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FROM THE EDITOR

This double issue of Food Research Quarterly was compiled from papers presented at the Conference: 'Dairy Ingredients - Production & Utilisation', held in Melbourne, 6-7th March, 1991. The conference was presented by the Dairy Research Laboratory, CSIRO Division of Food Processing.

K.C. Richardson

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Conference Opening Address

Dr. John Stocker
CSIRO Chief Executive

The presence of four distinguished overseas guests at the conference shows that the dairy industry is truly an international concern. The things which bother and excite us here also bother and excite our fellow researchers around the world.

That is something which CSIRO has come to realise more and more in the past few years. We are aiming at a world market and we are competing and collaborating with scientists from all over the globe.

Food processing is Australia's largest manufacturing sector. As far as we have gone with it, we have been pretty successful. But the harsh truth is still that we simply do not do enough food processing here.

A lot of time and energy has been wasted at a political level in Australia trying to lay the blame for our poor manufacturing record at someone's door. Some blame government; some blame business; some blame geography or unions, or demographics, or education levels - or even the climate!

The truth is that it does not really matter whose fault it is that we do not have a powerful manufacturing base. Laying blame is an occupation for politicians and historians. I suggest we leave it to them to sort out among themselves.

What does matter is what we are going to do about it. What matters is that business must see that there are profits as well as a warm inner glow to be had from their getting into value–adding.

This demands an early and productive dialogue between innovators and the decision makers of industry. As scientists we have to get better at using the language of business in a much more persuasive way. And this collaboration between industry and scientists has to start from the very early stages of development. We scientists need business's expertise in what the market is demanding as much as business needs our expertise in knowing how to supply it.

We have to study what the market wants and think laterally about how to supply it. But that does not mean we have to apply ourselves totally to the short–term demands of business and marketplace. To do that would take away one of science's most valuable problem–solving abilities, which is our ability to step back a little bit and think of a completely new way to tackling something. That is why the Dairy Research Laboratory conducts both short–term and strategic research and why it is important for industry in all sectors to support both kinds of research activity.

The catch–cry in this industry, as in so many others, is 'value–added'. That has been the catch–cry for several years and it probably will be for many more years to come. The challenge is to make it happen.

We have been told again and again that value–adding activity is where the greatest opportunities lie, especially in the food industry. Australia needs to capture more value from its exports by doing more to them before they leave our shores. But if it was easy everyone would be doing it already. A point which is often lost in the fine print when people are waxing lyrical about value-added is that it is not just the opportunities which are great. Value–added is also where the commercial and scientific challenges are greatest. In the food industry, using a familiar phrase, there is no such thing as a free lunch.

That is why we have seen the Dairy Research Laboratory move gradually away from

studying the bulk products on which the Australian dairy industry was founded. Instead it now looks more at getting the most out of processing those products. The Laboratory is researching better ways to tailor-make ingredients for individual sections of the food industry.

The Laboratory has had more than its share of successes in identifying niche markets. Through Cheesebase, for example, it has given the secret of eternal youth to cheese ingredients. Cheesebase, as most of you here would know, is a kind of cheese fudge which can be used to replace cheese as an ingredient in processing.

Cheesebase has three great advantages: a) it increases the amount of cheese obtained from a given amount of milk by at least 16 per cent, b) it behaves like young cheese, no matter how old it is and c) it can be made with the same composition as almost any type of hard or semi-hard cheese. Already Cheesebase is being used in the US as an ingredient in processed cheese. But there is still much room for commercial development.

That is one success story — and there are many more. Probably the most successful technology developed by the Dairy Research Laboratory has been its recombined milk powders. Each year the benefits to Australia flowing just from that project pays the cost of running the Laboratory nearly 10 times over.

An internal divisional study last year found the five successful Dairy Research Laboratory projects were worth $49.3 million annually to Australia. Those five projects alone paid for the total cost of running the Laboratory more than 15 times over.

We have been doing similar cost-benefits on many other areas of our research and have come up with similar findings. Investment in research and development pays off far better than the general rates of return in any other sector of the economy. CSIRO believes all industries would do well to look closely at some of those sums. We think it is in their own commercial interests to invest more money in research and development.

Of course some industries are more willing than others to invest in the future. The Australian dairy industry is showing - and I hope it continues to show - that it recognises the commercial benefits of research. Last year the industry opted for a progressive increase in the milk research levy. It was a far-sighted investment decision and one which will pay off handsomely in time.

The move to increase the milk research levy is a large step in the right direction and one which is all the more important because it came from the industry itself. It shows that the producers who are the backbone of the industry realise that spending on research and development is an investment, not a charity.

Of course CSIRO would like to see the industry spend even more on research. And I am convinced that the benefits which will flow from last year's levy increase will very quickly persuade producers that we're not being naive about this. Given the Dairy Research Laboratory's track record of successes, I doubt that dairy producers could find a more productive place to invest their levy revenue than in this Laboratory.

Looking at the Laboratory's future research, there are some very promising projects under development and in the pipeline. The conference heard about the extraction of useful proteins from cheese whey and for six years the Laboratory has done significant work on fractionating whey proteins.

The proteins isolated through fractionating whey are starting to look like extremely useful commercial performers. The beta fraction might be used as an additive to make UHT processing of fruit-juice beverages feasible. And the alpha fraction looks promising as a source of alpha-lactalbumin for improving infant formulas.

Another source of ingredients for improving infan formulas could well be the fractionation of casein. The casein beta fraction might also be a useful source of biologically active peptides, including some which act as opiates.

Consumers the world over are becoming increasingly suspicious of preservatives in food. They want natural food. And I believe that any significant change in consumer taste represents an opportunity which needs exploring. The Dairy Research Laboratory's work on bacteriocins as alternatives to preservatives like nitrite might prove to be one means to tap into this opportunity. If we can genetically engineer bacterial cells to produce more bacteriocins we might be able to make highly selective natural preservatives in commercial quantities.

This research is important for CSIRO, for the dairy industry and for Australia.

Trends in the Production & Utilisation of Dairy Ingredients

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Introduction

In order to obtain some understanding of the perspective in which trends in production and utilisation of dairy ingredients develop, it is helpful to first pay some attention to the scene and its actors, the scene being the markets and the actors the consumers.

Regarding the scene and its actors, four major areas can be distinguished: Japan and Korea, other Asian countries bordering the Pacific Ocean, North America and the European Community. Although it is impossible to give an accurate description of these markets in a nutshell, the following comments may be elucidatory.

In Japan, dairy product consumption for fluid milk, butter and cheese has risen by 5 percent, 31 percent and 56 percent respectively over the past 10 years (Tyler, 1990). These growth figures may give an indication for the future of dairy and dairy-related products in Japan and some other Asian countries. However, there seems to be insufficient basis for further general conclusions.

Let us consider Japan. A successful completion of the Uruguay Round with respect to the General Agreement on Tariffs and Trade in general will increasingly open up the Japanese market for imported goods. This will not necessarily mean that more dairy and dairy based foods will be imported, as the Japanese consumer has specific demands.

One of the most striking demands concerns the health promoting effect of a food product. The Japanese population is one the healthiest in the world. More than 24% of the population is 65 years of age or older. This population is very health-conscious and is interested predominantly in foods with health claims or health indications such as anti-infection, anti-tumour and immune response enhancing activities. Further, the wealth and the industrial climate of Japan are favourable conditions for the acquisition of state-of-the-art technologies and the development of value-added food products by the Japanese themselves. Similar tendencies may be expected in Korea.

In the other Asian countries bordering the Pacific Ocean the consumption of dairy products or dairy based products is still very low. The climatic conditions are difficult for dairy farming. The economic conditions do not yet allow the import of large volumes of dairy products. As a consequence the growing demand for dairy foods, in particular of the traditional type, will be satisfied gradually by growing domestic production and by imports from Australia, North America, Japan and the European Community.

North America and the European Community have some characteristics in common. Without governmental interference too much milk would be produced. Governmental control is exerted by maintaining quota systems. A tremendous reduction in the number of dairy enterprises and the number of dairy factories has taken place. During the last fifteen years the number of dairies in the United States has decreased from 2,791 to fewer than 1,750. Since 1950 the number of dairy ent-

erprises in the Netherlands has fallen from 500 to 28. Three companies only control more than 70% of all milk produced in the Netherlands. The situation is even more pronounced in Denmark, where one dairy cooperative controls more than 70% of all milk produced. Similar phenomena can be observed in France and Germany.

