



## Technical Report: Milk Protein Concentrates: Manufacturing and Applications

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Milk protein concentrates (MPCs) and milk protein isolates (MPIs) are high-quality proteins naturally found in milk. These high-protein milk powders offer the global food and beverage industry versatile food ingredients with excellent functionality and nutrition. The U.S. Dairy Export Council® and the Dairy Research Institute®, established under the leadership of America's dairy farmers through the dairy checkoff program, developed this report to highlight the state of the science for manufacturing and applications of these dairy ingredients. The information is intended to support food manufacturers in the selection, storage and optimization of MPCs in formulations by providing general characteristics, recent research summaries and practical tips. See Page 12 for an index of areas included within this report.

### What are milk protein concentrates (MPCs)?

Milk protein concentrates (MPCs) are complete proteins that contain both casein and whey proteins in the same or similar ratio as milk. These proteins are in their native state; that is, the caseins are still in a form that strongly resembles the initial casein micelles in milk and the whey proteins are largely undenatured, assuming that the heat load is kept to a minimum during processing.<sup>1</sup> In comparison with skim milk powder or whole milk powder, MPCs are higher in protein and lower in lactose. Thus, they provide a concentrated source of protein for enhanced nutritional, sensory and functional properties in final applications.

New technologies are often required to develop novel ingredients. Separation technologies provide the basis for adding value to milk by delivering protein ingredients that meet specific functional and nutrition needs not possible with other standard milk powders in food formulations.<sup>2</sup> MPCs are generally manufactured by filtration processes (microfiltration, ultrafiltration and diafiltration) — membrane separation technologies that remove the majority of lactose and soluble minerals while retaining the milk protein — followed by spray-drying.

### MPC types and composition

At present, there is no standard of identity for MPCs in the U.S. There also are no compositional standards (e.g., minimum or maximum standards for protein content) for MPC in the U.S. and many other countries around the world. In 2014, American Dairy Products Institute (ADPI) and the U.S. Dairy Export Council (USDEC) filed a Generally Recognized as Safe (GRAS) notification for MPCs and milk protein isolate (MPI) for use as food ingredients for functional or nutritional purposes in multiple food applications, except for infant formula.

In general, MPC and nonfat dried milk (NFDM) powders are similar products, but the main difference is that MPC protein is concentrated by removing lactose and soluble minerals. MPCs are manufactured ranging in protein content from 42 to 85 percent. Common MPC products are MPC 42, MPC 70, MPC 80, MPC 85 and MPI (which typically contains 90 percent or more protein by weight). MPC is typically made from skim milk, resulting in fat levels of less than 3 percent. The composition of MPC with different protein concentrations and MPI is presented in Figure 1. It is clear that, compared with NFDM, MPCs are enriched in protein and depleted in lactose with ash, fat and moisture contents reasonably constant over the range of protein contents.

As a rule of thumb, as the protein content of MPCs increases, the lactose levels decrease. For example, NFDM contains about 34 to 36 percent protein and 52 percent lactose, while MPC 42 contains 42 percent protein and 46 percent lactose, and MPC 80 contains 80 percent protein and 5 to 6 percent lactose, respectively. MPCs with even higher protein content also are available. They are generally known as MPIs with a minimum of 90 percent protein (generally in the range of 90 to 91 percent protein by weight) and micellar casein concentrates with 93 to 94 percent protein.

## Manufacturing of MPC and process flow chart

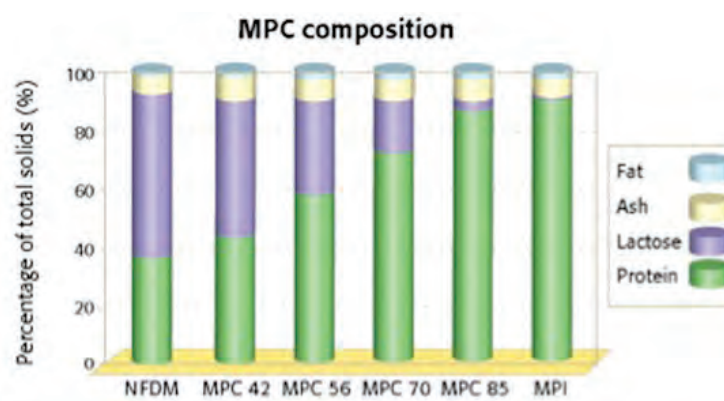
A typical process for the production of MPC is shown in Figure 2. Skim milk is generally used as the base material for the production of MPC. The first treatment of the skim milk is heat treatment (e.g., 10 to 20 seconds at 70 to 75°C). The heat treatment inactivates undesirable microorganisms and enzymes. The milk is then concentrated by ultrafiltration (UF). During the UF step, caseins, whey proteins, micellar salts and residual fat are concentrated in the retentate, whereas lactose, soluble salts and nonprotein nitrogen are removed with the permeate.<sup>4,5,6</sup> For high-protein MPCs such as MPC 85, UF alone is not sufficient to achieve the required protein-to-solids ratio in the retentate. Diafiltration (DF) is commonly applied to help remove additional lactose and soluble minerals.<sup>7,8</sup> The maximum protein content achievable is limited by the presence of residual fat and by the retention of micellar calcium phosphate.<sup>9</sup> Once the desired protein-to-solids ratio has been achieved, the UF retentate is evaporated and spray-dried.

Because of the considerably higher protein-to-solids ratio in UF retentate compared with skim milk, evaporation cannot achieve a solids content for MPCs that is similar to that of the skim milk solids. The feed to the spray-drier commonly has solids content of approximately 50 percent for skim milk but approximately 30 percent for MPC 70. This will be even lower for MPCs of even higher protein content.

## MPC production and global trade data

Among the wide variety of milk protein ingredients being produced, MPCs are a comparatively recent addition that is rapidly gaining wide popularity. Today, product developers are using MPCs in a range of new products for various benefits including flavor, functionality and formulating high-protein, low-lactose products.

