Manufacture and application of high milk protein powder

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Review

Manufacture and application of high milk protein powder[1]

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Abstract – A procedure was developed for the production of a high milk protein powder that was rich in both milk proteins, casein and whey proteins, and free of lactose. The method utilized ultrafiltration and diafiltration with no pH adjustment and a relatively low temperature. Spray drying was conducted at low temperatures (120 to 125 °C inlet air temperature, 75 to 80 °C outlet air temperature). The resulting powder contained at least 84% total protein (casein and whey proteins). Microstructural studies of the high protein powders revealed that the surface structure of the powders became smoother as lactose was reduced. The surface of the powders with the most lactose, such as skim milk powder, had the most wrinkles. The virtual absence of lactose in this powder allows storage at room temperature for a long time without deterioration or caking. Solubility index of the powder decreased (solubility increased) as temperature of reconstitution increased from 25 to 60 °C. Foaming capacity was highest at pH 10. Because of the similarity of the proteins of this powder to those of skim milk, and due to the absence of lactose, it was possible to use it in the manufacture of nonfat yogurts with good body and texture. Traditionally, nonfat yogurts have poor body and frequently have excessive whey separation. Use of gelling and stabilizing agents is therefore almost mandatory. The high milk protein powder, while adding protein to yogurt, served as a stabilizer to improve body and texture. The suitability of this powder as a medium for bulk starter was also investigated. The high buffering capacity of this powder in combination with nonfat dry milk made possible the production of an active bulk starter, which was subsequently used in the manufacture of Gouda cheese.

High milk protein powder / ultrafiltration / cheese / yogurt / diafiltration

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Résumé – **Fabrication et utilisations de poudres de lait enrichies en protéines.** Un procédé de production de poudre de lait enrichie à la fois en caséine et protéines de lactosérum, et sans lactose, a été développé. La méthode utilisait l'ultrafiltration et la diafiltration sans ajustement du pH et à température relativement basse. Le séchage par atomisation était effectué à basse température (température d'entrée de l'air : 120 à 125 °C, température de sortie de l'air : 75 à 80 °C). La poudre obtenue contenait au moins 84 % de protéines totales (caséine et protéines de lactosérum). Les études de la microstructure des poudres enrichies en protéines ont montré que la structure de surface des poudres devenait plus lisse lorsque le lactose diminuait. La surface des poudres contenant le plus de lactose, comme la poudre de lait écrémé, avait le plus de rides. L'absence virtuelle de lactose dans les poudres enrichies permet le stockage à température ambiante sur une longue période sans détérioration ni agglutination. L'indice de solubilité de la poudre diminuait (la solubilité augmentait) lorsque la température de reconstitution passait de 25 à 60 °C. Le pouvoir foisonnant était le plus élevé à pH 10. La similarité des protéines de cette poudre avec celles du lait écrémé et l'absence de lactose permettaient de l'utiliser dans la fabrication de yaourts maigres qui présentaient des fermetés et textures tout à fait satisfaisantes, au contraire des yaourts maigres traditionnels qui ont peu de fermeté et souvent une exsudation excessive de lactosérum, caractéristiques qui obligent à l'utilisation d'agents gélifiants et stabilisants. L'utilisation de cette poudre pour la préparation de milieux de culture de levains industriels a également été étudiée. Le pouvoir tampon élevé de cette poudre, permettait l'obtention d'un levain industriel actif, utilisé ensuite dans la fabrication de fromage Gouda.

Poudre de lait enrichie en protéines / ultrafiltration / fromage / yaourt / diafiltration

1. INTRODUCTION

New processing technologies that have emerged over the past several years have made it possible for the dairy industry to develop various types of novel ingredients at a reasonable cost and with unique functional properties. Among these, products of high milk protein content are an example. Whey protein concentrates were developed many years ago and are now an integral component of cheese making operations. They are widely used in the food industry for many applications. Powders in which both casein and whey proteins are present in high concentrations would be particularly valuable as ingredients in dairy and non-dairy foods because the unique characteristics of both proteins would be available. It would be particularly desirable if the proteins were in their native state. With whey proteins this is difficult because of sensitivity to heat [7] but denaturation can be minimized with the proper selection of processing techniques.

