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Making cheese from higher solids milk: advantages and pitfalls

David M. Babano, Ph.D.
Professor of Food Science
118 Stocking Hall
Cornell University
Ithaca, NY 14853
dmb37@cornell.edu

Introduction:

Fortification of milk for cheese making with nonfat milk solids in the form of nonfat dry milk or condensed skim has become common practice in the manufacture of barrel Cheddar, current Cheddar varieties, and non-aged Italian cheese varieties. There are several reasons why fortification of fresh raw milk makes good sense from a management perspective. First, fortification increases the total weight of cheese produced per vat and per hour of labor. Second, consistency of final cheese composition, flavor, and functionality can be improved by using a consistent standardized milk composition every day of the year. By using a fortification strategy that eliminates seasonal variation in milk composition and the ratio of casein to fat, the consistency of cheese composition (i.e., moisture, fat, and salt) can be improved. Third, the use of nonfat milk powders provides the cheese maker with the opportunity to purchase milk protein and other milk solids at a specified price and allows the storage of these nonfat milk solids. If powder prices are more stable than raw milk and skim milk prices, then nonfat milk powder can be used to reduce the impact of the short term volatility in fresh milk price. Given all these advantages, there are some precautions that must be noted. The use of too much milk powder or poor quality milk powder can cause quality defects.

In the future, many additional liquid and powdered milk derived ingredient choices will become available. Currently, liquid milk protein concentrates produced by ultrafiltration of fresh milk are available and can be desirable ingredients for cheese making. In addition, dry milk protein concentrates produced by ultrafiltration of skim milk are a possibility. Native milk casein concentrates (made by microfiltration of skim milk) in both liquid and powder form are not currently available but as the technology develops and when the economics are favorable, these products will appear in the market place. Non-native casein isolates (i.e., sodium caseinate, calcium caseinate, rennet casein) are dried products currently in the market place that may or may not allowed ingredients for cheese manufacture in different markets (i.e., countries). Finally, the most challenging milk derived ingredients will be dry blends of all of the products mentioned above. Provided with this vast array of potential ingredients that differ in composition, functionality, and price, the cheese maker faces a daunting formulation optimization challenge that has both economic and product quality considerations. These issues will be discussed.

Milk Powders and Condensed Skim Milk:

Productivity. The extensive use of nonfat dry milk powder as a an ingredient for cheese

manufacture in the United States (Milk Facts, 1999) is testimony to the economic and product composition advantages of using milk fortification strategies for cheese manufacture. This has been a learning process for the US cheese industry, but it provides a window to the future both in terms of technological development and economic trends in large scale commodity cheese manufacture. Increasing the milk solids concentration per vat, increases the amount of cheese produced per vat. Thus, many of the fixed costs (particularly labor, equipment, and physical facility) of cheese making and whey processing are spread over more total weight of cheese and whey product. The fixed costs in the quality assurance laboratory that are usually directly related to the number of vats of cheese produced are also spread across more total weight of cheese when the amount of cheese produced per vat is increased.

Use of nonfat dry milk or condensed skim milk solids also improves the productivity and efficiency of the whey product manufacturing plant. Again more whey product is produced per hour and per day of labor cost with the same equipment cost. This is particularly true for a cheese manufacturing plant producing whole whey products versus whey protein concentrates or isolates. In the case of a whey protein concentrate or a whey protein isolate facility, the economics of handling permeate and lactose in the factory will determine if advantages or disadvantages will occur on the whey processing portion of the cheese business as a result of fortification of cheese milk with nonfat dry milk powder. If a cheese plant that is producing whey protein concentrates is breaking even or losing money on permeate and lactose, then fortification of cheese milk protein concentrates instead of nonfat dry milk may be a more attractive fortification alternative from an economic point of view. This approach would increase the amount of cheese and WPC produced without increasing permeate production by the same proportion.

Composition, Functionality, and Flavor Consistency. When milk solids fortification strategies are initiated in a cheese factory, it provides an opportunity to combine the advantages of fortification with the advantages of the use of consistent standardized milk composition. On-line milk analysis systems for control of protein to fat or casein to fat ratio provide an opportunity to improve the consistency of product composition (i.e., fat on dry basis, moisture, and salt). Cheese buyers usually specify a range of acceptable product composition. Maximizing cheese moisture content, control of fat on a dry basis and salt level while meeting the customer's specifications allows the cheese maker to maximize profitability. Linear and combined linear/nonlinear mathematical optimization models can be very useful in selecting the proper blend of milk derived ingredients, cheese and whey product composition targets, and product production targets to maximize profitability.