**Figure 1: Composition of NFDM and MPC with different protein content.<sup>3</sup>**



**Figure 2: Process flow chart for manufacturing milk protein concentrates (MPCs).**

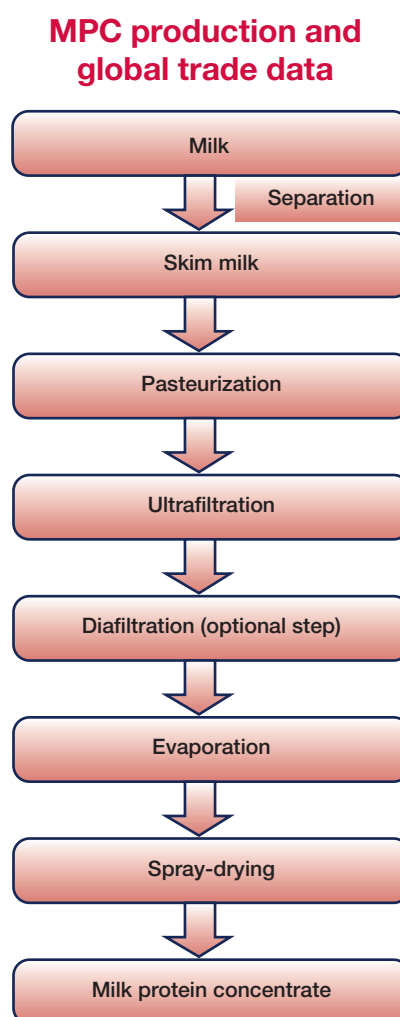


Figure 3 shows the share of the MPC export market. Demand for MPC has grown significantly in recent years. The worldwide market for MPC as an ingredient and consumer products formulated using MPC has grown over the last decade. For example, the production of MPC worldwide has increased from 40,000 metric tons in 2000 to approximately 270,000 metric tons in 2012.<sup>10</sup>

In recent years, U.S. ingredient processors have become increasingly specialized. Domestic MPC production has more than doubled over the past eight years but the U.S. still continues to import significant amounts of MPC because of overarching demand. For example, in 2006 the MPC production in the U.S. was minimal and required importing almost 80 to 90 percent of domestic needs (approx. 76,600 metric tons). In 2013, the U.S. produced an estimated 45,900 metric tons while the U.S. imported 55,000 metric tons of MPC (see Figure 4).

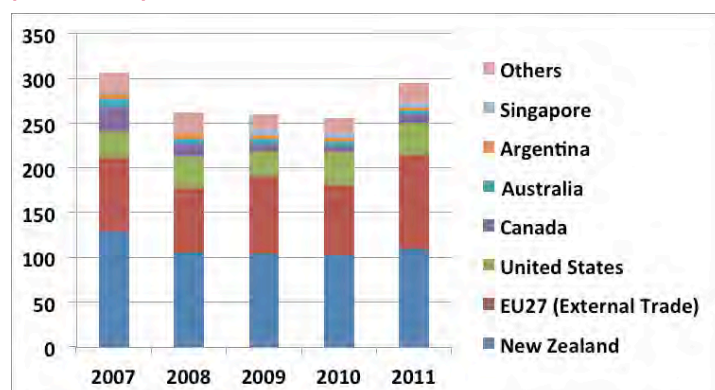
One major reason for increased MPC production and demand is that more products have been launched using MPC as an ingredient. Figure 5 illustrates the top 15 product categories introducing new products using MPC as an ingredient.

Overall, the growth of MPCs is mainly attributed to three key usage streams:

- 1) NFDM/skim milk powder (SMP) replacer (with low-protein MPC 42)
- 2) Cheese and yogurt manufacture (usually with MPC 42 and some MPC 70, where permitted)
- 3) High-protein MPC (80, 85, 90+) in nutritional/ dietetic formulations, high-protein nutritional and clinical formulations, infant formula and protein bars

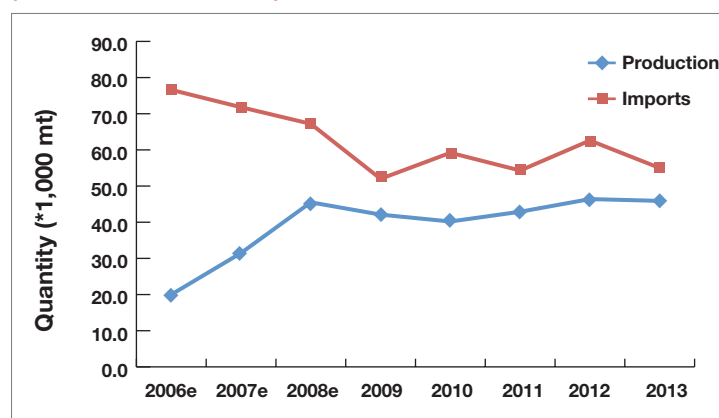
Also, in some countries, the milk permeate can be used for protein standardization of milk powders for the production of “Codex” products. Therefore, MPCs are very important ingredients for global food and beverage manufacturers.

**Figure 3: Major exporters of MPC and related products (in 1,000 mt).<sup>11</sup>**



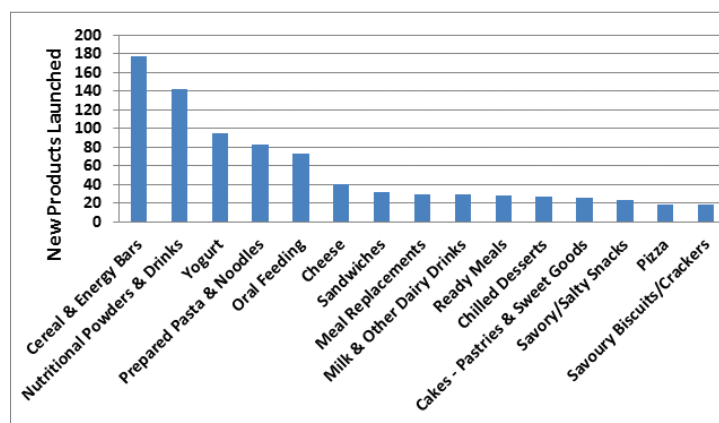
Source: GTIS Global Trade Atlas. Includes trade classified under HTS 0404.90 and 3502.20.

