that the insoluble material formed during storage was predominantly composed of hydrophobic casein molecules, with insignificant contribution from whey proteins. Mimouni et al. identified the micelles interactions of rehydrated MPC particles using a field emission scanning electron microscope [21]. The microstructures of fresh and aged particles were compared. It was noted that the micelles formed a "skin-layer" on the surface of the aged particles, making it potentially difficult for water to penetrate.

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Several studies have been conducted to understand the effects of spray drying conditions on the resultant functionalities of dairy powders. DeCastro and Harper found that an outlet temperature range of between 65 and 90 °C had no obvious effect on protein denaturation, but affected the moisture content and rehydration rate of the resulting particles [22]. Gaiani et al. studied the relationship between surface composition of high milk protein powders and the different drying temperatures [23]. They observed that fat and protein were preferably located on the surface of particles whereas lactose was enclosed in the core, in agreement with a previous study conducted by Kim et al. [24]. Also, Gaiani found that a lower outlet temperature led to increased fat and protein content on the surface of particles, to relate the powder's functionality (e.g. wettability) and the surface composition [23]. In a recent study, Gaiani et al. studied the effect of differing spray drying temperatures on surface competitive adsorption [25]. They found that at lower drying temperature, casein was over expressed on the particle surface compared with bulk composition, whereas higher drying temperature, the casein content at the surface was similar as in the bulk. In another study, Millqvist-Fureby et al. conducted a series of experiments to examine the surface composition of whey protein isolate particle with different heat treatments using electron spectroscopy for chemical analysis (ESCA) [16]. It was found that with increasing degree of denaturation (insoluble proteins), the fat coverage increased slightly, while protein coverage decreased and lactose coverage remained relatively constant on the particle surface. It showed that heat treatment could alter the composition of the particle surface. In pharmaceutical area, the drying dynamics on the resulting functionalities of pharmaceutical protein particle is also of interest. Maa et al. investigated the different outlet temperatures on the protein morphology, and the effects of different protein formulations [26]. They concluded that the outlet temperature as an indication of drying speed was the single most important parameter in the drying process, whereas the different protein formulations also strongly influenced the resulting particle morphology.

In current study, the relationship between spray drying temperature and the resulting powder solubility was investigated directly on mono-disperse MPC droplets dried under different inlet air temperatures in a pilot scale drier. The use of mono-disperse particles to study the drying effects provided several advantages. Each resulting particle would have similar heating history to form the same size and shape. Eliminating morphological and size differences in the dried particles provided a more accurate assessment from the dissolution test.

Our previous study had shown that the focused beam reflectance measurement (FBRM) could be used to characterize dairy powder dissolution with good reproducibility [4,27]. Here the dissolution property of MPC powder was measured using FBRM, while the degree of protein denaturation was quantified using sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE). The current study aimed to establish a direct relationship between the drying temperature and the functionality of the resulting products, while providing better insights into the microstructural changes caused by different drying conditions.

2. Materials and methods

2.1. Material

Fresh MPC 85 powder was kindly provided by a local manufacturer immediately after production. Powder was sealed in airtight bag and stored at 4 °C in fridge after manufacture. The industrially dried powder was used as the control benchmark for all comparison.

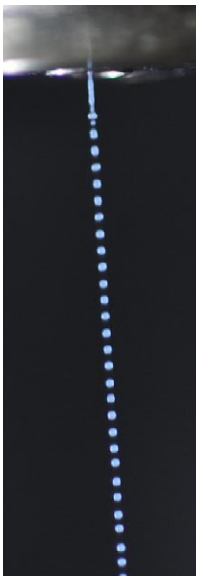

Fig. 1. Photograph of monodispersed droplets.

2.2. Pilot-scale production of MPC powders

20 wt% reconstituted MPC was prepared before commencing spray drying experiment. The reconstitution was carried out at 50 °C for 30 min. The extent of MPC powder dissolution was monitored using FBRM. After reconstitution, a single stream monodisperse atomizer was used to generate mono-dispersed droplets (Fig. 1). The mono-dispersed droplets were then dried at the pre-fixed temperatures (Table 1). The droplet and hot air were introduced into the drying chamber with co-current direction. After spray drying, the collected powders were stored in desiccators at room temperature overnight before functionality tests were performed. The drying temperatures in this paper referred to the inlet temperature readings from the thermocouple at the inlet of hot air in drier (i.e. the inlet air temperature).

2.3. Physical characterization

The moisture content measurement was immediately conducted once the powder was collected from the drier. The measurement was scaled down based on Niro method No. A 1 b [28]. MPC powder samples weighing 0.2 g were dried in the oven at 102 °C for 3 h. The weight difference before and after oven drying was recorded and reported as moisture content. The powder particle size and particle size distribution were analyzed using Olympus BX51M light microscope (Tokyo, Japan). The micro-structural changes of the particles from different drying temperatures were examined using JEOL 840A Scanning Electron Microscope (Tokey, Japan), which was operated at 20 kV in low vacuum mode and equipped with a backscatter detector. Sample was placed on a double-side carbon tape coated with platinum (4 nm thickness).

Table 1
Drying conditions.

Inlet air temperature (°C)	178 ± 2.0	155 ± 1.5	107 ± 1.2	77 ± 0.8
Outlet temperature (°C)	103 ± 1.5	93 ± 1.3	68 ± 0.7	54 ± 0.9
Flow rate (g/min)	2 ± 0.01	2 ± 0.02	2 ± 0.01	1.96 ± 0.01
Droplet size (μm)	207 ± 5	201 ± 7	230 ± 21	201 ± 4