Reducing Volatility of Total Milk Ingredient Costs. Generally, the volatility of nonfat dry milk price is much less than the price volatility of the skim portion of fresh whole milk under the current USDA Federal Milk Market Orders. At times the value of skim as nonfat dry milk is less expensive than the same solids in fresh milk and visa versa. Thus, not only the decision to fortify but the amount of fortification needs to be considered carefully. Volatility can also be reduced by increasing and decreasing the proportion of fresh and dry milk solids solids used with constant total standardized milk composition in the cheese vats. The strategy selected for reconstitution of nonfat dry milk powder becomes important for changing the ratio of fresh versus dried skim milk solids and this will be discussed in more detail later.

Precautions in Using Nonfat Milk Powders. There are several technical considerations when using nonfat milk powders for cheese making. The following quality attributes of nonfat dry milk are important: 1) the somatic cell count of the original milk before drying, 2) the amount of heat denaturation of whey protein, 3) the bacteriological quality of the powder and the milk it was produced from, and 4) the solubility of the powder. Items 1, 2, and 3 are characteristics that cheese makers measure and control in their fresh milk supply and these factors are equally important for the quality of milk based powdered ingredients for cheese making. If the milk that the powder was made from was high somatic cell count, then a portion of the casein in the nonfat dry milk powder will be enzymatically damaged and will be lost in the whey. In processing fresh raw milk, the cheese maker controls the amount of heat denaturation of whey proteins by controlling the heat exposure in the pasteurization process. Excessive heat denaturation of whey proteins will cause yield loss due to weak coagulation and higher loss of fat and fines in the whey. However, some heat denaturation of whey protein can be desirable because it provides some cheese yield enhancement due to retention of whey protein in the cheese, but at the same time it will decrease the yield of the whey protein by-product. The higher the value of the whey product being produced and the lower the value of the cheese, the more carefully the cheese maker should consider this point. Thus, the net impact of heat denaturation on the total financial return on cheese plus whey products needs to be considered.

The bacteriological quality of the milk used for milk powder production has the same impacts as cheese yield as the bacteriological quality of raw milk. High psychrotrophic bacteria counts, of the milk prior to drying, will cause damage to milk casein and higher loss of casein into the whey. Low powder solubility will lead to yield loss and will cause physical quality defects in the cheese. Unfortunately, the analytical methods to measure the quality attributes of milk powder for cheese making are not as well developed as those for raw milk. Often the cheese maker does not give much consideration to these issues when purchasing nonfat milk powders. Another point is the protein and casein content of the milk powder. Just as the concentration of protein and casein in raw milk is important for cheese, so is the protein and casein content of the nonfat dry milk powder. Better quality assurance methods for measurement of protein and casein content, enzymatic damage to casein, and degree of heat denaturation in milk powders are needed.

Reconstitution Decisions - Water or Skim Milk? Generally, two different reconstitution media can be used for nonfat dry milk: water and skim milk. Both approaches are used in the industry. Once the reconstitution media is selected, then the desired level (i.e., solids content) for reconstitution needs to be determined. The level (i.e., percent solids) of reconstitution, in water or skim milk, should be decided based on the economic evaluation of the alternative condensed skim milk available. Usually this will result in a conclusion, based on the economics, that the total solids content of the on-site produced reconstituted "condensed" milk should be made at the same total solids concentration (e.g., 33% solids) as the competing condensed skim milk resource. If the reconstitution is done at lower percent solids, then the locally available condensed skim milk may be a more attractive from a maximization of net revenue point of view. Finally, a decision needs to be made with respect to the total amount of the skim solids in the vat that should be supplied from nonfat dry milk and from fresh milk.

Several factors need to be considered in the decision to use water or skim milk as a reconstitution media. The quantity and quality of the water available for reconstitution. When water is used for reconstitution, the cost of removal of the extra water needs to be considered. Also a soft water supply that does not have off-flavors is important. When skim milk is used for the reconstitution of nonfat milk powder, there is a need to separate whole milk to produce fresh skim so it can be used as a reconstitution media. If a relatively low level of total skim portion replacement with dry milk solids is desired, then probably reconstitution in skim milk or even in whole milk makes the most sense. However, if the price of fresh skim milk is much higher than the equivalent milk casein as nonfat dry milk, then using water for reconstitution is much more desirable. This will allow the replacement of a larger portion of fresh skim milk with dry skim solids, assuming that fresh cream is available at an appropriate price to achieve the desired casein to fat ratio needed to achieve the fat on a dry basis target in the cheese.