**Figure 4: Production and import of MPC in USA (2006-2013, in 1,000 mt).**



Source: U.S. Dairy Export Council

**Figure 5: Number of products launched containing MPC as an ingredient (top 15 major sectors).**



Source: Innova 2011

## Applications and benefits of using MPC

The applications of MPCs in different products can vary depending on the protein content. Typically, lower-protein MPCs (42 to 50 percent protein content) are used as ingredients in cheese, yogurt and soup applications, while higher-protein MPCs (70 percent and greater protein content) are used in beverages, medical foods, enteral foods and protein bar applications. Application of MPCs in cheese products includes nonstandard cheeses such as baker's cheese, ricotta, feta and Hispanic cheese, processed cheese, processed cheese spread products and other fresh cheeses. However, MPCs are not included as an ingredient in cheese with a U.S. federal standard of identity (e.g., Cheddar). Other common applications of MPC include desserts, baked goods, toppings, low-fat spreads, dairy-based dry mixes, dairy-based beverages and texture improvement for yogurt.<sup>12</sup>

In select applications, MPCs can be used as a replacer for whole milk powder (WMP) and skim milk powder (SMP) on an equivalent protein or milk solids nonfat (MSNF) basis. Lactose-free fermented milks also can be produced using MPCs.<sup>13</sup> Many patents have been filed by major food companies, universities and research organizations on applications of MPCs in various products including processed cheese, cream cheese, natural cheese, ice cream, beverages, etc. Figure 6 summarizes the wide range of applications driving global demand of MPC.

There are many opportunities for using MPC because of:

- Formula functionality optimization
- Favorable tariff classifications
- Flexible labeling rules
- Focus on product quality, shelf life and casein ratio adjustments

## Nutrition and functional benefits

There also are specific benefits or functional properties of MPC, which attracts product developers to use MPC in their formulation. Some of these benefits include:

- **Nutrition:** The demand for exciting new food products in global consumer markets is driving the development of new products at a faster pace. MPCs are used in these products for their nutritional and functional properties. They are a high-quality source of protein and have approximately 360 kcal/100 g. MPCs also contribute valuable minerals like calcium, magnesium and phosphorus to the formulations, which may reduce the need for additional fortification. MPCs are now widely used in many protein-fortified foods but primarily in meal replacements, nutritional beverages and bars. High-protein MPC is used for its nutritional qualities in pediatric and geriatric nutrition, medical nutrition (enteral foods), weight management products, powdered dietary supplements and sports nutrition products. It is common to find both MPC and whey protein ingredients used alone or in combination with other proteins in these applications.
- **High-protein/low-lactose products:** The demand for high-protein, low-lactose beverages and foods has been increasing rapidly in recent years. MPCs with higher protein content can be used to enhance the protein content of foods and beverages by imparting a clean dairy flavor without adding significant levels of lactose, which may cause

Figure 6: Applications of milk protein concentrates (MPCs).

### Applications of milk protein concentrates

- Desserts, baked goods, toppings, low-fat spreads, dairy-based dry mixes
- Emulsions, e.g., soups, sauces, salad dressing
- Geriatric nutrition
- Ice cream
- Follow-up formula, growing up milks
- Low-lactose products and beverages
- Medical and clinical nutrition products
- Processed cheese, cream cheese and fresh cheeses
- Protein/nutrition bar applications
- SMP and NFDM replacement in various food formulations
- Sports and nutritional beverages, meal replacement beverages
- Standardization of protein content in cheese milk, cheese milk extension
- Yogurt/fermented dairy products
- Weight management food and beverages

browning. Therefore, these high-protein MPCs are finding application in low-lactose, high-protein products (such as cheese sauces and UHT beverages). MPCs also can be used to increase the protein content of ice cream without increasing its lactose content.<sup>14</sup>

- **Excellent functional properties:** MPCs are highly functional ingredients. Incorporation of MPCs in food and beverage formulations can provide a range of benefits including water binding, viscosity, gelling, foaming/whipping, emulsification and heat stability. In addition, MPCs in formulations also can provide opacity and a pleasant milky flavor profile. Considering their excellent functional properties, MPCs may be suitable for many beverage and yogurt applications in the food industry (see Table 1).
- **Replacement of casein, caseinates and milk powders:** Traditionally, many products used caseins, caseinates and milk powders. MPCs can be used to replace these ingredients. MPCs are currently widely used in manufacturing a range of products including analogue cheeses, processed cheese, cream cheese, ice cream and frozen desserts, yogurt/fermented dairy and meal replacement and nutritional beverages, and ready-to-drink (RTD) and powdered beverages.
- **Adjustment of protein levels and standardization of milk:** MPCs can find applications in which the original structure of the milk proteins is desired for its functionality (i.e., the standardization of cheese milk, the protein fortification of yogurt and ice cream mixes). Because micellar calcium phosphate is largely retained in the casein micelles during the UF process, MPCs contain high levels of encapsulated bioavailable calcium in its natural form, further enhancing their popularity for infant and clinical nutrition.

**Table 1: Selected functional properties of milk protein concentrates (MPCs) and their applications in the final products.<sup>15</sup>**

No.	Functional Properties	Applications
1	Water binding, thickening and viscosity	Soups and sauces, meat products, bakery products, confectionary, chocolate, yogurt, cheese
2	Emulsification	Soups and sauces, ice cream, confectionary, meat products, coffee whitener
3	Foaming and whipping	Ice cream, desserts, whipped toppings
4	Gelation	Cheese, yogurt, bakery, confectionary
5	Heat stability	Recombined milk, soups and sauces, and enteral and clinical nutrition
6	Color/flavor development	Chocolate, confectionary

## Summary of scientific research on MPC

Several research reports are available in the literature on the solubility of MPC and describing successful applications of MPC in many products including yogurt, ice cream and cheese. These research reports are broadly summarized in the following section.

### Studies on mechanisms of insolubility

Generally, MPC retains good solubility for six to eight months when stored at ambient to refrigerated temperatures (35 to 70°F) and low relative humidity. However, one of the challenges for the high-protein MPCs<sup>16,17</sup> is that it can suffer from poor solubility, particularly when stored above ambient temperatures<sup>18,19,20,21</sup> at high moisture content and water activity.<sup>22</sup> As complete dissolution of MPC is necessary for the expression of their functional properties, the solubility of MPC is regarded as a critical property by the manufacturers and end users of MPC. Many studies have been conducted to understand the mechanisms behind reduced solubility of MPC during storage, and several different theories have been reported in the literature to explain the mechanisms of insolubility of MPC.