This situation will result in a new era of unprecedented competition with survival itself at stake. Current estimates for market redundancy in some European countries are, according to Robert Forrestal of the Federal Reserve Bank of Atlanta, '...As high as 30 percent. With the drop in restrictions complete by 1993, inefficient or outdated producers will be fair game for merger or acquisition or, in the worst cases, going out of business. With exports expected to decline slightly in the world market and softer prices generally available, the competitive scene on the international market is intensifying' (Forrestal, 1990). In general it is felt that an international market introduction with internationally renowned brands improves a company's position. Consequently, some dairy cooperatives, such as Land O'Lakes in the United States, MD Food in Denmark and ULN in France are trying to internationalise, thus following major international companies, such as Nestle, Unilever, Sanofi, Kraft General Food and Borden.

In the new era of international competition, as indicated before, products with higher value added are considered as a panacea. The utilisation of dairy components as food ingredients could offer possibilities for increasing the added value. Therefore, these possibilities are investigated extensively. However, products with higher value added have to serve the consumer in these markets.

In view of this, it should be asked: 'Who are these consumers and how can their needs be described?' This question cannot be answered in a single phrase. Even the consumers in a single country behave increasingly divergently. However, the following characteristics can be used to typify broadly some consumer needs:

Food safety and food hygiene

Contamination with any non-food ingredient, either hazardous or non-hazardous, should be prevented. Conditions have to be created under which contamination with hazardous microorganisms is limited and multiplication is impossible. For this purpose, good manufacturing practice and strict temperature control in the distribution chain is a must.

Healthy food

Healthy food is interpreted in different ways.

• Sometimes it refers solely to low energy food, e.g., jam with a reduced sugar content, or liquid milk with a reduced fat content. Full ranges of 'light' ('lite') products based upon these principles have been developed and introduced in markets in Western Europe and North America. Do they really satisfy the consumers' sensory perception or would the consumer be more satisfied sensorily by consuming the traditional food in a smaller quantity?

• Healthy food sometimes means low fat, in particular low animal fat in order to reduce the risk of cardiovascular diseases. For this purpose imitation cheese has been introduced in which milkfat has been replaced by vegetable fat.

• Healthy food sometimes means a reduced content of sodium chloride, which can be beneficial in case of hypertension. Reduction of the salt content of a food may give rise to microbiological instability.

• A new fashion is a dairy food with a reduced cholesterol content suggesting wrongly to the consumer that exogenous cholesterol may make a real contribution to an increase in the cholesterol level of the blood serum and ignoring the fact that by making such suggestions the usual dairy products obtain a negative image.

• Sometimes dairy products with high viable counts of *L.acidophilus* and *B.bifidus* are offered as healthy foods. The consumption of such foods in Europe is increasing. Still the scientific justification seems rather weak.

Food style and portioning

Western society is becoming increasingly individualised. This means a multitude of consumer preferences—sometimes convenience foods and sometimes foods that require additional preparation; sometimes exotic foods and sometimes simple daily foods. In general, families become smaller and children leave home at a

younger age. This means also an increasing demand for foods and food ingredients in small portions.

The Play

After this short description of the scene and its actors, namely the markets and the consumers, we will now give attention to the play. The play actually comprises the trends in production and utilisation. In this respect utilisation is not always an established reality. In many cases, utilisation does not surpass the border of what is expected, but never realised. In these cases consumer demands are estimated inadequately. As it is impossible to describe the play in every detail, in the following we will pay attention to the main acts.

Milk product ion

Manipulation of milk production offers a wide horizon of possibilities. Externally, milk production can be manipulated to some extent by the composition of the feed. Also the treatment of cows with bovine somatotropin (BST) can be used to manipulate milk production, provided that legislation allows it.

With regard to the cow itself, genetic factors seem to be of greater importance. Several decades of cattle breeding resulted in high yield cows. Unfortunately the milk of these cows has an increased fat content, which is not in line with the present market demand. Embryo transplantation techniques as developed during the last decade favour a fast distribution of the best genetic material available. Classical breeding technology can give rise to milk with very specific characteristics, e.g., an increased content of χ casein B and of β-lactoglobulin B, both of which increase cheese yield (Van den Berg *et al.*, 1990).

Modern molecular biology techniques, such as electroporation and microinjection, may lead much more directly to transgenic cows with modified milk composition. In particular, the technique developed by Bremel and co-workers according to which the lactalbumin genome is characterised (Bremel *et al.*, 1989) (Mao and Brand, 1990) and combined with an anti-sense gene seems a very promising means of reducing the fat content of milk.

Molecular genetics techniques may also be used to develop cows producing milk with an increased content of a pharmaceutical component, such as interleukin and factor IX (Henninghauser *et al.*, in press).

The production of pharmaceuticals by transgenic cows could be rather near. However, it will be many more years before transgenic cows are allowed by the legislator and accepted by the consumer for the production of modified liquid milk.

Lactose

Lactose is used in the food and pharmaceutical industries. Food applications include infant formulas, candy, baked goods, sauces, dressings, instantised food powders and flavours. These applications are mainly based upon the flavour enhancing, colour enhancing and freeflowing properties of lactose. In the pharmaceutical industry lactose is used as a basis for tablets. Both applications, in food industries and in pharmaceutical industries, will be further exploited in coming years.

A variety of lactose derivatives are known: sweeteners, artificial sweeteners, food additives, chelating agents, acidulants, surfactants and polymers. A sweetener derived from lactose is obtained by hydrolysis. By hydrolysis the relative sweetness compared with sucrose increases from 37% to more than 60%. At the same time, solubility and browning in baking increase and viscosity and sandiness decrease (Modler, 1985b). Hydrolysis can be performed by lactase, acids or hydrogenation (Ryder, 1988). Up till now the application of lactose hydrolysis seems limited. The price of the product and its specific property with respect to rapid browning might be the reason for this limited use.

Recently lactitol, an artificial sweetener derived from lactose and prepared by catalytic hydrogenation over Raney nickel, has been introduced (Visser *et al.*, 1988). Products with lactitol, like products with mannitol, have approximately 50% fewer calories than comparable products made with sucrose. These products are *'sugar free', thus tooth friend*ly. However, like all polyols, lactitol has a slight laxative effect (Anonymous, 1990).

Other lactose derivatives are lactulose, lactobionic acid and lactitol esters of fatty acids. Lactulose is obtained by alkaline isomerisation of the glucose moiety into a fructose group. It is supposed to possess a 'Bifido factor', that would repress coliform bacteria and

stimulate *B.bifidum* in the intestines of babies.

Lactobionic acid is recommended as a complexing agent for metal ions and as a food acidulant with a mild sweet taste. Iron and copper complexes have been used in a limited way in the fortification of milk with trace elements (Visser *at al.*, 1988).

Lactitol esters of fatty acids have been described as surface active agents (Velthuizen *at al.*, 1977). It is hard to say whether this will lead to a substantial utilisation.

In principle, lactose could be utilised very well as a raw material for the production of lactic acid. As the world market for lactic acid exceeds 75,000 tonnes annually, this utilisation seems to be very promising. The majority of the lactic acid produced consists of a mixture of both stereo-isomers, L(+) and D(-) lactic acid, and is used in the food industry. Stereospecific D(-) lactic acid for specific purposes can be produced according to a special process (Veringa, 1987). Unfortunately most of the lactic acid is produced by microbiological conversion of sucrose instead of lactose for the simple reason that the former raw material is usually cheaper.

We now come to a general conclusion with respect to lactose. In principle, lactose derivatives can be utilised in a great many ways. However, only a limited number of these applications are specific for lactose. In many cases the same or a comparable effect can be obtained with sucrose derivatives. Then it is the cost price of the raw material that finally determines whether lactose or sucrose is used.

Milk Fat

In several parts of the world for many years the milk pricing system was a stimulus to promote the production of milkfat with a high fat content. In the European Community this led to an excess of milkfat for many years. The recent campaign for a reduction of animal fat in the diet in the United States and the political developments in Eastern Europe during last year give rise to a further pressure on the world market of milkfat. In view of this, research has been performed and is still being performed to find new outlets for milkfat. However, as the price of milkfat in these parts of the world is maintained artificially at a high level, new utilisations should offer something unique for milkfat rather than being a replacement for vegetable fat.