Reconstitution Decisions - Skim Solids Concentration. Several points need to be considered in the selection of a concentration of total solids in the standardized whole milk at the vat. In general if the prices of raw milk and dry milk based ingredients are such that use of a dry milk solids fortification strategy makes economic sense, then usually the economics will favor fortification to the highest possible level. The limits become the maximum standardized milk solids concentration will still achieve acceptable cheese quality and the maximum standardized milk solids level that cheese manufacturing equipment can physically handle. With respect to cheese quality, the first problem is usually retention of too much lactose and/or calcium in the cheese. While some increased retention of these components will provide an economically attractive increase in cheese yield efficiency, too much retention can result in off-flavor, excessive acidity, calcium crystallization in the cheese, or stimulation of the growth of gas producing nonstarter bacteria.

The curd handling capacity of the cheese making equipment will vary from one factory to another. However, in general the equipment in cheese factories is designed for a certain capacity in weight of cheese per hour with an ability to run about 10 to 20 percent higher. Even this increase in production per day presents a limit to achievement of the full economic benefit of fortification strategies. To push the limits of fortification strategies and economically viable formulation possibilities in the future, cheese making systems will need to be designed to work routinely with highly fortified, standardized milk. This presents an opportunity for new designs of cheese making equipment that are optimized to allow the cheese maker achieve larger economic benefits of milk standardization strategies.

Reconstitution Decisions - Proportion of Fresh Versus Dry Nonfat Milk Solids. Generally, a cheese maker must contract for a quantity fresh milk supply for a fixed period time to ensure a milk supply for cheese making. At the same time the cheese maker wants to be able to respond to both short and long term opportunities to manufacture and market increased quantities of cheese. These quantities of cheese may exceed the short or long term availability of the local supply of fresh milk in the vicinity of the cheese manufacturing factory. For this reason a base-line milk fortification strategy should be used by every cheese maker producing barrel Cheddar, current Cheddar varieties, and most Italian cheese varieties. This strategy should include a target total nonfat milk solids fortification level that is used every day of cheese manufacture, regardless of the proportion of fresh versus dry nonfat milk solids used. This will

help the cheese maker achieve consistent cheese quality and composition, when the ratio of fresh versus dry nonfat milk solids is changed. Therefore, when the need to rapidly increase or decrease the production of cheese occurs due to changes in the short term cheese market, the proportion of dry nonfat milk solids to fresh nonfat dry milk solids can be increased or decreased without changing the composition of the standardized milk used for cheese making. This allows continuous utilization of the contracted fresh milk supply, while using nonfat dry milk powder and cream to balance surges in demand for increased cheese production. This strategy is highly dependent on availability and price of milk fat as fresh cream. In the future, development and availability of alternative concentrated milk fat ingredients would provide cheese makers with other ingredient alternatives. To achieve the maximum advantage of being able to rapidly increase the proportion of nonfat milk solids provided by nonfat dry milk, water (not fresh skim milk) should be used to reconstitute nonfat dry milk. This point should be one of the key factors in the decision of using water versus skim milk as the liquid for use in reconstitution of nonfat dry milk solids. The key to being able to seamlessly change the proportion of fresh to dry nonfat dry milk solids is the control of both the quality of raw milk and the quality of nonfat dry milk solids, so that they are on a par with each other. Methods for evaluation and control of nonfat dry milk solids quality need improvement.

Future - A Larger Range of Ingredient Choices:

In the future many new liquid and dry ingredients for cheese making may become available. Use of many of these ingredients in the manufacture of natural cheeses with a Standard of Identity will be slower than in other cheese varieties, because some of these ingredients may not be allowed within the scope of current Standards of Identity in the US. The nomenclature and definition of many of these liquid and dry ingredients is not standardized currently. In general, the term milk protein concentrates is used much more broadly in the industry today than the definition that I will use in this paper. However, my definitions are for the purpose of clear communication of the issues surrounding the potential use of these different ingredients.

Milk Protein Concentrates. Fresh liquid full-fat, raw milk protein concentrates have become available in the market place in the US. These are produced by cold ultrafiltration of raw whole milk at a farm or by ultrafiltration of raw or pasteurized whole or skim milk at a processing plant. Usually, these concentrates are produced at about 3 to 3.5X concentration factor. these materials allow the more efficient transportation of the highest value components of raw milk to distant points for utilization as fresh ingredients. In recent times, these concentrates have been shipped from the southwest region of the US to as far away as the northeast region of the US for use in cheese making. These fresh products of ultrafiltration can also be dried, if there is a market demand for these dry ingredients.