## Mechanisms of insolubility

Reduced solubility of high-protein MPCs has been related to excessive protein-protein interactions on the surface of the powder particle.<sup>20,23</sup> The insoluble protein material has been shown to consist primarily of caseins — predominantly of  $\beta$ - and  $\beta$ -caseins — and involves little or no whey protein.<sup>20,23</sup> This material was formed by weak, noncovalent (hydrophobic) protein-protein bonds, with some disulphide-linked protein aggregates consisting of  $\beta$ -casein,  $\beta$ -lactoglobulin and  $\beta$ -casein.

Based on some of the research, the protein conformational modifications and water-protein interactions are two major factors believed to induce instability of protein and eventually affect the solubility of MPC.<sup>24</sup> The storage of MPC at different  $a_w$  (0.0-0.85) and temperature (25 and 45°C) for up to 12 weeks showed that the solubility of MPC decreased significantly with aging. This process was enhanced by increasing  $a_w$  (water activity) and storage temperature. Minor changes in protein secondary structure were observed with FTIR spectroscopy, which indicated some degree of unfolding of protein molecules, suggesting that protein-protein interactions may be initiated by the unfolding of protein molecules, which eventually affects solubility.<sup>24</sup>

Researchers observed that, even after prolonged storage, approximately 20 percent of the total protein, equivalent to the proportion of whey protein in MPC, remained soluble.<sup>20</sup> Using mass spectrometry, they showed that the casein was lactosylated with storage time. They speculated that the insolubility of the MPC 85 could have been due to cross-linking of the proteins at the surface of the powder.<sup>20</sup> Additional research found that the solubility of MPC decreased with an increasing proportion of calcium in the mineral fraction of the product.<sup>5</sup> Similar results showed that the whey proteins and the nonmicellar salts (e.g., sodium and potassium) dissolved readily into the soluble aqueous phase up on the reconstitution of MPC 85.<sup>25</sup> In contrast, the caseins, as well as the salts associated with the casein micelles (e.g., calcium, magnesium and phosphate) dissolved slowly, suggesting that these minerals interfere with protein solubility. Ingredient processors may want to consider techniques to control and customize the mineral content of their ingredients for use in specific food and beverage applications.

In another series of studies,<sup>26</sup> researchers also concluded that the storage-induced loss of solubility for MPC was due to changed rehydration kinetics and not due to the formation of insoluble material during storage.<sup>27</sup> They reported that the rehydration process of MPC 85 powder occurs in two overlapping steps: the disruption of agglomerated particles into primary powder particles and, simultaneously, the release of micelle material from the powder particles into the surrounding aqueous phase. The latter process appeared to be a rate-limiting step of dissolution of MPC 85 and was accelerated by an increase of the solvent temperature. In contrast, water penetration into the powder particles was not a rate-limiting factor, as molecules larger than water (whey proteins and lactose) were freely released out of the powder structure in both fresh and stored MPC.<sup>26</sup>

In subsequent studies, the authors used scanning electron microscopy to investigate the microstructure of rehydrated MPC powder particles.<sup>25</sup> They found that a combination of different types of interactions (e.g., bridges, direct contact) between casein micelles results in a porous, gellike structure that restrains the dispersion of individual micelles into the surrounding liquid phase without preventing water penetration and solubilization of nonmicellar components. During storage of the powder, increased interactions occur between and within micelles, leading to compaction of micelles and the formation of a monolayer skin of casein micelles packed closely together, the combination of which are proposed to be responsible for the slow dissolution of stored MPC powders. Because of the poor release of casein micelles from the powder particles, particularly from the surfaces of the particles, structures resembling hollow shells can remain after the reconstitution of MPC (i.e., the constituents disperse from the interior, but a hollow shell of the original particle remains).<sup>16,26</sup>

## Studies on improving solubility of MPC

Several researchers report that the solubility of high-protein MPC and micellar casein can be improved by addition of monovalent salts such as sodium chloride (NaCl) and potassium chloride (KCl). The hygroscopic nature of NaCl was used to explain the enhanced reconstitution of micellar casein. Furthermore, improved rehydration due to these minerals is believed to be associated with modified protein-protein interactions<sup>28</sup> or by modification in the casein micelle structure.<sup>29</sup>

Additional researchers also reported significant improvement in the solubility (greater than 60 percent) for MPC 85 samples treated with monovalent salt as compared with the control sample.<sup>30</sup> Similar results for enhanced solubility of MPC 85 were previously reported where calcium was partially replaced with sodium.<sup>31</sup> Further to these studies, additional research showed significant improvement in solubility (100 percent) in MPC 80 samples treated with sodium and potassium compared with control samples.<sup>32</sup> More than 90 percent solubility in sodium- and potassium-treated MPC was retained even after one year of storage at 21°C or 70°F. This improved solubility after prolonged storage is believed to be attributed to the enhancement of electrostatic repulsive forces between the casein micelles.<sup>23</sup> Another explanation for such a dramatic increase in the solubility is due to release of calcium and phosphate from the casein micelles.<sup>32,33</sup> Besides electrostatic forces, hydrophobic forces also play an important role in the solubility of high-protein milk powders.<sup>20,23,34</sup> Enhanced solubility of MPC 80 treated with monovalent salts such as sodium or potassium likely modifies hydrophobicity of proteins<sup>33</sup> and reduces the disulfide bond formation. Such changes could modify protein-protein interactions that may limit protein aggregate formation and contribute to the improved solubility.<sup>34</sup>

### Studies on the use of MPC as an alternative ingredient in yogurt and ice cream

It has been shown that MPCs can be used efficiently as alternatives for traditional skim milk ingredients, such as from NFDM/SMP and are generally added to increase the protein content and improve the texture, to minimize whey separation and to improve the stability of yogurt. Replacing NFDM with MPC had no negative effect on the desirable textural properties of the yogurt.<sup>35,36</sup> Please check local regulations for standards and labeling requirements.

