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Combined effect of denatured whey protein concentrate level and fat level in milk on rennet gel properties

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ABSTRACT

A factorial experimental design was used to evaluate the effect of denatured whey protein and fat concentrations in milk on rennet gel properties. The coagulation properties were characterized by dynamic rheometry. Decreased coagulation rate and storage modulus (G′) were observed when denatured whey protein concentrate (DWPC) was added to milk. Increasing the fat content barely affected milk coagulation, with a slight decrease in G′ at 60 min. The contraction kinetics of the gels during cooking was also characterized. Only the increase in DWPC reduced the contraction capacity of the gel. The use of DWPC in miniature cheese production linearly increased cheese yield and moisture. Introducing DWPC did not reduce fat retention in the curd, except at 0.75% when combined with the highest fat level (3.4%). Fat globules and DWPC aggregates are both considered to be fillers in rennet gels, but our results clearly show different impacts on gel mechanical properties.

1. Introduction

Cheese consumption is increasing around the world. In 2014, the annual production of Cheddar cheese and Mozzarella cheese in Canada amounted to more than 140,000 and 120,000 metric tonnes, respectively (Statistics Canada, 2015). This production has generated more than 2 million metric tonnes of whey, including about 15,000 metric tonnes of whey proteins. The efficient management of dairy fluids and the recovery of high-nutritional-value components such as whey proteins are highly desirable from an eco-efficiency perspective. An essential part of the cheese-making process is the conversion of a liquid (milk) to a solid material (curd) and remaining excess fluid (whey). During this process, caseins form the curd structure, and serum proteins are to a large extent drained out of the curd in the whey during drainage.

In recent years, several research endeavours have focused on whey protein recovery in cheese. The following three approaches to whey protein recovery have been investigated and reviewed (Hinrichs, 2001; Lawrence, 1993; Lelièvre, 1995). (1) The application of high-temperature heat treatment to cheese milk (Singh & Waungana, 2001); it was found that the denaturation of whey proteins by heat and their complexation with casein lead to defective milk coagulation and cheese texture issues. (2) The ultrafiltration of cheese milk (Jensen & Stapelfeldt, 1993); it was reported that the reduction of the aqueous phase of milk is better suited for high-moisture cheeses (Hinrichs, 2001). (3) The processing of whey into a microparticulated whey protein concentrate; this concentrate can be recycled into cheese milk in a subsequent batch (Banks & Muir, 1985; Lebeuf, Lacroix, & Paquin, 1998; Schenkel, Samudrala, & Hinrichs, 2011). The whey protein recovery approach should be chosen mainly on the basis of the type of cheese to be produced and the desired texture. For semi-hard cheese, the whey processing method has the advantage of not disturbing the cheese-making process. In addition, that method avoids the alteration of rennet coagulation properties and cheese texture defects associated with milk heated at high temperature (Hinrichs, 2001; Lebeuf et al., 1998; Lelièvre, 1990).

Cheese milk fortification with denatured whey protein concentrate (DWPC) is generally associated with increased cheese yield, largely because of increased water retention (Banks & Muir, 1985; Lebeuf et al., 1998; Schenkel et al., 2011). Denatured whey

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proteins are known to bind water and have detrimental effects on whey drainage (Giroux, Lanouette, & Britten, 2015; Hinrichs, 2001; McMahon, Alleyne, Fife, & Oberg, 1996; Schenkel et al., 2011), which can explain the increased water retention in DWPC-fortified cheese. However, the exact mechanisms responsible for impaired syneresis of the curd in the presence of DWPC remain to be clarified.

Microparticulated whey proteins also play a predominant role as fat replacer in cheese production. Denatured whey protein concentrates were shown to improve the texture properties of low-fat semi-hard cheese, such as Gouda (Schenkel et al., 2011; Schenkel, Samudrala, & Hinrichs, 2013) and Mozzarella (McMahon et al., 1996). However, some studies showed that DWPCs have a detrimental effect on rennet gel properties (Giroux et al., 2015; Steffl, Hafenmair, Hechler, & Hinrichs, 1999a) and cheese texture (McMahon et al., 1996; Mead & Roupas, 2001). According to the literature, the effect of the use of a DWPC on rennet gel and cheese properties is not consistent and seems to depend on the concentrate used and on the enrichment practices applied. Some studies reported the effect of using commercial DWPC powders such as Simplesse (McMahon et al., 1996; Schenkel et al., 2013) or Dairy-Lo (Fenelon & Guinee, 1997; McMahon et al., 1996). Other studies reported the effect of using denatured whey protein isolates or concentrates produced experimentally (Giroux et al., 2015; Lebeuf et al., 1998; Steffl et al., 1999a) or DWPCs produced following patented processes, such as Centri-Whey (Banks & Muir, 1985) or ALPMA CreamoProt (Schenkel et al., 2011). To date, the use of DWPC in cheese production through a closed loop is recognized as a refined practice (Schenkel et al., 2011) and is fairly common in large-scale industrial production. However, according to the expected impact of cheese fortification with DWPC (e.g., specific textural properties and moisture control), the denaturing conditions of whey proteins must be optimized, as must the cheese-processing conditions. Nowadays, DWPC is not only used to increase cheese yield but also to control the moisture content and texture of certain cheeses, especially when cheese milk with a high protein content is being used. To optimize the use of DWPC in cheese production, the mechanisms responsible for changes in coagulation properties and cheese yield, moisture, and texture associated with this practice must be further elucidated.