For many years the possibilities of fractionation of milkfat and the utilisation of different milkfat fractions have been studied. Fractionation by short-path distillation offers an excellent opportunity to obtain fractions from milkfat with distinctive chemical and physical properties (Makhlouf *et al.*, 1987). The process suffers from high thermal requirements.

Separation of milkfat fractions by crystallisation from organic solvents, such as acetone, can easily be accomplished. However, this method has not found industrial application because of the loss of flavour components, the colour alteration and the problem of solvent residue in the milkfat fractions.

Fractionation of milkfat by melt crystallisation has been applied in practice for many years already (Badings *et al.*, 1983). The hard fraction is utilised by industrial pastry manufacturers. The soft fraction is used for standardising anhydrous milkfat for manufacturing of ice cream and is recombined with skim milk.

Fractionation of milkfat in supercritical carbon dioxide has been under investigation for some years. The results obtained in the Netherlands showed that the selectivity is relatively low (Schaap *et al.*, 1986). This relatively low selectivity, the poor solubility and the high capital and energy expenditures do not make this technique very promising. A process for the extraction of flavours from milkfat with supercritical carbon dioxide has been designed. A 90% extraction of the flavours in a two step process leads to a price of approximately US $ 125/kg, which is too high (De Haan *et al.*, 1990).

Finally, some words have to be devoted to enzymatic modification of milkfat. Up till now this subject has received only limited attention. This is probably because enzymatic processes will modify milkfat in such a way that the favourable characteristics, such as natural character, flavour and mouthfeel, will be lost.

Casein and caseinate

Casein can be prepared from skim milk through acidification or by enzymatic hydrolysis. Lactic casein is normally produced by fermentation to achieve pH reduction. Hydrochloric acid and sulphuric acid caseins are manufactured by direct acidification. The precipitated casein is further processed by draining, washing and

drying. Recently an extrusion process for the production of acid caseins has been developed (Fichtali and Van der Voort, 1990).

Caseinates are produced by converting either the wet acid curd or reconstituted acid casein powder to Na-, K-, NH_4- or Ca- caseinate by neutralisation at a pH between 6.8 and 7.5.

Casein and caseinates are commonly used in food product applications where solubility, heat stability and surface-active properties are required. Soluble caseinates are used in a wide variety of products, mainly due to water binding and surface activity: meat products, margarine, cream substitutes, coffee whiteners, foamed and whipped foods, instant breakfasts, puff snacks, cheese and milk analogues and texturised vegetable proteins. Acid caseins are used primarily in breakfast cereals and baked goods and as a protein supplement in food systems where dispersibility is more important than solubility (Modler, 1985[a]).

Whey proteins

After removal of casein from milk the proteins remaining are primarily whey proteins. Some of the characteristics of whey proteins are given in Tables 1a and 1b (Marshall and Harper, 1988).

Much effort has been devoted to adding value to whey. Initially the product was roller dried. The dried product had limitations in terms of flavour, solubility and hygroscopic nature. The spraydrying process led to the production of non-hygroscopic, non-caking whey powder. However, modern evaporating and spray drying techniques deliver a product in which a substantial part of the whey proteins has been denatured.

Partially delactosed whey powder can be prepared from whey by lactose crystallisation and subsequent separation. The product is mainly used in animal feed.

Demineralisation of whey offered new ways of utilisation. The demineralised product contains 10-15% protein and is used in food formulations as a partial replacement for skim milk powder, e.g., in ice cream, bakery products, infant formulas, special dietetic foods and confectionery products (Modler, 1985[b]).

Traditional lactalbumin is produced by heat precipitation or acid precipitation. The traditional product retains its nutritive value but is denatured and is insoluble in water, thus losing its gelation and foaming properties. A range of lactalbumins with varying degrees of functionality can be produced by a variety of heat treatments and pH adjustments. In general these lactalbumins are utilised for protein enrichment of food products.

Soluble whey protein, containing 25-95% protein, is produced by thermal treatment at low pH, ultrafiltration, ion exchange adsorption or polyelectrolyte precipitation. During a thermal treatment for 15 min. at 95°C and at a pH between 2.5 and 3.5 whey proteins are partially denatured but soluble in water. After neutralisation and drying, a product with good water adsor-

Table 1a - Whey protein characteristics (Marshall & Harper, 1988)

Protein	Approximate weight contribution (g/l)	Molecular weight	Isoelectric point
β-lactoglobulin	3.3	18,400	5.35 - 5.49
α-lactalbumin	1.2	14,200	4.2 - 4.5
immune globulins	0.5	80,000-900,000	5.5 - 8.3
bovine serum albumin	0.3	66,300	5.1
proteose-peptone	0.2	4,000- 80,000	5.1 - 6.0
β-casein	< 0.1	24,000	4.7
minor proteins	< 0.05	30,000-100,000	—

Table 1b - Whey protein characteristics (Marshall & Harper, 1988) (continued)

Protein	Stability to heat	Comments
β-lactoglobulin	heat labile	dominates functional properties of whey protein
α-lactalbumin	slightly heat labile	concentrates solubility, gelation, whipping, emulsification
proteose-peptone	heat stable	surface active, enhances whipping
imnune globulin	very heat labile	contributes to gelation
bovine serum albumin	heat labile	binds lipids
soluble casein	heat stable	modifies functionality

ption, foaming and gelation characteristics and good viscosity is obtained.

Ultrafiltration offers the advantage that no denaturation takes place. However, during ultrafiltration the remaining lipids are also concentrated, which has a negative effect on some of the functional properties and the flavour. Several techniques have been developed to remove these remaining lipids.

At pH values lower than their isoelectric point, whey proteins can be adsorbed on cation exchangers and at pH values above their isoelectric point they can be adsorbed on anion exchangers. Thus acid whey is adsorbed at pH < 4.5 to Spherosil S and sweet whey is adsorbed at pH > 5.5 to Sperhosil QMA. Also, with a cellulose based exchanger, called Vistec, adsorption can take place at pH<4.5, whereas elution can take place at pH > 5.5. As compared to concentrates obtained by ultrafiltration, the concentrates obtained with the ion exchange processes are free of remaining lipids and oxidative agents. As a consequence, the functional properties are superior. The Vistec process is said to be commercialised by Bio-isolates in Ireland and the USA to produce a whey protein concentrate with up to 97% protein on dry weight basis.

In Table 2 a summary of the composition of some of the aforementioned whey products is given (Modler, 1985[b]).

A further step in recent developments is the separation of the individual whey proteins. Maubois *et al.* (1987) described a process in which the lipid fraction is removed from whey by heating with calcium ions at pH 7.3 and 50°C followed by microfiltration to remove the lipids. The clarified whey is ultrafiltered and diafiltered followed by heating at pH 3.8 and 55°C for 30 min. to aggregate alactalbumin, followed by centrifugation. In this way native α-lactalbumin with a purity of 80% and native β-lactoglobulin with a purity of 98% are obtained. Al-Mashikhi *et al.* (1988) showed that it is possible to separate immunoglobulin by adsorption and affinity chromatography with copper as chelating agent.

A process for the extraction of pure fractions of lactoperoxidase and lactoferrin from milk serum has been developed and patented by SMR in Sweden (Burling, 1988).

The milk serum is microfiltered and passed through a strong cation exchanger at a high rate of flow for selective adsorption of lactoperoxidase and lactoferrin. Then they are eluted successively and selectively with saline solutions of different concentrations. A similar process for cheese whey is said to be in operation in Belgium.

Whey protein concentrates and individual whey components are used in food products for their nutritive value or for their functional properties. Further individual components are said to be util-

Table 2 - Composition of some whey products (Modler, 1985)

Product	Protein	Fat	Lactose	Ash
whey powder	12.9	1.1	74.5	8.5
partially demineralised whey powder	15	2	78	
partially delactosed whey powder	16-24	1-4	60 (max.)	11-27
whey protein concentrate delactosed, demineralised	27-37	2.4-4.3	40-80	1.4-2.0
whey protein concentrate ultrafiltrated	50-62	1.5-15	15-40	0.5-6
whey protein concentrate ultrafiltrated and defatted	63.1	.5	28.9	2.3
whey protein concentrate Spherosil QMA	79.4	1.0	3.3	1.9
whey protein concentrate Spherosil S	96.4	1.0	.1	1.9
whey protein concentrate Vistec	90	.2	.2	3

ised for specific purposes. Some of these possible utilisations are summarised in Table 3.