For ice cream mixes, it has been demonstrated that traditional skim milk ingredients can be substituted, on a similar protein basis (4%), using MPC 56 or MPC 80 without compromising the desirable physical properties of the ice cream mix,<sup>37</sup> which suggests MPC is a suitable ingredient for the production of reduced-lactose ice cream, where regulations allow.

### Studies on the use of MPC in standardization of cheese milk

MPC has been used to standardize milk for the manufacture of non-standard of identity cheeses; e.g., pizza cheese, certain Mexican-style cheeses and soft, fresh cheese varieties such as feta cheese. Researchers also have studied the use of MPCs in manufacture of mozzarella,<sup>38,39</sup> feta<sup>38,40</sup> and Cheddar cheeses.<sup>38,41</sup> Cheese milk standardized by MPCs or ultrafiltered milk offer cheese processors an opportunity to produce consistent cheese throughout the year.<sup>41</sup>

Researchers studied the effect of adding either skim milk or a commercial MPC to whole milk on the composition, yield and functional properties of Mexican-style Oaxaca and found that actual dry matter and moisture-adjusted cheese yields significantly decreased with the addition of skim milk powder but increased with the addition of MPC.<sup>42</sup> Additional research found that standardization of cheese milk using MPC increased the yield of cheese from 13.8 percent to 16.7 percent due to the higher recovery of the total milk solids and proteins in MPC cheese and due to slightly higher cheese moisture.<sup>39</sup> It also has been reported that increasing the milk protein content decreases the fat-protein ratio and eliminates the need for cream separation. This practice also improves the ability of the casein matrix to retain more fat and provides higher fat recoveries for Cheddar cheese when the fat to protein ratio is optimized.<sup>43</sup>



### Studies on rheological properties of acid or rennet-induced gels using MPC

It has been reported that the gelation times of rennet-induced gels were not affected by MPC type (MPC 70 and MPC 85) or by hydration treatment.<sup>44</sup> Other researchers studied the rheological properties of rennet gels containing MPCs with protein concentrations of 56, 70 and 90 percent versus reconstituted skim milk.<sup>45</sup> They found that the gelation time of MPC dispersions was considerably lower and the storage modulus was higher than those of reconstituted skim milk with the same protein concentration. The study also evaluated the rheological properties of MPC with different ratios of  $\kappa$ -casein. Conclusions were that the ratio of  $\kappa$ -casein was an important parameter in determining both the small and large deformation rheological properties of rennet-induced gels.<sup>46</sup>

In an additional study, the rennet gelation behavior of reconstituted MPC and skim milk were examined.<sup>47</sup> Researchers reported that reconstituted MPC did not coagulate unless supplemented with approximately 2 mm calcium chloride.<sup>47</sup> This and some other studies indicated that high-protein MPCs (e.g., MPC 80) require the addition of calcium chloride to ensure desirable coagulation properties,<sup>44,45,47</sup> suggesting that the ionic equilibrium was key to the functionality of MPC. This effect is related to excessive removal of soluble calcium during the UF and DF stages applied in the production of the MPCs. However, the addition of sufficient calcium could restore rennet coagulation kinetics and gel strength of reconstituted MPC to approximately that of raw skim milk.

The storage of MPC can also affect the strength of acid or rennet gels prepared from MPC solutions. The final complex modulus (final  $G^*$ ) and the yield stress of the rennet-induced skim milk/MPC 85 gels decreases exponentially with storage time of the MPC 85 for storage temperatures greater than 20°C, with a greater effect at the higher storage temperatures. The primary phase of renneting (cleavage of  $\kappa$ -casein) was not affected by the storage of the MPC 85; hence, the effect was related to the secondary stage of renneting (aggregation/coagulation of rennet-treated casein micelles).<sup>48</sup> Heat treatment of recombined milk prepared from MPC resulted in a slower rate of increase in the storage modulus ( $G'$ ) of rennet-induced gels, a reduction in the gelation time and a decrease in the yield force required to fracture gels. The extent of whey protein denaturation (as a result of heat treatment) was related to the decrease in the  $G'$  value of gels as well as the yield force.<sup>49</sup> Proteolysis and aggregation of milk proteins during enzymic coagulation also were dependent on changes to the proteins during preheating of MPC solutions irrespective of the pH at which coagulation is performed.<sup>50</sup>



### Studies on the role of MPC to stabilize oil-in-water emulsions

Several reports suggest that MPC can be used for stabilizing oil-in-water emulsions and enhancing both the emulsion properties (oil/water interface) and the whipping properties (air/water interface) in applications such as soups, sauces, processed meats, dairy drinks, salad dressings, vinaigrettes, bakery products and more.

The phase behavior of protein-stabilized emulsions is influenced by aggregate size. Emulsions made with the large casein aggregates found in MPC 85 and NFDM were more stable to creaming than those made with sodium caseinates. This may be because the protein aggregates in MPC and SMP are too large to cause depletion flocculation, or because they cause a high degree of depletion flocculation and thus form very viscous emulsions, which also will reduce creaming.<sup>51</sup> The same researchers further reported that the dispersion of aggregated proteins in dissociating buffer improved emulsifying ability.<sup>52</sup>

Researchers studying the effects of processing conditions on the rheology and physicochemical properties of MPC-stabilized oil-in-water emulsions found a high correlation between emulsion stability and the fluid consistency index.<sup>53</sup> Emulsion conductivity was not affected by processing conditions. During subsequent studies, they reported that increasing protein concentration resulted in a decrease in emulsion stability for MPC-stabilized emulsions. They also reported that the heated emulsions were of pseudoplastic character; consequently, higher preheating temperature caused more pronounced shear-thinning behavior of the final emulsion and higher emulsion viscosity, whereas the unheated



emulsions behaved as viscoplastic fluids and changed their behavior from shear-thinning to shear-thickening for higher protein content.<sup>54</sup> Preheating of either continuous phase (MPC solutions) or dispersed oil phase influenced flow properties and stability of the emulsions.<sup>55</sup>