Protein products high in casein independently or in combination with whey proteins are not new. They have been available for many years and manufacturing procedures are relatively simple. Traditional technologies for the manufacture of these products include acid or rennet precipitation. To achieve proper solubility and functionality, the precipitated casein is frequently in the form of calcium or sodium caseinate. If whey proteins are to be included with casein, coprecipitation techniques are required. This involves the application of high heat during the precipitation process to co-link the two proteins but this also denatures the whey proteins. These co-precipitates can then be dried and used as ingredients. The nutritional quality is better than that of caseinates but functionality is limited to applications where denatured whey proteins are desirable, such as in bakery products.

To address this limitation, in 1983 New Zealand Milk Products Inc., patented a process for the production of total milk protein isolates. The process involves the co-precipitation of caseins and whey proteins using a series of pH adjustments to prevent the heat denaturation of whey proteins [5, 17]. These products, also known as isolates, are different from co-precipitates in that there isn't any extensive denaturation of whey proteins, hence the inherent functional properties are also retained. A modification of this process that involves ultrafiltration has also been patented [2].

We have developed a process for the production of a high milk protein powder (HMPP) for applications in cheese and yogurt making [9]. This process was developed using ultrafiltration and diafiltration of skim milk without pH adjustment to concentrate the proteins followed by spray drying. The process is described below.

2. MANUFACTURE OF HIGH MILK PROTEIN POWDER

One hundred and eighty kg skim milk containing approximately 3.2% protein was pasteurized (72 °C for 15 s) and ultrafiltered at 38 °C to approximately 15.16% protein and 3.8% lactose (Fig. 1). An Abcor spiral wound UF model 1/1 pilot plant unit was employed. Membrane surface area was 5.6 m^2 (Wilmington, MA, USA). The retentate (ultrafiltered milk) was batch diafiltered three times at 32 °C with water to 18.9% protein, less than 0.1% lactose,

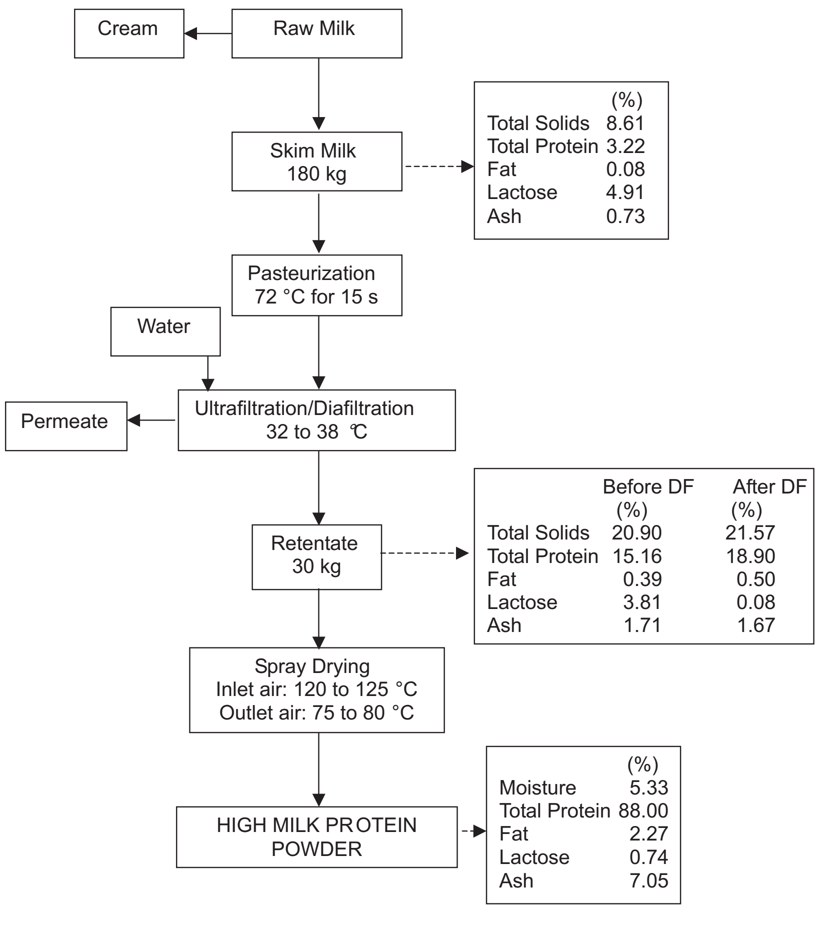

Figure 1. Production of high milk protein powder and composition of products.