Fresh and dry milk protein concentrates offer some advantages over condensed skim and nonfat dry milk. When milk protein concentrates are used, instead of nonfat dry milk or condensed skim, the cheese maker can fortify to higher concentrations of casein plus fat in cheese vat before there is a problem with excessive level of lactose retained in the cheese. Adjustments to the cheese making procedure to control the final concentration of calcium in the cheese may be needed to avoid calcium crystallization or other functionality defects in the

cheese. In addition, more whey protein will be retained in the cheese, particularly when levels of fortification become very high. This may enhance cheese yield, but it may have a negative impact on flavor development and functional properties of cheese. Also, whey protein product yield will be decreased if whey proteins are retained in the cheese.

The economic impact of using milk protein concentrates on the whey product portion of the business has to be considered. If the cheese factory is making whey powder, then yield of whey powder per unit of cheese will not increase in a direct relationship to the increase in cheese yield, as it does when using condensed or nonfat dry milk to fortify. The yield of whey powder per unit of cheese will decrease. The composition of the whey powder will also change, with the whey powder containing more protein as a percentage of solids. The whey powder yield will increase but not as fast as it would when using nonfat dry milk to fortify. This will represent a lost opportunity for the cheese maker, if the cheese maker was making a profit on sales of whey powder. Thus, the composition of the whey powder will vary with the level of fortification with milk protein concentrate. This would be undesirable.

If the cheese factory is manufacturing 34% whey protein concentrate (WPC) or any other whey protein concentrate product, the use of milk protein concentrates to fortify the cheese milk will not change the WPC composition (i.e., protein content) because the WPC composition can be controlled independently in the whey ultrafiltration process, however the yield of WPC will increase in a direct relationship on a percentage basis with increase in cheese yield. At the same time, the amount of whey permeate solids will not increase at as rapid rate as cheese and WPC yield. This may be an advantage for a cheese factory purchasing milk protein concentrate, if they are only breaking even or losing money on whey permeate solids.

Native Milk Casein Concentrates. I define these materials as milk derived ingredients that are produced by microfiltration of skim milk and used as a fresh liquid casein concentrate or dried as a dry powder of native milk casein. No non-milk derived ingredients have been added in the preparation of these liquid or dry concentrates. The availability of these ingredients for cheese making may be driven more by processors outside of the cheese manufacturing industry. These processors may fractionate milk proteins to harvest milk serum proteins for use as food ingredients and sell the native milk casein concentrates (in a liquid or powder form) as an ingredient for cheese making or other for other food formulation ingredient uses. Ultimately, there may be food ingredient markets for individual types of milk caseins (i.e., α_{s}-casein, β-casein, or κ-casein).

The use of native milk casein concentrates in combination with fresh milk will provide the cheese maker with another fortification strategy. Fresh and dry milk native milk casein concentrates offer some advantages over condensed skim, nonfat dry milk, and milk protein concentrates for fortification. When native milk casein concentrates are used, the cheese maker can fortify to higher concentrations of casein plus fat in cheese vat before there is a problem of retaining too much lactose or whey protein in the cheese. Issues of retaining too much calcium in the cheese will be similar to when milk protein concentrates are used. As with fortification with milk protein concentrates, adjustments to the cheese making procedure to control the final concentration of calcium in the cheese may be needed to avoid calcium crystallization defects in the cheese.

The economic impact of fortification of cheese milks using native milk casein concentrates on the whey product portion of the business is very different from the impact of fortification using milk protein concentrates. If the cheese factory is making whey powder, then yield of whey powder per unit of cheese will decrease, but the composition of the whey powder will not change. If the cheese manufacturer is making WPC, the yield of WPC per unit of cheese made will decrease. If the cheese maker is buying native milk casein concentrate, then part of the milk solids (i.e., lactose and whey protein) normally collected in whey has been removed.. If the cheese maker uses microfiltration of skim in the cheese factory prior to cheese making instead of buying native milk casein concentrate, then the cheese maker would produce a new co-product (milk serum protein concentrate, SPC), in addition to cheese and the whey product being produced prior to the use of this ingredient fortification strategy. Presumably this new co-product (SPC) will have a higher value than WPC (due to the absence of contaminants normally present in whey such as color, bleaching agents, coagulant, and starter culture enzymes) and will represent a potential new revenue stream for the cheese factory. The SPC may be an attractive ingredient in formulated foods where Kosher and other certifications are required. This would be desirable for the cheese maker.