Protein modifications

Physical modification by heat treatment.

A partial denaturation caused by heat treatment gives rise to unfolding of the proteins. This makes hydrophobic groups available which then can orient themselves to an oil-water interface. A mild heat treatment of whey protein concentrate improves the solubility and the emulsifying and foaming properties (De Wit and de Boer, 1975).

Chemical modifications

Modification of the electrostatic repulsion by creating negative charges (acetylation) gives rise to an elongation or unfolding of the proteins and a reduction of the surface tension for oil-water and air-water interfaces (Vuillemard *et al.*, 1989). By acetylation the solubility of casein of low pH and the water binding properties of whey proteins is increased. By succinylation of whey proteins most of the functional properties are improved.

By esterification of proteins the negative charge of carboxylic groups at a neutral pH is changed to a positive charge. In this way emulsion stability can be improved considerably.

By phosphorylation the internal electrostatic repulsion of proteins is increased. As a consequence foaming properties, viscosity and water retention of casein are improved but solubility and emulsifying properties are slightly diminished.

A typical chemical modification takes place during the formation of meat analogues. Jaynes and Asan (1976) described a process in which fibres are prepared using acetic acid and NaCl as the coagulant.

Enzymatic modification

During the last decade enzymatic modification of proteins has received much attention. A variety of enzymes such as trypsin, chymotrypsin, pronase, prolase, pancreatin, etc., has been investigated (Vuillemard *et al.*,1989). The objectives of enzymatic modification are various. The objective may be the production of a

Table 3 - Same possible utilisations of whey proteins and whey components

Product/component	Preparation	Possible utilization or function	Reference
whey protein concentrates	ultrafiltration	nutritive value functional properties	
specific whey fractions	ultrafiltration and diafiltration	with 1% fetal calf serum as medium for cell cultures	Derouiche *et al.* (1990)
phospholipids	microfiltration, ultrafiltration, heating and	liposomes in cosmetics, emulsifying agent diafiltration	Baumy *et al.* (1989)
defatted whey protein concentrates	microfiltration, ultrafiltration, heating and diafiltration	functional properties; egg white replacer	
immunoglobulins	electrophoreses and ion exchange chromatography	in food formulas	
lactoperoxydase	ion exchange chromatography	in infant formulas	
lactoferrine	ion exchange chromatography	infant formulas	
α-lactalbumin	thermal precipitation	influence on brain functions (hunger, sleep, local contraception)	
peptides	enzymatic hydrolysis of whey protein concen-.trate	enteral nutrition	
whey protein/ egg white fat substitute		ice cream, sour cream, yoghurt, butter, spreads, dressings	Umhoefer (1988)

hypoallergenic food for babies with milk protein allergy, the production of a partially digested protein for patients with insufficient pancreatic activity, the production of a rehabilitation food for patients who have suffered a serious illness, the production of cosmetics based upon liposomes in which dermatologically active peptides are included, or the production of products with improved functional properties, such as solubility or water binding, emulsifying, foaming and gelation properties.

In recent years much attention has been given to the role of specific peptides derived from casein which seem to have physiological activities. Some of these peptides are believed to have an influence on sleep, some are believed to have an opiate activity influencing among other things the secretion of insulin and somatostatin, some are believed to stimulate the immune system and others are believed to have antihypertension activity system in neonates (Maubois and Leonil, 1989). However, many of these physiological effects need additional scientific evidence.

Conclusions

In the foregoing I have shown that present day scientific and technological know-how offers a multitude of possibilities for the production and utilisation of dairy ingredients. We may expect that continuing research and development efforts will further enlarge this technology push as was the case in past years.

However, we have to take into account that it is not just technology push but even more so market pull that plays a role. In order to understand which possibilities can be realised in practice, we have to pay full attention to the scene and its actors, the market and the consumers. I have shown that in specific cases the market or the consumers may prevent a possible utilisation becoming a successful utilisation in practice.

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Developing Non-Fat Milk Powders with Specific Functional Properties

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The successful application of dairy-based ingredients in food products depends on their capability of providing one or more functional attributes to the food. There is a continuing need to develop new and innovative dairy-based ingredients that can meet the increasingly sophisticated requirements for specific functional performance sought by the developing food industry. Non-fat milk powders are significant within the range of dairy-based ingredients that can be tailor-made with specific functional properties. Non-fat milk powders, because of their innate physico-chemical properties, possess a wide range of functional attributes. In addition, the functionality of non-fat milk powders can be readily modified by available industrial processes. This paper discusses the development of non-fat milk powders with specific functional properties. Attention will be given to current methods for modification of functionality, strategies for developing a new range of functional non-fat powders and factors affecting their utilisation in manufactured food products.

Introduction

Milk is an excellent raw material which readily lends itself to modification by industrial processes to yield a diverse range of dairy-based ingredients with extensive functional and nutritional properties. There are numerous reports in the literature on the emergence and utilisation of functional dairy based ingredients in a variety of foods (Evans 1982; Kirkpatrick and Fenwick 1987; Early 1990; Snyden 1990). Among some of the major applications of dairy-based ingredients are their use in recombined and manufactured dairy products (IDF, 1982; Rothwell, 1984; Jensen, Ipsen *et al.*, 1987), chocolate and confectionery (Mann, 1980a; Edwards, 1984; Mann, 1985; Campbell and Pavlasek, 1987; Munksgaard and Ipsen, 1989), meat and meat products (Mann, 1980b; Lankveld, 1987; van der Hoven, 1987) and bakery goods (Mann, 1980c; Parkinson, 1984; Sanderson, 1985; Cocup and Sanderson, 1987).

It is evident that dairy-based ingredients, amongst which non-fat milk powder is significant, have a prime position amongst functional food ingredients. The versatility of dairy-based ingredients has no doubt contributed to their popularity. However the developing food industry is placing more stringent requirements on specific properties and functional performance of ingredients.

The dairy industry has the ability to respond to the needs of the growing food ingredient industry by developing a new range of innovative food ingredients. However, the extent to which dairy-based ingredients can maintain their current status within the lucrative food ingredients market and obtain a greater share of this market will depend on the competitiveness of the new dairy ingredients against other available non-dairy ingredients which offer a similar range of functional attributes. This in turn will be reliant upon the functional performance of the new ingredients, their ability to reduce manufacturing costs, their capacity to produce a superior manufactured prod-

uct and their role in aiding product diversification of food products (West, 1984; Early, 1990).

This paper discusses the development of non-fat milk powders or skim milk powders (SMP) with specific functional properties. Current methods and alternative approaches to manufacture of tailor-made SMP are considered. Issues on selection and utilisation of SMP in manufactured food products are included.

Development of SMP with Specific Functional Properties

The successful development of SMP with specific functional properties requires an understanding of the intrinsic functional attributes of the milk proteins, knowledge about factors affecting functionality and processing methods that can be used for modification of functionality. In tailor-making SMP with specific functional properties for a particular food application, it is also essential that the functional performance required of the ingredient is well defined.

Functional properties of SMP

The functional attributes of SMP are essentially the manifestation of the functional properties of milk proteins. They include water absorption and water binding properties, solubility, emulsification and foaming characteristics, viscosity, gelation and colloidal and heat stability (Kinsella, 1984; Modler, 1985). These are the major functional properties that govern the role of SMP and other protein products in food applications. More information on aspects of physicochemical properties and functionality of milk proteins can be found in recent comprehensive reviews on the subject (Fox, 1989; Kinsella *et al.*, 1989; Mulvihill and Fox, 1989).

As for other food proteins, the functionality of milk proteins can be altered by application of a number of physical and chemical modification methods which include the application of heat, pH modification, ionic manipulation, chemical derivatisation and enzymic modification (Kinsella *et al.*, 1984; Modler, 1985).