and 21.57% total solids. This represented a 99.7% reduction in lactose. Approximately 30 kg of diafiltered retentate was collected. The purpose of diafiltration was to remove lactose and minerals, and concentrate the proteins. During ultrafiltration the flux rate dropped from an initial 31.15 to 19.28 $L \cdot m^{-2} \cdot h^{-1}$ when the volumetric concentration was 5:1 (15.16% protein). When diafiltration commenced, part of the flux was recovered (26.47 $L \cdot m^{-2} \cdot h^{-1}$) and there was a slight drop during diafiltration to 6:1 (19.28 $L \cdot m^{-2} \cdot h^{-1}$). The diafiltered retentate was spray dried in a pilot Niro spray drier, model ASO 412E (Columbia, MD, USA) equipped with a rotary atomizer and a propane-fired heater. To minimize heat denaturation of whey proteins, minimum possible processing temperatures were selected. Inlet and outlet air temperatures were 120 to 125 °C and 75 to 80 °C respectively. To improve the efficiency of drying, the diafiltered retentate could be vacuum evaporated to higher solids level. The powder obtained was sieved with a USA standard testing Sieve number 18 (Tyler equivalent 16 mesh, Fisher Scientific Co., Minneapolis, MN, USA). The average composition of the HMPP was 5.3% moisture, 83.9% total protein, 2.3% fat, 0.7% lactose, and 7.1% ash. The protein distribution in the powder according to SDS-PAGE was similar to that of skim milk.

3. PROPERTIES OF HIGH MILK PROTEIN POWDER

Due to the high protein content of HMPP and low mineral and lactose content, the powder was white in color and had a bland flavor. It had a loose density of 0.31 $g \cdot mL^{-1}$, which is lower than that of conventional nonfat dry milk (NDM) [12]. This is more a function of the drying process and conditions than the HMPP itself; the HMPP was produced from a concentrate of approximately 21% solids, whereas NDM is produced from skim milk that has been concentrated to 45% solids. Powders produced from concentrates of low solids generally have a low bulk density because of large amounts of occluded air. During storage of the powder there was no apparent change in color or flavor after 1 year at 25 to 30 °C, and caking did not occur. No hydroxymethylfurfural (HMF) was detected during storage at –20 to 45 °C for 3.5 months. The HMF in NDM stored under similar conditions increased. The absence of HMF in the high protein powder is attributed to its low lactose content, i.e., browning was absent in these powders during extended storage. During storage at < 10 °C for 105 days, the solubility index of HMPP remained below 3.3 mL but when the storage temperature increased to 32 °C, it was 12.5 mL. Lactose, which has a protective effect on whey proteins [20], was present in low amounts in HMPP. Rapid whey protein denaturation is therefore likely to have occurred in the HMPP during the higher temperature storage, leading to a high solubility index.

The powders exhibited interesting structural properties (Fig. 2) [10]. Microstructure of the high protein powders was identical to those of commercial caseinates but considerably different from those of milk dried in the same spray drier to approximately the same moisture content. The latter contained particles with wrinkled surface (Fig. 2A) whereas the high protein powders contained collapsed spheres with smooth surface (Fig. 2B). Subsequent studies with variations in lactose content of powders demonstrated that the surface properties of the powder were dependent on the lactose content of the powders. Powders with the most lactose content had a highly wrinkled surface [14].

Foaming properties were determined by whipping 3.75 g of powder in a total mix volume of 75 mL for 5, 10, and 15 min and at pH 7, 8, 9, and 10 [10]. Foaming capacity was measured by recording the weight of a fixed volume of foam and was expressed as