In a more recent study, researchers compared the properties of emulsions stabilized using MPC with different calcium content and noticed that emulsions formed with low-calcium MPCs were finer and the total surface protein concentration was lower.<sup>56</sup> It also was reported that the aggregation state of casein dominates the emulsifying and absorption properties of MPC. In low-calcium, MPC-stabilized emulsions, the stability of the emulsions decreased with an increase in the emulsion droplet size at low-protein concentrations. The emulsion stability also decreased with increasing protein concentration beyond a maximum level, suggesting that the protein state in low-calcium MPCs may cause depletion flocculation in the emulsions.<sup>56</sup>

It also was reported that the presence of some nonmicellar casein fractions gave better emulsification and conferred a protective stabilizing effect on whey protein aggregation, in both the dispersed phase and the continuous phase during the secondary heat treatment in the emulsions stabilized with low-calcium MPC.<sup>57</sup> They also reported that the heat stability, the creaming behavior and the flow behavior of the model emulsion were influenced by both the emulsifier type and the type of protein in the continuous phase.<sup>58</sup> Further, they found the effect of pre- and post-heat treatments on the physico-chemical, microstructural and rheological properties of MPC-stabilized oil-in-water emulsions and reported that the emulsions stabilized with preheated MPC had fewer droplet-droplet interactions than that stabilized with unheated MPC because of denaturation of whey proteins, which led to a reduction in subsequent heat-induced droplet-droplet and droplet-protein interactions.<sup>57</sup>

## Analysis and test methods for MPC

Due to relatively poor dissolution properties of MPC, traditional testing methods are ineffective for characterizing its functional properties. To date, various techniques have been used to determine the functional properties of MPC. Most of these tests are conducted offline and involve considerable sample preparation that influences the reproducibility of the measurement. Many of the current methods used for measuring solubility of MPC depend on the accuracy of the operator and may lead to wide variation in the test results, depending on the accuracy of an operator.

Attempts have been made to develop different methods to study the solubility of MPCs. Researchers recently reported a new method to characterize the solubility of MPC that uses focused beam reflectance measurement (FBRM) to monitor the dissolution process of an MPC powder.<sup>21</sup> FBRM provides the ability to monitor *in situ* changes in chord length with time over a wide range of suspension concentration, which directly reflects the solubility of MPC. A higher rate of chord length reduction implies better solubility. They reported that this approach can potentially be applied to predict the dissolution behavior of specific dairy powders in a more robust manner than conventional solubility tests.<sup>21</sup>

## Formulation tips for working with high-protein MPC:

- The solubility of MPC can be improved by reconstituting MPC at slightly elevated reconstitution temperatures (optimum between 90 and 140°F) for approximately 30 to 40 minutes to allow better rehydration of milk proteins.<sup>59,16,25,21</sup>
- The application of shear also can help in improving reconstitution of MPC.<sup>16</sup> The use of high-speed mixing like a tri-blender or vortex mixer can help with faster and better reconstitution.
- If the formulation requires pH adjustment, avoid pH adjustment until the MPC is completely rehydrated.
- Once MPC is in the solution, try to avoid foaming by reducing the speed of agitation or use intermittent agitation. Foaming can be an issue in further processing of MPC into final products, so the use of an antifoaming agent is recommended, if permitted, while preparing MPC solutions in order to avoid excessive foaming.
- Homogenization of MPC solutions is recommended (particularly for high-protein solutions and/or prior to ultrahigh temperature processing (UHT) and retort processing).

MPCs are now widely used in many varieties of protein-enhanced foods but primarily in meal replacements, nutritional beverages and bars. Higher-protein MPCs provide protein enhancement and a clean dairy flavor without adding significant levels of lactose to food and beverage formulations. MPCs also contribute valuable minerals like calcium, magnesium and phosphorus to formulations, which may reduce the need for additional sources of these minerals. MPCs also are multifunctional ingredients and provide benefits such as water binding, gelling, foaming, emulsification and heat stability. Today, the Dairy Research Institute, the National Dairy Foods Research Centers and the U.S. Dairy Export Council are focusing efforts to improve knowledge and capabilities about processing technology, fundamentals and applications to advance the science of MPCs.

For more information about dairy ingredient research, visit [InnovateWithDairy.com](http://InnovateWithDairy.com), [USDairy.com/DairyResearchInstitute](http://USDairy.com/DairyResearchInstitute) or [USDEC.org](http://USDEC.org). For assistance with new or improved products using dairy ingredients, contact Dairy Technical Support at [techsupport@innovateWithDairy.com](mailto:techsupport@innovateWithDairy.com).



**Dairy Research Institute®** was established under the leadership of America's dairy farmers with a commitment to nutrition, product and sustainability research. The Dairy Research Institute is a 501(c)(3) non-profit organization created to strengthen the dairy industry's access to and investment in the technical research required to drive innovation and demand for dairy products and ingredients globally. The Institute works with and through industry, academic, government and commercial partners to drive pre-competitive research in nutrition, products and sustainability on behalf of the Innovation Center for U.S. Dairy®, National Dairy Council® and other partners. The Dairy Research Institute is primarily funded by the national dairy checkoff program managed by Dairy Management Inc.™



**The U.S. Dairy Export Council® (USDEC)** is a non-profit, independent membership organization that represents the global trade interests of U.S. dairy producers, proprietary processors and cooperatives, ingredient suppliers and export traders. Funded primarily by the dairy checkoff program through Dairy Management Inc., the mission of USDEC is to enhance U.S. global competitiveness and assist the U.S. industry to increase its global dairy ingredient sales and exports of U.S. dairy products. USDEC accomplishes this through programs in market development that build global demand for U.S. dairy products, resolve market access barriers and advance industry trade policy goals. USDEC is supported by staff across the United States and overseas in Mexico, South America, Asia and the Middle East.