Modification of functionality of SMP

The methods currently available for modification of functionality of SMP are primarily those that are available for altering the functional properties of milk proteins and other protein foods.

The application of a heat treatment of milk, prior to evaporation and drying during powder manufacture has been the most widely used method for establishing different functional properties in SMP. Although comparatively new, the use of ultrafiltration (UF) technology holds considerable promise for development of a new range of powder products (Kelly, 1987).

a) Application of heat: The judicious application of heat has been used to develop a range of SMP with specific functional properties. The three basic grades of SMP available commercially are low-, medium- and high-heat. These classifications relate to the type of heat treatment applied during powder manufacture. The different SMPs are usually distinguished on the basis of WPNI (whey protein nitrogen index) which is a measure of the amount of soluble whey protein nitrogen per gram of powder (Anon., 1971).

b) Use of UF technology: Research has shown that it is possible to exploit UF technology to broaden the range of SMP with desirable functional properties (Butterick and Higgins, 1982; Jimenez-Flores and Kosikowski, 1986; Jensen 1990). A range of skim milk retentate powders, made from milk that has been concentrated to varying extents by UF, have emerged on the market. Their major application has been in the manufacture of selected recombined cheeses (Bjerre, 1990; Mahaut and Maubois, 1990).

Strategies for Developing SMP with Different Functional Properties

It is interesting to speculate on alternative approaches for modification of functionality that may lead to new tailor-made SMP with specific functionalities. It appears that current commercial methods are based on the use of selected methods of modification in isolation, usually either heat treatment or UF. In principle, a broader range of functionalities can be established in SMP by combining two or more methods available for modification. Research on the interplay of a combination of process variables and modification methods on functional properties of SMP using a multi-

variant statistical design is perhaps warranted. A multivariant design to study the interacting roles of processing variables may at first seem to be a formidable task. It is made more complex by the natural variation of the raw material, skim milk. However, there are clues in the literature about the potential value of this approach from fundamental studies on milk protein and functionality. For example, the value of this approach is evident from the work of Nielsen *et al.* (1973) who used a four-factor response surface experimental design to determine the composite effect and inter-relationship among four major processing variables on whey protein denaturation.

It is recognised that the development of specific functional properties of milk proteins and skim milk which are subjected to different heat treatments is a consequence of a number of important chemical and physico-chemical reactions. Among the major reactions that take place during heating are whey protein denaturation, interaction of denatured whey protein and casein, changes in mineral equilibrium and the Maillard reaction. Various processing variables such as time and temperature of heating, pH, ionic equilibrium and total solids content affect the rate and extent of the heat-induced changes in milk and milk proteins (Morr, 1985; IDF, 1989). Alteration of time and temperature of heating has been used for developing the different functional properties of SMP. One can also expect that simultaneously altering other process variables, in addition to time and temperature of heating, may lead to the development of functional attributes in SMP which are different to those possessed by the conventional low-, medium-, and high heat powders. For example, there is evidence that adjustment of pH of skim milk prior to heating has effects on the extent of interaction between, β-lactoglobulin and κ-casein (Creamer, Berry and Matheson, 1978). Since the functional attributes of heated proteins are influenced by the degree of this interaction, it is likely that adjustment of pH prior to application of heat can be used for alteration of functional attributes. Singh *et al.* (1988) found that pH of milk at the time of heating affected the influence of heating on rennet coagulation characteristics.

There is evidence that an approach to development of tailor-made SMP which is based on a combination of processes can be advantageous. Recent studies have shown that application of a combination of UF-concentration and heat treatment has some beneficial effects on cheese making properties of milk (Green, 1990; Sharma, Hill and Goff, 1990). Heat treatment impairs the rennetability of milk. In contrast, UF-concentration of milk leads to rapid gelation during cheesemaking and can thus be used to counteract the effect of heat on rennetability. Both processes increase the recovery of milk protein in cheese, but by different mechanisms. There is a reduced amount of whey released in cheesemaking with UF concentrates, which results in the retention of more native whey protein. The increased recovery of milk protein in cheese made from heated milk is a consequence of the heat-induced interaction between whey protein and casein which causes more of the whey protein to be retained. In addition, heated milk forms a finer protein network with more retention of fat and water. The results of Sharma, Hill and Goff (1990) showed that when heated skim milk was ultrafiltered, its curd-forming ability was restored. Green (1990) investigated the alternative sequence of application of UF-concentration of whole milk followed by heat treatment on the cheesemaking potential of milk. It was found that heating had progressively less influence on coagulability with increasing UF-concentration and that heat treatment of UF-concentrates led to reduced whey loss and a slight improvement in curd but did not affect fat loss (Green, 1990). In view of the potential market for manufacture of recombined cheese from skim milk retentate powders, it will be of interest to apply and extend these results to the development of tailor-made retentate powders for selected recombined cheesemaking operations.

Various possibilities exist for further development of a range of skim milk retentate powders which capitalise not only on the combined effects of UF-concentration and heat treatment but also exploit the effects of changing process variables within each process and alteration of the sequence of application of individual processes on functionality. The framework for development of these powders can be provided by using a multivariant statistical design to simultaneous-

ly study these effects and their interaction on the expression of functionality. In planning the design, it is of utmost importance to take into account the available evidence in the literature for identification of important variables that are likely to alter functionality. For example, if the application of a heat treatment is studied, factors such as concentration of milk solids, pH, whey protein-casein ratio, ionic equilibria and temperature/duration of heating should be considered. When applying UF as a modification process, factors such as pH and temperature of UF and preheat treatment of milk are of importance as they affect the properties of the ultrafiltered milk (Hallstrom and Dejmek, 1988a, 1988b) and consequently will have an influence on the functionality of the skim milk retentate powders. Accurate identification of the important factors and processes affecting functionality are essential for a scientifically-based design for evaluating the composite influence of various factors on modification of functionality.

Selection and Utilisation of SMP as Food Ingredients

As the basic conventional grades of SMP in the market have been low-, medium and high-heat powders, food manufacturers have tended to sel-

Table 1: Utilisation of skim milk powder (SMP) in selected food products

Food Product	Type of SMP ingredient commonly used	Perceived major performance offered by SMP
Recombined milk	Low- and low-medium-heat	Solubility and lack of cooked flavour
Recombined evaporated milk	High-heat	Good heat stability
Recombined cheese	Low-heat	Good rennetability
Ice cream	Medium-heat	Emulsification, foaming and water absorption
Confectionery	High-heat	Water absorption and texture modification
Comminuted meat	High-heat	Emulsification, gelation and water absorption
Baked goods	High-heat	Water binding and texture modification

ect SMP on the basis of their heat classification. As a result of this traditional selection process, recommendations about the suitability of SMP with different pre-heat treatments in a variety of products have been built up over the years.

Table 1 lists the commonly used types of SMP in selected food products and the major functional attributes required of the skim milk powder ingredient (Kinsella, 1984; Molder, 1985; Sjollema, 1988; Jensen, 1990). SMP has many functional attributes and its functional role in a food product may be due to its ability to impart one or more properties to the food. Sometimes the major functional performance required of the SMP ingredient is obvious. However, because of the many interactions between SMP and other ingredients, it is often difficult to ascertain the exact functional role played by the SMP ingredient.

The recommendations in Table 1 are generalisations of limited validity. Although heat induces changes in functionality and alters suitability of SMP for specific food applications, judgements on functional performance of SMP in a range of food products are not directly predictable from classifications of SMP based on heat treatment received during powder manufacture. This may often be due to inadequate control of other parameters (e.g. pH, ionic equilibria, whey and casein content) which affect the rate and extent of heat-induced changes. Even results from tests on functional properties of SMP in model systems cannot always be accurately extrapolated to define and predict functional performance in the food product. For example, specifications for SMP intended for recombined evaporated milk manufacture dictate that high-heat powders should be used and in addition require that a 20% solids non-fat reconstituted milk withstand coagulation at 120°C for a specified time. However, this approach to powder selection was not always reliable as it did not ensure that SMP exhibited the required functionality when incorporated into recombined evaporated milk (Kieseker and Aitken, 1988). A new improved product-related heat-stability test was subsequently developed (Kieseker and Aitken, 1988).