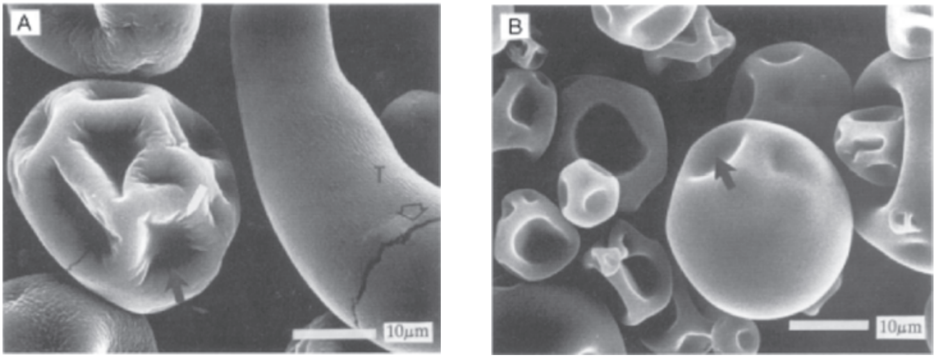

Figure 2. Microstructure of high milk protein powders. (**A**) Scanning electron micrograph of nonfat dry milk – note wrinkled surface (white arrow) and dents (black arrow). (**B**) Scanning electron micrograph of high milk protein powder – note smooth surface and dents (black arrow). (From: Food Structure 11 (1992) 73–82).

percentage overrun. Foaming was low at pH 7 and 8, but increased at higher pH, e.g., after 10 min of whipping. Overrun at pH 7, 8, 9, and 10 was 470, 404, 709, and 941%, respectively. Foaming increased more with time at higher pH than it did at lower pH, e.g., at pH 7 overrun at 5, 10, and 15 min was 470, 471, and 437% whereas at pH 10 it was 921, 941, and 982%. Fat suppresses foaming. The HMPP contained 2.3% fat, which may explain the relatively lower foaming capacity of the HMPP compared to commercial protein products. With more efficient centrifugal separation, it may be possible to significantly lower the fat content and increase foaming ability.

4. APPLICATIONS OF HIGH MILK PROTEIN POWDER

The HMPP has certain characteristics that present potential for applications in the manufacture of other products. For example, the protein composition of the powders is similar to that of skim milk. The absence of lactose makes it a useful ingredient for products such as nonfat yogurt, ice cream, and cheese.

Application in low fat and nonfat yogurts would be particularly useful. In spite of the success of these types of yogurts, weak body and poor texture are still prevalent because of the lower milk solids content. It is a common practice to add stabilizers, or nonfat milk solids, to improve the body. The amount of NDM that can be added is limited because too much can lead to a powdery taste and high lactose content, which ultimately results in a highly acidic product.

Low fat yogurts were produced from skim milk fortified with the HMPP [11]. The powder was added to skim milk to obtain 5.2 to 11.3% total protein, 11.1 to 15% total solids, and 1.6 to 7.9% lactose. The mixtures were homogenized and pasteurized at 90 °C for 10 min and fermented with a yogurt culture at 45 °C to pH 4.6. Controls were made from skim milk fortified with NDM to 14% solids. Yogurts made with mixtures containing up to 5.6% protein, 0.2% fat, 10.5% total solids, and 3.75% lactose after fermentation were similar in firmness to the control. Sensory scores of these yogurts when fresh and at two weeks were comparable to those of the control. Yogurts with above 5.6% protein were too firm and had an astringent flavor. Acetaldehyde content of all yogurts was comparable to that of the control.

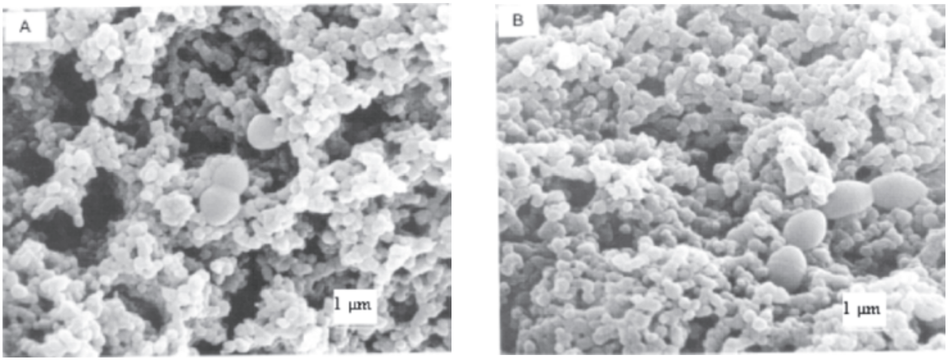

Figure 3. Microstructure of low fat yogurts manufactured with: (**A**) Nonfat dry milk (control – note open structure). (**B**) High milk protein powder to 5.07% protein – note dense structure. (From: J. Dairy Sci. 75 (1992) 947–957).

