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Physical and functional properties of cheese powders affected by sweet whey powder addition before or after spray drying

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ABSTRACT

Cheese powder properties are affected by the use of different cheese raw materials, addition of ingredients, spray drying and storage conditions. Sweet whey powder can be added after spray drying, in a dry mixing process, or before spray drying into the cheese feed to improve physical properties like flowability, particle size, color and reconstitution properties. This work focused on how addition of sweet whey powder before (co-sprayed) or after spray drying (dry mixed) affected the physical, flow, thermal and reconstitution properties of Danbo cheese powder. It was demonstrated that co-sprayed samples presented smaller particles, faster dissociation, better solubility and rehydration ability (by ^{1}H NMR relaxometry), whereas solid-state ^{13}C MAS NMR and differential scanning calorimetry were utilized to show that lactose was mainly amorphous for co-sprayed powders and mainly present as crystalline lactose monohydrate in dry mixed powders. Also, dry mixed showed the lowest flow functional coefficient and a weaker structure after rehydration (1:1 *w/w*). Rheological measurements indicated the presence of a stable and elastic network after rehydration. In conclusion, lactose state and particle size are the main factors affecting the properties of cheese powder added sweet whey powder.

1. Introduction

Cheese powders are produced by spray-drying and are widely used as a multifunctional ingredient to provide an optimum combination of taste and texture in ready meals, sauces, creams, soups, etc. They can be produced from a variety of cheeses such as Cheddar, Danbo, Camembert, or Gouda. During production the cheeses are comminuted, mixed with water and other ingredients, and heated to form a homogenous emulsion, termed cheese feed. Generally, the cheese feed is held at 60 °C for at least 1 h, pasteurized and then spray dried [1,2].

Cheese powder properties such as physical, thermal and rehydration properties can be affected by the use of different cheese raw materials, addition of ingredients, spray drying and storage conditions [1–4]. For example, the use of fillers, such as maltodextrin and whey powder in cheese powder production may reduce the raw material cost and improve the physical properties, especially the rehydration properties of powders [5]. Sweet whey powder is one of the most common filler materials used in the food industry [6].

Sweet whey powder (SWP) is produced from liquid whey derived from the manufacture of cheese or rennet casein by coagulation of milk at pH of 6.0–6.5. Prior to spray drying, the lactose present in the sweet whey is crystallized in order to produce non-hygroscopic whey powder [7]. SWP is widely used in powder formulations to improve the physical quality of powders such as particle properties, flowability, and reconstitution abilities [8–11]. In cheese powders, SWP can be added before spray drying into the cheese feed, or after spray drying, in a dry mixing process, resulting in powders with e.g. different particle sizes and flowability.

Most spray dried dairy ingredients contain lactose in an amorphous state [12]. Amorphous sugars are thermodynamically unstable and more susceptible to crystallization and to participation in Maillard reactions, consequently causing browning [12].Therefore, an understanding of the thermal reactions is important to predict the quality of dairy ingredients [13]. Likewise, reconstitution is an important attribute of powdered ingredients and has been investigated using different methods such as light-scattering, microscopy, rheology and low field nuclear magnetic resonance (LF-NMR) spectroscopy [14–17]. More specifically, rehydration is an important property for the final product and will depend on the structure and composition of a given dairy powder [18–20].

Only a few studies have investigated the characteristics of cheese powders, and they have mostly dealt with flavor properties [21,22]. Recently, Erbay and Koca [2] investigated the physical properties of cheese powder produced from white cheese and liquid whey or maltodextrin, and they concluded that the addition of maltodextrin resulted in cheese powders with high densities, optimum reconstitution properties, and low content of free fatty acids. Powder particles produced with liquid whey, were larger than the particles of powders produced without liquid whey addition, spherical, and uniform [5].

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We aimed to investigate the effect of sweet whey powder addition before (co-sprayed) or after spray drying (dry mixed) on the physical, flow, and reconstitution properties of cheese powder made from Danbo (smear-ripened Danish cheese). Since the structure of lactose is important in relation to the functional properties of the cheese powders, solid-state ^{13}C cross-polarization (CP) magic angle spinning (MAS) NMR and differential scanning calorimetry were utilized to analyze the state of lactose in the cheese powders.

2. Materials and methods

2.1. Cheese powder

Cheese powder samples were kindly provided by Lactosan A/S, Ringe, Denmark. Sweet whey powder (SWP, 11.0% protein, 1% fat, 74% lactose, 3% moisture) was supplied by Melkweg Holland B·V (Johan Bosboomlaan, The Netherlands).The cheese powders were produced by spray drying a mixture of melted cheeses (smear-ripened Danbo), water and 3.5% *w*/*w* emulsifying salt (disodium hydrogen phosphate (DSP), BK Giulini, Ludwigshafen, Germany) as described previously [1]. The spray dryer used for production was an industrial two-stage spray dryer (FILTERMAT™, GEA, Søborg, Denmark) with a belt dryer at the bottom of the drying chamber. The feed enters the drying chamber via a set of high pressure nozzles and the air flow pattern in the drying chamber directs the particles to the belt dryer where the second drying stage occurs. In the first step, the fines are returned to the drying chamber. After the first stage, the powder has a moisture content of approximately 6%, and it reaches the final moisture content (4%) on the belt dryer. Inlet and outlet drying temperatures were 185 and 75 °C, respectively. Three samples were produced for this study: a control without SWP, a co-sprayed with SWP (5% *w*/*w*) and a dry mixed with SWP (5% *w*/*w*). Samples with sweet whey powder as filler contained 10% less cheese. The dry mixing was done in laboratory scale, sweet whey powder was added to the cheese powder to a final proportion of 5% and mixed for 20 min. The amount of SWP added was chosen based on previous experience. The samples were packed in aluminum foil laminate bags, which were sealed and stored at 10 °C until analysis.