Different types of skim milk powder have been advocated for use in yoghurt manufacture, depending on the manufacturing process for production of recombined yoghurt. Jensen (1990) suggested that high-heat powder is suitable for recombined yoghurt manufacture. Sjollema (1988) suggested that it is preferable to apply the high-heat treatment in the recombined yoghurt plant than during powder manufacture and therefore recommends the use of a low-to medium-heat SMP. However if the high-heat treatment cannot be carried out in the recombining plant a high-heat powder should be used (Sjollema, 1988). In yoghurt manufacture the major functional attributes required of the milk protein are water binding and viscosity and the application of a high-heat treatment which improves hydration properties is therefore necessary. Different manufacturers may have different manufacturing practices and it is important for the supplier of SMP to be aware of these as alteration of processing variables and product formulation during production of manufactured food products may change the functional requirements of the ingredient.

Conclusion

The successful development and utilisation of new SMP in food products depends not only on the ability of the dairy technologist to manufacture a wide range of powders with different functional properties but is also dependent upon tailor-making the powders to meet the specific functional performance required of an ingredient in particular food product. Ideally the dairy technologist, powder supplier and food manufacturer should work together as their inputs are required for:

1) Identification of the most important functional attributes required of the SMP in a targeted food application;

2) Application of appropriate modification procedures to achieve the desired functionality of SMP (based on an understanding of the fundamental basis for functionality and factors controlling it) and

3) Evaluation of the functional performance exhibited by SMP when it is incorporated into the specific food product that has been targeted.

There is also a need to develop more relevant product-related specifications which define the functional performance requirements of SMP ingredient

which take into account the manufacturing processes used for production of the food product.

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High Fat & Full Cream Powders as Food Ingredients

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Definitions

Full cream milk powder (FCMP), also known as whole milk powder (WMP) is 'whole milk in powder form'. If a typical composition milk of 3.5% milk fat and 13% total solids is dehydrated to a powder containing 2.5% moisture, the fat content will be 26.3%. On this basis 26.0% has been accepted internationally as the minimum milk fat permitted for a powder to be termed 'full cream' or 'whole'. The majority of the world production of milk fat containing powder is processed to contain milk fat in the range 26 to 29%.

High fat powders do not have such specific standards for composition, but a reasonable definition is that of Early (1990) whereby high fat powders are those with in excess of 35% milk fat. The nomenclature used for high fat powders is often descriptive of the production ingredient providing the milk fat, or is indicative of the dairy product of which it is the dry form equivalent (Table 1).

Full Cream Powder as a Food Ingredient

From the definition given above, it follows that FCMP can be utilised wherever total milk solids are required.

This may be for reasons of organoleptic property, functional characteristic, or nutritional value provided by the major components of milk (Table 2).

Considering the wide range of properties that FCMP can impart to foods, and the convenience of obtaining total milk solids in an easy-to-handle concentrated form, it is not surprising that its use as a food ingredient is extensive. (Table 3).

The information in Table 3 is based on industrial usage of FCMP.

My company commissioned a survey to determine the domestic usage of milk powders and the results for a group of purchasers of FCMP show that it is principally used as a cooking or baking ingredient (Table 4).

Manufacture of Full Cream Milk Powder

The scope of this paper does not allow for a comprehensive treatment of the details for manufacturing FCMP. A brief outline is included to provide the basic manufacturing process steps (Table 5), some of which are referred to elsewhere in the text.

Process Controls Relative to Ingredient Usage of FCMP

The following examples are indicative of the many controls that can be exercised during the manufacturing process to maximise FCMP functionality relative to its use as an ingredient in specific foods.

Milk chocolate

Milk fat is compatible with cocoa butter but when supplied from milk powder it needs to be in a readily extractable form, termed free fat, to maximise the reduction in viscosity of the liquid chocolate mass

TABLE 1

Names, source of milk fat, and fat content for milk fat powders

Names	Source of milk fat	% milk fat
Full cream powder Whole milk powder	Whole milk	26 - 29
Butterfat powder	Anhydrous butterfat	26 - 50
Cream powder	Cream	36 - 72
Powdered whipping cream	Anhydrous milk fat or cream	50 - 75
Butter powder or cream	Anhydrous milk fat	75 - 85

TABLE 2

Composition of FCMP and contribution as a food ingredient

Major components	Typical %	Contribution as an ingredient
Carbohydrate (100% lactose)	38.0	Flavour, colour from Maillard reaction
Protein	27.0	Nutritional value, gelation, emulsification
Milk fat	26.5	Creamy flavour, viscosity adjustment, texture
Minerals (as ash)	6.0	Nutritional value e.g., Ca

TABLE 3

Foods in which FCMP is used as an ingredient

Confectionery
Milk chocolate
Candy
Icings
Fudge

Bakery products
Cakes
Pies
Biscuits
Cookies

Dry mix products
Cake mixes
Pancake mixes
Beverage whitener

Other
Soft-serve ice mix
Canned custard
Sweetened condensed milk
Chocolate drink

TABLE 4

Domestic usage of FCMP according to market survey in Melbourne & Sydney

Usage occasion	% of survey group	Cooking/baking	% of survey group
Cooking/baking	82	Cakes	68
In coffee/tea	41	Custards	52
On cereal	35	Sauces	30
Drink as milk	29	Puddings	25
In cocoa drinks	22	Slices	16
When camping	9	Scones	16
Fresh milk extender	6	Casseroles	10
Emergency milk supply	5	Biscuits	5

TABLE 5
Process outline for manufacturing FCMP

Operation	Typical Systems Used
Standardisation	Adjustment of fat to solids-not-fat ratio usually by addition of skim milk.
Pre-heating	Indirect and direct heaters with variable holding time.
Evaporation	Evaporator with multi-effects operating under decreasing temperature - increasing vacuum.
Homogenisation	Single or 2-stage homogeniser.
Spray drying	Pressure jet or rotary disc atomisation; multi stage drying.
Packaging	25kg polylined multiwall paper sacks; bulk bins (wooden or fibre board).

TABLE 6
Foods in which high fat powder is used as an ingredient

Dry Mixes
- Soup
- Sauce
- Ice cream
- Cake

Bakery Products
- Cakes
- Puff pastry
- Flaky pastry

Confectionery
- Milk chocolate
- Coatings
- Pastes
- Fillings

Other
- Canned soup
- Canned sauce
- Cream liqueur

TABLE 7

Examples of high fat powder compositions

Butter powder (1)		Powdered Whipping Cream (2)	
	%		%
Milk fat	82.0	Milk fat	66.048
Skim milk solids	6.7	Skim milk solids	32.080
Caseinate-citrate	6.7	Emulsifier	1.415
Free-flow agent	0.5	Whipping-agent	0.377
Moisture	0.6	Anti-oxidant blend	0.080

(1) Hansen(1963)

(2) Kieseker *et al.* (979)

that is a consequence of its addition (Hansen and Hansen 1990). Powder with high free fat can be manufactured by co-spray drying cream and concentrated skim milk using a rotary atomiser with a double wheel and twin-feed system (Pisecky 1990).

Sweetened condensed milk (SCM)

The initial viscosity and rate of age thickening of SCM is largely dependent on the heat-treatment and homogenising pressures to which the FCMP has been subjected. The preheating conditions must be selected to give a medium-heat product, and the relatively low pressure, two-stage homogenisation employed. (Kieseker *et al.* 1984).

Beverage whitener

There is an increasing demand for FCMP to function satisfactorily as a tea or coffee whitener. This requires characteristics that include flowability and rapid dispersion. Considerable contribution towards obtaining these functions is achieved by manufacturing the FCMP as an agglomerated powder using the technique of recycling fine powder particles back into the wet-zone of the primary drying chamber.

High Fat Powder as a Food Ingredient

Clearly the emphasis on contribution as a food ingredient for high fat powder is in respect of the milk fat component. As with FCMP, the milk fat may be required to contribute to flavour, viscosity adjustment or texture, but high fat powder is also viewed as a very convenient form for handling milk fat and incorporating it in to foods as a shortening. For example, it has been reported that butter powder blends more easily and quickly with flour and gives a more homogeneous mix than does butter (Bazin 1989).

Composition of high fat powders

For stability during spray-drying the milk fat needs to be in the form of an oil-in-water emulsion while the end-use often demands that the milk fat be de-emulsified to some extent. It is therefore usual for high fat powders to contain emulsifying and stabilising agents at carefully selected levels to give the desired functional properties.