It was concluded that supplementing skim milk with HMPP up to 5.6% protein could produce low fat yogurts of good quality. The added protein helps to provide a firm body without the use of stabilizers. This was evident from microstructure studies of the yogurts (Fig. 3). The control yogurt consisted of protein particles linked in chains and was porous (Fig. 3A). As the protein content increased and the mineral content decreased, the porosity decreased and the proteins were clustered (Fig. 3B). These yogurts also had the least whey separation.

Another potential application is in cheese making. This application is similar to the use of ultrafiltration for cheese making. The improved yield benefits typically observed with ultrafiltration are to be expected, but in addition HMPP allows for flexibility in usage because of its shelf stability.

In our cheese making experiments, two applications with HMPP were explored: use in producing a bulk starter and supplementation of milk for Gouda cheese making [13]. For the production of bulk starter the limited lactose content and the high buffering of HMPP due to the high protein content provided a means to control the acid production and maintain a high level of starter bacteria numbers. This application is similar to the use of ultrafiltered milk for starter production [6]. A blend of HMPP and NDM containing 10% milk protein and approximately 4.3% lactose was determined to be the most suitable for the production of bulk starter. At the end of starter production (13 h at 22 °C) the HMPP starter had a lactic acid bacterial population of 1.36×10^9 cfu·mL^{-1}, and a control starter produced with NDM had a count of 5.8×10^8 cfu·mL^{-1}. Consequently, the HMPP starter provided improved activity when inoculated in reconstituted NDM: 0.24% developed acidity in 4 h at 32 °C compared with 0.15% with NDM starter.

Supplementation of cheese milk with HMPP (2%) and using the HMPP bulk starter had noticeable effects in Gouda cheese from manufacturing to ripening [13]. The pH decreased faster from milk renneting to pressing of curds, coagulation time was shorter, curd was firmer, and more effort was needed to cut the gel. Addition of 2% HMPP (5% protein in cheese milk) increased cheese yield by almost 2.4 kg per 100 kg milk compared to the control, but the cheese retained more moisture and had higher protein and less fat. This adversely affected the sensory properties of the cheese. Addition of 1% HMPP to cheese milk and fat standardization would produce a Gouda cheese with good sensory qualities as well as increased cheese yield.

5. GENERAL ASSESSMENT OF HIGH PROTEIN POWDERS

High milk protein powders, now also known as milk protein concentrates (MPC), have become increasingly important over the past few years. Because there is no specific standard of identity, these products can have a wide range of compositions and hence functionality and applicability. The powders described above are examples of products with very high protein content but products with much lower protein content are sometimes also regarded as MPC and have commercial applications. For example, ultrafiltration of raw milk on the farm to approximately 3.5:1 (approximately 12% protein) followed by the use of this concentrate to slightly boost the protein content of cheese milk is also sometimes regarded as a high protein application.

A number of patents have recently been issued that specifically employ high protein products for making Process cheese [1, 3, 15, 16, 21]. A patent by Moran et al. demonstrates a continuous method for manufacturing Process cheese [15]. In this method acidified milk is ultrafiltered and diafiltered to a concentration factor of 4 to 7 and then evaporated up to 70% solids to form reduced calcium pre-cheese. This pre-cheese is converted into Process cheese in the traditional manner using flavoring agents and emulsifiers. These methods completely modify the Process cheese making procedures. No base cheese is required, but instead high protein concentrates are used as the base material along with flavoring agents for the manufacture of Process cheeses.

Other examples include the use of microfiltration and ultrafiltration to produce powders that are rich in micellar casein [19]. This process produces a powder with casein content of almost 90%; casein forms almost 96% of total protein [18]. Casein concentrates have applications in cheese making and increase the yield of cheese [4]. Such powders provide flexibility in usage regardless of the extent of heat treatment because the κ-casein complex typically found in NDM does not exist due to the removal of the β-lactoglobulin during microfiltration.

Other applications of protein concentrates such as for coffee whiteners have also been developed [8] but these concentrates also present interesting challenges. For example, in the US much of the MPC has to be imported (approximately 55 million kg in 1999) because of very limited domestic production. There is a concern, therefore, that dried concentrates may have the potential for displacing local milk supplies. The US Code of Federal Regulations allows use of up to 3% MPC or casein in starters for making standardized cheeses such as Cheddar and Mozzarella.

Thus, high protein products will continue to evolve and offer new applications. New processing technologies make it possible to capture the inherent biological and nutritional properties of milk for a diverse range of uses.

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