2.2. Composition, color and water activity

The content of moisture, fat, protein, lactose and ash in the cheese powders were determined using standard techniques [23]. Lactose was measured using an enzymatic method [24]. In addition, the pH of a solution of cheese powder in water (1:10) was determined using a digital pH-meter (Hach HQD, Loveland, Colorado, US). The moisture and ash content were determined gravimetrically at 105 ± 2.0 °C and 525 ± 25 °C, respectively. Fat was determined by the Gerber method. Protein was quantified by Kjeldahl using a nitrogen-to-protein conversion factor of 6.38. All methods were as described by Ardö & Polychroniadou [23]. Analyses were performed in triplicate. Color L (lightness), a (redness) and b (yellowness) were measured with a Chroma Meter CR-400 (Konica Minolta Business Technologies, Inc., Tokyo, Japan). The colorimeter was standardized using the white calibration plate. Six determinations were performed for each sample and results were expressed as average values. In addition, color was measured during 8 weeks under accelerated storage conditions (30.0 ± 1.0 °C). Hence, color differences ΔE and Browning index (BI) were calculated using L, a and b according to Eqs. (1) and (2), respectively [5]. Water activity was measured using an Aqua Lab 3 TE (Decagon Devices, Inc., USA) at temperature 20 ± 1 °C. Particle size distribution was determined by laser diffraction using a Mastersizer 2000 (Malvern Instruments Ltd., United Kingdom) and the results expressed as weight mean (D [3,2]).

$$\Delta E = \sqrt{L^2 + a^2 + b^2} \tag{1}$$

$$BI = \frac{100 \times \left\lfloor \left(\frac{(a + 1.75 \times L)}{5.647 \times L + a - 3.012 \times b} \right) - 0.31 \right\rfloor}{0.17} \tag{2}$$

where L: lightness, a: redness and b: yellowness.

2.3. Microstructure

The microstructure of cheese powders was evaluated using confocal scanning electron microscopy and scanning electron microscopy. For the confocal images, an inverted SP5X (Leica Microsystems GmbH, Wetzlar, German) confocal laser scanning microscope was used. The samples were dyed with Nile Red 0.01% in 1,2-propanediol, which stained the oil phase, and Fast Green FCF 0.001% in 1, 2-propanediol which stained the protein. Illumination was provided by an Argon laser at 488 nm and a Helium/Neon laser at 633 nm. Scanning electron microscopy (SEM) was carried out using a FEI Quanta 200 scanning electron microscope (FEI Company, Hillsboro, USA) equipped with a back-scattered electron detector. Prior to analysis samples were attached to double-sided adhesive carbon tabs mounted on scanning electron microscopy stubs, coated with gold/palladium.

2.4. Flowability

Powder flowability measurements were performed using a Schulze Ring Shear Tester (RST-Xs) with a pre-shear of 1 kPa and normal stresses of 200, 500 and 800 Pa. A Type XS-Mr shear cell was used containing 30 cm^3 of cheese powder. The values of major consolidation stress (MCS), i.e. the maximum normal stress undergone by a certain powder at a given state of compaction, unconfined yield strength (UYS), the normal stress necessary to make the powder yield at zero shear stress, and effective angle of internal friction were obtained from Mohr's circles and the flow function coefficient (FFC) was calculated [6,25].

2.5. Differential scanning calorimetry

Thermal profiles of cheese powders were evaluated by differential scanning calorimetry (DSC 1, Star^e System, Mettler Toledo, Switzerland) in a normal pressure cell. A sample of 10 mg were placed in in aluminum pans and heated from 0 °C up to 300 °C with a heating rate of 5 °C/min. An empty sealed aluminum pan was used as reference in every test. Heat flow (Wg^{-1}) versus temperature curves was obtained [13,26]. Six replicates were measured for each cheese powder sample.

2.6. ^{13}C CP/MAS nuclear magnetic resonance

Solid samples were analyzed by ^{13}C cross-polarization (CP) magic angle spinning (MAS) NMR spectroscopy using a Bruker Avance 400 (9.4 T) NMR spectrometer operating at Larmor frequencies of 400.13 and 100.63 MHz for ^1H and ^{13}C, respectively. All CP/MAS [49] experiments were recorded at 296 K using a double-tuned CP/MAS probe equipped for 4 mm rotors employing a spin-rate of 9 kHz, rf-field strengths of 70 kHz for both ^1H and ^{13}C, a contact time of 1.2 ms, a recycle delay of 1024 s and 152 scans. For both experiments the acquisition time was 49.9 ms during which TPPM [59] ^1H decoupling was applied. All spectra were referenced to the carbonyl resonance of α-glycine at 176.5 ppm (external sample).

2.7. Reconstitution properties

Cheese powders are commonly used as ingredient in food formulations; therefore, understanding of dispersion and reconstitution properties is essential.