High fat powder requires some special manufacturing conditions. Pneumatic conveying systems are unsatisfactory as they become blocked and the high velocity movement in cyclones and narrow air ducts causes the release of fat as free fat. Immediate and rapid cooling is necessary for the powder to remain freeflowing.

The Future for FCMP & High Fat Powders

FCMP is well established as a food ingredient, quantities used annually being in the order of hundreds of thousands of tonnes on a world-wide basis. This situation can be maintained provided manufacturers keep tuned-in to customer requirements and the researchers and technologists keep process and product modifications occurring to meet market needs.

For example, the use of FCMP is frequently challenged by skim milk powder and anhydrous milk fat because these two products have a longer shelf-life. The New Zealand dairy industry is meeting this challenge by introducing gas-barrier liners into 25kg bags and using a system of nitrogen flushing and form-fill-seal packaging that achieves a low residual oxygen content. This concept is not new and the process is costly to establish, but the potential marketing advantage is considerable.

The use of high fat powders based on milk fat is challenged by such products as:

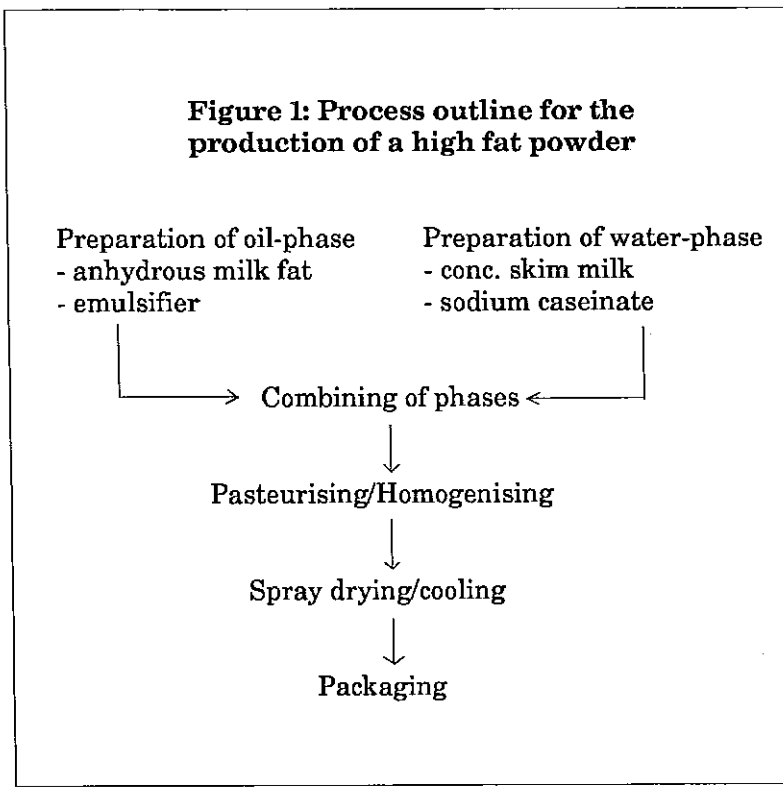
- High fat powders based on vegetable fat (usually hydrogenated) claimed to have longer shelf-life and better functional properties, e.g. shortening.
- Fresh products, e.g. cream, on the basis of flavour.
- Less costly fats and oils.

There are answers to these challenges. The great advantage that milk fat has over other fats and oils is its flavour: one that is widely accepted and desired in many foods the world over. This fact still has considerable potential for market exploitation. The nitrogen-flushing/barrier packaging concept has application with such products that can command a premium price. Technology is already available that enables milk fat-based powders to perform with equivalent functionality to other products.

The convenience of transporting, storing, handling and measuring dry ingredients when compared to liquid systems must have significant appeal. Perhaps there is also a place for powdered hard-fraction milk fat, produced by cold temperature spray drying, as is being done with animal fat.

Increased utilisation of milk fat to avoid surplus stocks occurring is a concern of every dairying country. Because of its diverse functional properties as an ingredient in many foods, FCMP is playing a significant role towards that end and will continue to do so in the future. There is potential for increased use of high fat powders and this will be realised as customers better identify their requirements, technologists answer the requirement challenges and market forces allow milk fat to be competitively priced.

Figure 1: Process outline for the production of a high fat powder



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Opportunities for Whey & Permeate Powders

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Introduction

The world-wide production of whey powder has increased significantly over the past 15-20 years, driven mainly by pressures to reduce effluent loading, but more recently by increasing market opportunities for food applications.

Significant markets have developed over the past 20 years for whey as a partial or total replacement for skim milk powder.

The dairy industry itself uses whey in the manufacture of ice-cream, processed cheese, cheese powders and in increasing numbers of milk powder blends which are being produced from mixtures of whey, skim milk, buttermilk and/or wholemilk. These blends, in addition to various whey powders, are being used in the confectionery industry (especially in fudge and caramel) and the bakery industry (in breads, biscuits and cakes) where its use can significantly enhance the flavour, colour and texture of the final product.

In more recent years, whey has become a key component in the formulation of infant foods. As infant formulae have been modified to more closely resemble human milk, the need for a quality source of both lactose and whey protein has increased. Whey has these key components and can be processed to meet the strict requirements of the infant formula manufacturers. However, as with the manufacture of skim milk powder, whey powders must now be manufactured to meet specific composition and functional requirements. The industry must be prepared to manufacture such products to the specific requirements of the end user.

Manufacture of Whey Powders

How can the functional/compositional properties of whey powder be altered? Currently, the major modifications are achieved through either drying techniques (to reduce the highly sticky nature of the product) or by demineralisation to reduce the mineral or 'ash' content of the whey. However, membrane processing, such as ultrafiltration may also be employed to increase the protein content (without necessarily proceeding as far as producing a whey protein concentrate) and it is quite probable that other techniques may be applied in the near future to alter the ratio of some of the individual whey protein fractions present.

Non-Hygroscopic Whey Powder

Normal whey powders are sticky because of the high level of lactose, most of which is in the very unstable amorphous or 'glass' state. This form of lactose rapidly absorbs moisture causing the powder to become sticky and to lump. It is possible to significantly reduce this problem by precrystallising the lactose in the whey concentrate before drying. Further improvements can be achieved if the powder is initially dried to a relatively high moisture content and held to

allow crystallisation of the remaining lactose before final drying.

In today's market 'ease of use' is important. It is generally accepted that for most applications crystallisation of the lactose in the concentrate is a minimal prerequisite in the manufacture of a standard cheese whey powder.

Demineralisation

Because of the relatively low mineral content of human milk, demineralisation is an essential process for whey powder destined for infant formulae. Minerals have been traditionally removed from whey by the processes of ion exchange and/or electrodialysis.

Ion-exchange has become the most widely used process, mainly because of its much lower capital cost. However, it has high variable costs and results in significant quantities of acid and alkali effluents resulting from column regenerations. In addition, most infant food manufacturers today are not only concerned with the total mineral content of the whey but also with the individual mineral levels, placing upper limits on some and lower limits on others. Because of the different preferential removal of minerals achieved by ion-exchange and electrodialysis, some of the more sophisticated whey processing plants employ combinations of the two processes, so that they may achieve the appropriate mineral balance in the final whey powder.

More recently, a new technique for a least partial demineralisation of whey has been developed. This is a membrane process known either as nanofiltration (NF) or ultraosmosis (UO). The process is very similar to reverse osmosis, except the operating pressures are significantly lower (typically 30-40 bar) and the membrane is slightly porous, permitting the passage of water and of the monovalent ions such as sodium, potassium and chloride. Such preferential removal of these ions makes it an ideal 'companion' to ion-exchange processing in the production of demineralised whey powder.