A rennet gel can be described as an emulsion-filled gel (Dickinson, 2012). Like fat globules, denatured whey protein particles end up embedded in the casein network during milk coagulation (Desai & Nolting, 1995; Steffl et al., 1999a). Based on composite materials theories, whey protein particles must have a diameter between 0.1 and 10 μm to act as filler elements in a gelled system (Hinrichs, 2001; Lelièvre, 1990). Whether denatured whey protein particles act as interacting or non-interacting fillers remains to be determined, however. Some authors suggested that such aggregates may act as inactive fillers (Desai & Nolting, 1995; Schenkel et al., 2013; Steffl, Schreiber, Hafenmair, & Kessler, 1999b). However, a recent study showed that whey protein aggregates and perhaps other small protein compounds in heat-denatured whey protein concentrate/isolate may interact with renneted micelles and impair rennet gel properties (Giroux et al., 2015).

Few studies have looked specifically at the effect of cheese milk fortification with DWPC in an industrial context. Moreover, to our knowledge, no study has examined the combined effect of two fillers, such as fat globules and whey protein particles, on the properties of rennet gels. The objective of this study was to evaluate the effect on rennet gel properties of the combination of cheese milk fat level and the level of cheese milk fortification with DWPC.

2. Materials and methods

2.1. Materials

Instant low-heat skim milk powder was supplied by Agropur coopérative (Granby, Quebec, Canada). Milk protein isolate (MPI) containing 81.8% protein (w/w), as specified by the manufacturer, was obtained from Idaho Milk Products (Jerome, ID, USA). In the present study, MPI is used to increase the protein content of reconstituted milk with minimal effect on lactose and soluble salts concentrations. Fresh raw cream was provided by Fromagerie Corneville/Agropur coopérative (Saint-Hyacinthe, Canada). Liquid DWPC was provided by Agropur cooperative. The DWPC was produced by heat denaturation of whey protein concentrate followed by homogenization according to Agropur's proprietary process.

2.1.1. Spray drying of denatured whey protein concentrate

Liquid DWPC (15.9% total solids) was spray-dried with a VERSATILE P-6.3 spray dryer (GEA Niro, Copenhagen, Denmark) equipped with a rotary atomizer (model FU-11-BAA06; GEA Niro). The ingredient was kept under constant stirring until drying. The spray dryer was prewarmed by introducing hot air at 195 °C and was allowed to reach a steady state by initially spraying water. The DWPC was then introduced at a flow rate of about 320 mL min^{-1}. The cyclone pressure was maintained at 56.5 kPa, and the air temperature at the outlet was kept below 63 °C.

2.1.2. Compositional analysis of denatured whey protein concentrate

Total protein content of spray-dried DWPC was determined by the Kjeldahl method (AOAC, 2005b). Before analyses, DWPC was reconstituted to 10.0% (w/w) protein in deionized water. The content of proteins insoluble at pH 4.6 in the ingredient was determined to evaluate the whey protein denaturation level (Giroux & Britten, 2004; Law & Leaver, 2000; de Wit & van Kessel, 1996). The ingredient was diluted to ~1% protein in deionized water at room temperature. The pH was adjusted to 4.6 to precipitate denatured whey proteins, using an TitraLab 865 autotitrator (Radiometer Analytical, Lyon, France) and 0.5 N HCl. The dispersion was then centrifuged at 20,000 × *g* for 15 min. Protein concentration in the initial ~1% protein dispersion (P_i) and in the supernatant (P_s) were determined by the Kjeldahl method, and the denaturation level (D%) was calculated as follows:

$$D\% = (1 - Ps/Pi) \times 100 \quad (1)$$

The fat content in reconstituted DWPC was measured by infrared analysis (MilkoScan FT-120; Foss North America, Brampton, ON, Canada). Total solids were determined by gravimetry after dehydration in a vacuum oven at 100 °C for 3 h (AOAC, 2005a). Ash content was determined by gravimetry after calcination in an oven at 550 °C for 16 h (AOAC, 2005c). Total Ca, K, Mg, P, and Na were measured by inductively coupled plasma–optical emission spectrometry (ICP-OES) with a Prism High Dispersion ICP Spectrometer (Teledyne Leeman Labs, Hudson, NH, USA). Nitric acid (0.24 N) was used to prepare the standards and the samples. Two separate sets of standard curves were prepared, to reduce the interference between the various minerals and to improve the accuracy of the readings: (1) Ca, K, and Mg; and (2) P and Na. Reconstituted DWPC was dispersed 1:10 in nitric acid. Just before analysis, the dispersion was centrifuged at 3000 × *g* for 15 min and filtered through a 0.45-μm syringe filter.