- <sup>1</sup>Martin GJO, Williams RPW, Dunstan DE. Effect of manufacture and reconstitution of milk protein concentrate powder on the size and rennet gelation behaviour of casein micelles. *Int Dairy J.* 2010;20:128-131.
- <sup>2</sup>Huffman L, Harper WJ. Maximizing the value of milk through separation technologies. *J Dairy Sci.* 1999;82(10):2238-2244.
- <sup>3</sup>Smith K. Dried dairy ingredients. Understanding Dairy Markets website. 2008. Available at: [http://future.aae.wisc.edu/publications/dried\\_dairy\\_ingredients.pdf](http://future.aae.wisc.edu/publications/dried_dairy_ingredients.pdf). Accessed December 17, 2013.
- <sup>4</sup>Green ML, Scott JK, Anderson M, Griffin MCA, Glover FA. Chemical characterization of milk concentrated by ultrafiltration. *J Dairy Res.* 1984;51(2):267-78.
- <sup>5</sup>Babella G. Scientific and practical results with use of ultrafiltration in Hungary. *Bull Int Dairy Fed.* 1989;244:7-25.
- <sup>6</sup>Bastian ED, Collinge SK, Ernstrom CA. Ultrafiltration: partitioning of milk constituents into permeate and retentate. *J Dairy Sci.* 1991;74(8):2423-2434.
- <sup>7</sup>Getler J, Nielsen A, Sprogo J. Drying technology: functional process for MPC. *Dairy Ind Intl.* 1997;62(3):25-27.
- <sup>8</sup>Singh H. Interactions of milk proteins during the manufacture of milk powders. *Lait.* 2007;87:413-23.
- <sup>9</sup>Kelly PM. Milk protein concentrate. In: Fuquay JW, Fox PF, McSweeney PLH. *Encyclopedia of Dairy Science, 2nd Edition*. Amsterdam: Elsevier;2011:848-854.
- <sup>10</sup>USDEC Sourcebooks. 2011. Data presented at American Dairy Science Association conference. 2012.
- <sup>11</sup>U.S. Dairy Export Council. 2012.
- <sup>12</sup>Garde S. Dairy solutions to application challenges. *Prepared Foods.* 2008;177(10):77-78, 81-82, 85-86, 88.
- <sup>13</sup>Szigeti J, Krasz A, Varga L. A novel technology for production of lactose-free fermented milks. *Milchwissenschaft.* 2006;61(2):177-180.
- <sup>14</sup>Patel MR, Baer RJ, Acharya MR. Increasing the protein content of ice cream. *J Dairy Sci.* 2006;89(5):1400-1406.
- <sup>15</sup>Huppertz T, Patel H. Advances in milk protein ingredients. In: Ghosh D, Das S, Bagchi D, Smarta RB, ed. *Innovation in Healthy and Functional Foods*. Boca Raton, Fla: CRC;2012:363-386.
- <sup>16</sup>McKenna AB. *Effect of processing and storage on the reconstitution properties of whole milk and ultrafiltered skim milk powders*. Palmerston North, New Zealand: Ph.D. Dissertation, Massey University; 2000.
- <sup>17</sup>De Castro-Morel M, Harper WJ. Basic functionality of commercial milk protein concentrates. *Milchwissenschaft.* 2002;57:367-370.
- <sup>18</sup>Mistry VV, Pulgar JB. Physical and storage properties of high milk protein powder. *Int Dairy J.* 1996;6(2):195-203.
- <sup>19</sup>Mistry VV. Manufacture and application of high protein milk powder. *Lait.* 2002;82(4):515-522.
- <sup>20</sup>Anema SG, Pinder DN, Hunter RJ, Hemar Y. Effects of storage temperature on the solubility of milk protein concentrate (MPC85). *Food Hydrocolloid.* 2006;20:386-393.
- <sup>21</sup>Fang Y, Selomulya C, Chen XD. Characterization of milk protein concentrate solubility using focused beam reflectance measurement. *Dairy Sci Technol.* 2010;90(2-3):253-270.
- <sup>22</sup>Baldwin AJ, Truong GNT. Development of insolubility in dehydration of dairy milk powders. *Food Bioprod Process.* 2007;85(3):202-208.
- <sup>23</sup>Havea P. Protein interactions in milk protein concentrate powders. *Int Dairy J.* 2006;16(5):415-422.
- <sup>24</sup>Haque E, Bhandari BR, Gidley MJ, Deeth HC, Moller SM, Whittaker AK. Protein conformational modifications and kinetics of water-protein interactions in milk protein concentrate powder upon aging: effect on solubility. *J Agr Food Chem.* 2010;58(13):7748-7755.
- <sup>25</sup>Mimouni A, Deeth HC, Whittaker AK, Gidley MJ, Bhandari BR. Rehydration of high-protein-containing dairy powder: slow- and fast-dissolving components and storage effects. *Dairy Sci Technol.* 2010;90(2-3):335-344.
- <sup>26</sup>Mimouni A, Deeth HC, Whittaker AK, Gidley MJ, Bhandari BR. Investigation of the microstructure of milk protein concentrate powders during rehydration: alterations during storage. *J Dairy Sci.* 2010;93(2):463-472.
- <sup>27</sup>Mimouni A, Deeth HC, Whittaker AK, Gidley MJ, Bhandari BR. Rehydration process of milk protein concentrate powder monitored by static light scattering. *Food Hydrocolloid.* 2009;23(7):1958-1965.
- <sup>28</sup>Schuck P, Briard V, Mejean S, Piot M, Famelart MH, Maubois JL. Dehydration by desorption and by spray drying of dairy proteins: influence of the mineral environment. *Dry Technol.* 1999;17(7-8):1347-1357.
- <sup>29</sup>Baldwin AJ. Insolubility of milk powder products — a mini review. *Dairy Sci. Technol.* 2010;90:169-179.
- <sup>30</sup>Carr AJ, Bhaskar GV, Ram S. Monovalent salt enhances solubility of milk protein concentrate. U.S. Patent 0208955.
- <sup>31</sup>Bhaskar GV, Singh H, Blazey ND. Milk protein concentrate products and process. International Patent Specification WO01/41578.
- <sup>32</sup>Sikand V, Tong PS, Vink S, Walker J. Effect of powder source and processing conditions on the solubility of milk protein concentrates 80. *Milchwissenschaft.* 2012;67(3):300-303.
- <sup>33</sup>Sikand V, Tong PS, Walker J. Effect of adding salt during the diafiltration step of milk protein concentrate powder manufacture on mineral and soluble protein composition. *Dairy Sci Technol.* 2013;93(4):401-413.