If the cheese factory is manufacturing 34% whey protein concentrate (WPC) or any other whey protein concentrate product, the use of native milk casein concentrate to fortify the cheese milk will not change the WPC composition (i.e., protein content) because the WPC composition can be controlled independently in the whey ultrafiltration process, however the yield of WPC will decrease in a inverse relationship with the increase in yield of SPC, if the microfiltration is done in the cheese factory. If the factory is just purchasing native milk casein concentrate, then the yield of WPC and permeate solids per unit of cheese will decrease. The total amount of permeate solids will remain constant if the microfiltration of skim milk is used within the cheese plant to produce native milk casein concentrate.

Ultimately, the use of native milk casein concentrate opens the door to continuous cheese making without cheese vats, using similar strategies to those that were attempted with milk ultrafiltration. This approach using ultrafiltration was not successful for Mozzarella and Cheddar cheeses in the US because the retention of whey proteins caused large changes in functionality and flavor development. Use of microfiltration has a higher probability of technical success (because the process does not increase the amount of whey proteins), if the economics are right.

Isolated Casein. I define isolated casein as sodium, calcium, or rennet caseinate. These are typically prepared by acid or rennet precipitation of casein from skim milk followed by a process to improve solubility. These dry isolated casein products are not manufactured currently in the US and are not allowed as ingredients in cheeses made in the US that have a standard of identity. Some other countries allow the use of isolated casein as an ingredient in cheese making. The proposed CODEX cheese standards would allow the use of any milk derived ingredients, which would include isolated casein. There is not much experience in the US with these products as ingredients. The efficiency of recovery of these forms of casein and their impact on cheese functionality and flavor is not well characterized for major cheeses of the US market.

Dry Blends of Different Milk Derived Ingredients. An almost infinite range of products can be produced by dry blending various milk and whey derived ingredients. At the present time there are powders that are identified as milk protein concentrates 40 to 80% protein that are blends of nonfat dry milk powder, isolated casein, and/or whey powder or WPC. These are not included in my definition of milk protein concentrate as I use the term in this presentation. A systematic approach for classification and analysis of these products is needed..

Decision Making Process. Given the wide range of milk derived ingredients and costs of these materials plus the price and availability of fresh milk, the process of optimization of ingredient selection to maximize profitability of the cheese plus whey production process has become more complex. Different milk derived ingredients with different composition partition differently between cheese and by-products. This makes the process of calculation of the optimal mix of ingredients at any point in time that will maximize profitability cheese plus whey product production a much more complex task. At times the decision of the optimal fortification strategy to maximize profitability can be driven by the whey product production instead of the cheese production. Some of the mathematical relationships in this optimization problem are nonlinear will require future models to use a combination of linear and nonlinear solver approaches to find the optimal solution.

Equipment: Directions for the Future. In general, it has always been clear that increasing the concentration of casein and fat in milk used for cheese making will allow a higher amount of cheese to be produced per unit volume of standardized milk. The availability of both liquid and dry concentrates of milk protein and/or casein and fat have provided ingredients for the cheese maker that will increase productivity and spread fixed cheese and whey product manufacturing costs across more cheese and whey product. When the economics are favorable to utilize fortification strategies that provide much higher yields of cheese per unit volume of standardized milk, the current design of conventional cheese making equipment becomes a limitation. At the present time the cheese manufacturing industry is not be ready to implement continuous cheese making from microfiltered milk. However, over the next decade a design of cheese making equipment that would allow the production of Mozzarella or Cheddar cheese varieties from higher concentrations of casein plus fat fortification will be attractive. As the consumption of these types of cheeses grows in developing markets in other regions of the work, this type of equipment may be ideally suited for the cheese maker that desires to produce and market cheese in another country were concentrated (liquid and dry) milk derived ingredients may be provided from a variety of local and remote sources depending on quality, availability, and cost.

Summary:

The technology for manufacture of traditional mass-produced cheeses such Cheddar cheese for processing, short-hold varieties of Cheddar, Mozzarella, and some other Italian cheese varieties will continue to change to achieve cost more efficient manufacture. The trend to control the composition of standardized milk and to use a mixture of milk ingredients that has the highest sum of casein plus fat (i.e., yield) will continue and will be driven by the desire to reduce cheese manufacturing costs. As a result, development of cheese and whey manufacturing equipment to accommodate higher concentrations of casein plus fat will continue. The need for

more advanced ingredient optimization software for decision making in ingredient selection and selection of optimal utilization levels to maximize profitability of cheese and whey products together will increase. Better analytical methods to rapid measure both the composition and the quality of liquid and dry milk derived ingredients and to control, in real-time, the process blending milk derived ingredients to achieve the target cheese composition will be needed. Starter culture technology or a combination of innovative methods of direct acidification combined with starter culture and enzymes will need to keep pace with the changing needs of the developments in cheese manufacturing technology.