- <sup>34</sup>Mao X, Tong PS, Gualco S, Vink S. Effect of NaCl addition during diafiltration on the solubility, hydrophobicity, and disulfide bonds of 80% milk protein concentrate powder. *J Dairy Sci.* 2012;95(7):3481-3488.
- <sup>35</sup>Mistry VV, Hassan HN. Manufacture of nonfat yogurt from a high milk protein powder. *J Dairy Sci.* 1992;75(4):947-957.
- <sup>36</sup>Guzmán-González M, Morais F, Ramos M, Amigo L. Influence of skimmed milk concentrate replacement by dry dairy products in a low fat set-type yoghurt model system. I: use of whey protein concentrates, milk protein concentrates and skimmed milk powder. *J Sci Food Agr.* 1999;79(8):1117-1122.
- <sup>37</sup>Alvarez VB, Wolters CL, Vodovotz Y, Ji T. Physical properties of ice cream containing milk protein concentrates. *J Dairy Sci.* 2005;88(3):862-871.
- <sup>38</sup>Harvey J. Protein fortification of cheese milk using milk protein concentrate: yield improvement and product quality. *Aust J Dairy Technol.* 2006;61(2):183-185.
- <sup>39</sup>Francolino S, Locci F, Ghigletti R, Iezzi R, Muchetti G. Use of milk protein concentrate to standardize milk composition in Italian citric mozzarella cheese making. *Lebensm-Wiss Technol.* 2010;43:310-314.
- <sup>40</sup>Kuo CJ, Harper WJ. Effect of hydration time of milk protein concentrate on cast Feta cheese texture. *Milchwissenschaft.* 2003;58:283-286.
- <sup>41</sup>Rehman SU, Farkye NY, Considine T, Schaffner A, Drake MA. Effects of standardization of whole milk with dry milk protein concentrate on the yield and ripening of reduced-fat cheddar cheese. *J Dairy Sci.* 2003;86(5):1608-1615.
- <sup>42</sup>Caro I, Soto S, Franco MJ, Meza-Nieto M, Alfaro-Rodriguez RH, Mateo J. Composition, yield, and functionality of reduced-fat Oaxaca cheese: effects of using skim milk or a dry milk protein concentrate. *J Dairy Sci.* 2011;94(2):580-588.
- <sup>43</sup>Guinee TP, O'Kennedy BT, Kelly PM. Effect of milk protein standardization using different methods on the composition and yields of Cheddar cheese. *J Dairy Sci.* 2006;89(2):468-482.
- <sup>44</sup>Kuo CJ, Harper WJ. Rennet gel properties of milk protein concentrates. *Milchwissenschaft.* 2003;58:181-184.
- <sup>45</sup>Ferrer MA, Hill AR, Corredig M. Rheological properties of rennet gels containing milk protein concentrates. *J Dairy Sci.* 2008;91(3):959-969.
- <sup>46</sup>O'Mahony JA, McSweeney PLH, Lucey JA. Rheological properties of rennet-induced skim milk gels made from milk protein concentrate solutions with different ratios of  $\kappa$ -:  $\lambda$ -casein. *Milchwissenschaft.* 2009;64(2): 135-138.
- <sup>47</sup>Martin GJO, Williams RPW, Dunstan DE. Effect of manufacture and reconstitution of milk protein concentrate powder on the size and rennet gelation behaviour of casein micelles. *Int Dairy J.* 2010;20(2):128-131.
- <sup>48</sup>Hunter RJ, Hemar Y, Pinder DN, Anema SG. Effect of storage time and temperature of milk protein concentrate (MPC85) on the renneting properties of skim milk fortified with MPC85. *Food Chem.* 2011;125(3):944-952.
- <sup>49</sup>Pomprasirt V, Singh H, Lucey JA. Effect of heat treatment on the rennet coagulation properties of recombined high total solids milk made from milk protein concentrate powder. *Int J Dairy Technol.* 1998;51(3):65-71.
- <sup>50</sup>Zbikowska A, Szerszunowicz I. Effect of heating milk protein concentrate on enzymatic coagulation phase. *Pol J Food Nutr Sci.* 2002;52(11):23-28.
- <sup>51</sup>Euston SR, Hirst RL. Comparison of the concentration-dependent emulsifying properties of protein products containing aggregated and non-aggregated milk protein. *Int Dairy J.* 1999;9(10):693-701.
- <sup>52</sup>Euston SR, Hirst RL. The emulsifying properties of commercial milk protein products in simple oil-in-water emulsions and in a model food system. *J Food Sci.* 2000;65(6):934-940.
- <sup>53</sup>Dybowska BE. The effects of processing conditions on the rheology and physicochemical properties of milk protein-stabilized O/W emulsions. *Milchwissenschaft.* 2001;56(2):63-66.
- <sup>54</sup>Dybowska BE. Influence of protein concentration and heating conditions on milk protein-stabilized oil-in-water emulsions. *Milchwissenschaft.* 2007;62(2):139-142.
- <sup>55</sup>Dybowska BE. Properties of milk protein concentrate stabilized oil-in-water emulsions. *J Food Eng.* 2008;88(4):507-513.
- <sup>56</sup>Ye A. Functional properties of milk protein concentrates: emulsifying properties, adsorption and stability of emulsions. *Int Dairy J.* 2011;21(1):14-20.
- <sup>57</sup>Liang Y, Patel H, Matia-Merino L, Ye A, Golding M. Effect of pre- and post-heat treatments on the physicochemical, microstructural and rheological properties of milk protein concentrate-stabilised oil-in-water emulsions. *Int Dairy J.* 2013;32(2):184-191.
- <sup>58</sup>Liang Y, Patel H, Matia-Merino L, Ye A, Golding M. Structure and stability of heat-treated concentrated dairy-protein-stabilised oil-in-water emulsions: a stability map characterization approach. *Food Hydrocolloid.* 2013;33(2):297-308.
- <sup>59</sup>Schuck P, Piot M, Méjean S, Fauquant J, Brulé C, Maubois JL. Dehydration of an ultra-clean milk and micellar casein enriched milks. *Lait.* 1994;74:47-63.

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