The Murray Goulburn Co-operative Co. Limited has recently installed an ultraosmosis plant (Filtration Engineering Company Inc., Minneapolis, U.S.A.) at its Kiewa Branch. The plant has a capacity of approximately 200,000 litres per day and consists of

Table 1

Typical Composition of 'Whey Powder'

	Cheese Whey	UO Whey	Demin. Whey	UF Milk Permeate
Moisture	3.5	3.5	3.5	<0.5
Fat	1.5	1.5	1.5	-
Lactose	72	77	81	88
Protein	13	13	13	3
Ash	10	5	1	9
pH	5.8-6.2	6.0-6.2	6.4-7.5	6.6

two stages of spiral wound, cross-linked, polyamide membranes with a total installed membrane area of 900m^2. Cheese whey is separated, pasteurised and fed into the plant at 18-20°C. The whey is concentrated to approximately 22-23% total solids (i.e. 3.5-4.0:1 concentration ratio). The membrane has a high (70-75%) permeability for sodium, potassium and chloride and a low (5-10%) permeability for calcium, magnesium and phosphorous. During this concentration stage, an overall demineralisation of 35-40% can be achieved. The membranes are sensitive to oxidising agents such as chlorine, have a tolerance of pH2.3-10.0 and maximum operating temperature of 57°C. Cleaning is achieved by daily enzyme and alkali treatment and a citric acid wash is required at least every other day.

The concentrated, partially demineralised whey is transported to the Cobram Branch where it is either evaporated and dried directly, or blended with other wheys, further demineralised by ion-exchange, evaporated and dried.

The plant has now been in operation for over six months, averaging 20 hours per day. Operating pressures and flux have not changed significantly since commissioning.

Milk Permeate

Permeate from the ultrafiltration of skim milk or whole-milk consists of mostly lactose and minerals. Because the product is extremely high in lactose, it is difficult to dry on normal spray drying plants. Blockages occur frequently and because the material sticks to the chamber and walls, burning or scorched particles frequently occur. Permeate powder requires some level of demineralisation for it to be classified as a food grade lactose. This may be achieved without the traditional lactose crystallisation and washing process, by ion-exchange and, depending on mineral level, the application of ultraosmosis. The product, however, has limited applications as a food lactose or fermentation medium.

The approximate composition of the various whey powders, referred to in this paper is shown in Table 1. The major variables are the levels of lactose and minerals. While the total ash or mineral content can be individually altered, for some applications (especially in infant food formulae) the quantity of the individual minerals must also be controlled. The process of ultraosmosis has proved to be a commercially viable option to electrodialysis and can be used to help manipulate the final mineral composition in a demineralised whey powder.

Milkfat Fractionation & Cholesterol Removal

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Introduction

Dry fractionation is a chemical-free technology which is very suitable to separate the hard and soft fats within milkfat. Milkfats with softening points of 5°C to 44°C can be obtained, whilst maintaining the 'naturalness' and flavour of the original product. The range of fractions obtained provides the opportunity to develop new products and to improve the quality of some existing products. The technology is readily available and well established commercially in many countries.

Several technologies to remove cholesterol from milk products and milkfat are also emerging. No single method for cholesterol removal stands out as best under all circumstances.

Having regard to the nutritional issues involved and the official guidelines in many countries, it is expected that there will be a market for 'low cholesterol' milk and milkfat products for the foreseeable future. Labelling constraints may prevent the ability to take full marketing advantage of cholesterol removal.

New Technologies

Recent technologies make it possible to adapt milkfat to a wider range of uses than traditionally possible. Also, some of the real or perceived physical and nutritional disadvantages of milkfat can be largely overcome by the application of these technologies. Most of these involve some kind of fractionation or separation process.

Many of the desired melting and other physical properties of milkfat can be selected by 'dry fractionation' of the whole milkfat. Dry fractionation has become the dominant and probably the only commercially used fractionation technology. The process is termed 'dry' as no chemicals, soaps or solvents are used. Only mild heating, cooling and filtration are involved, thus preserving the delicate flavour and the naturalness of milkfat. In Europe over 800 tonnes of milkfat are fractionated each day (nearly 10% of all butter and butter oil produced) and the fractionation capacity is still expanding. Two new plants were installed in 1990. Although some major butter producing countries like Ireland, the UK and Italy do not fractionate milkfat at all, in Belgium the fractionation capacity exceeds the domestic milkfat production. Table 1 lists the production capacities installed in various countries.

Technologies are also emerging which allow the nutritional properties of milkfat to be changed by cholesterol removal. Unlike fractionation, no single technology stands out. There are several systems which are on the verge of commercial reality and there are some in the late stages of their development. Each method has advantages and disadvantages, which will be discussed.

Dry Fractionation

Dry fractionation is the only process used to fractionate high quality milkfat and the dominant commercial system is supplied by Tirtiaux SA Fractionnement, from Belgium (Tirtiaux, 1990). Other systems, where the total installed capacities are lower include those of De Smet, also from Belgium (Kokken, 1990a), and the proprietary systems in the Netherlands and New Zealand.

A brief description of the Tirtiaux process follows and the reader is referred to recent papers for further details if required (Nagant, 1986; Deffense and Tirtiaux, 1989; Tirtiaux, 1989; and Versteeg and Taylor, 1990).

In the Tirtiaux process butteroil is melted and heated to over 60°C in a jacketed tank. Under agitation the butteroil is cooled over a period of several hours to a temperature near the melting point. At that point some crystals have been formed consisting of saturated triglycerides (Deffense, 1988). Then the cooling is slowed to give a very mild super-cooling, allowing any fat crystals present to grow to a relatively large size (0.2-0.4mm). If the cooling or agitation is too fast, more and smaller crystals are formed which agglomerate and are not easily filtered (Nagant, 1986; Deffense and Tirtiaux,

Table 1

Installed dry milkfat fractionation capacity by the Tirtiaux process[1]

Country	Daily Capacity[2] (x 1000kg)	Annual capacity[3] (x 1000kg)
Belgium	300	60,000
Denmark	32	6,400
Finland	12	2,400
France	242	48,400
Germany	32	6,400
Japan	25	5,000
Netherlands	100	20,000
Norway	32	64,000
Total	775	155,000

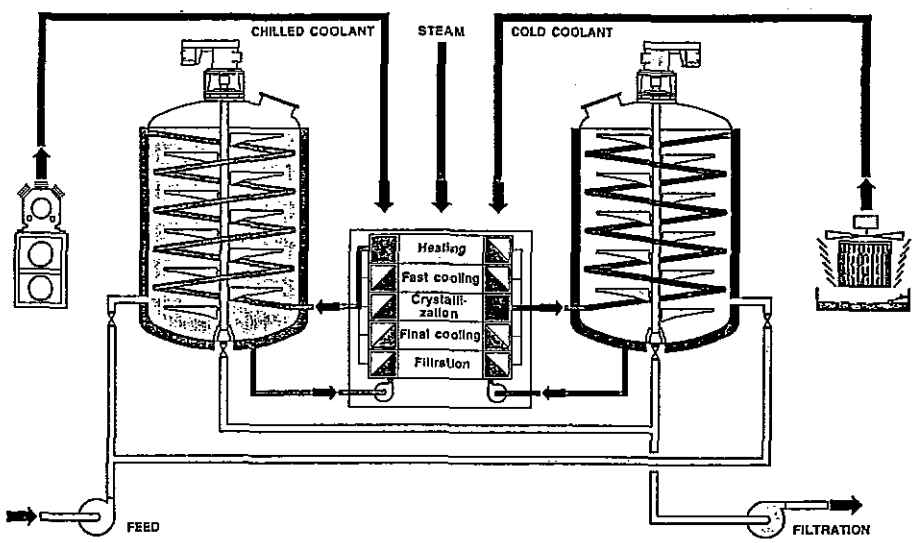
[1]Not included in this table are dry fractionation facilities of other types installed in Belgium, the Netherlands and New Zealand.

[2]Source: Tirtiaux (1990)

[3]Annual capacity calculated from the daily capacity assuming single step fractionation and 200 working days a year.

Figure 1.

Crystallisation tanks of a Tirtiaux fractionation Plant (Source: Tirtiaux).



a pilot plant scale under Australian conditions and Table 2 shows the yields of hard fraction using a typical butteroil produced in summer and a spring butteroil. For about half of the year the milkfat in Australia is closest in properties to the harder and higher yielding summer milkfat (Knightbridge and Black, 1978). The softening point of the soft fraction can be controlled to range from about 28°C down to 20°C. When even softer fractions are required, the soft fraction can be fractionated again in a two-step or three-step fractionation. Table 3 shows the yields and softening points of three-step fractionation of a soft (spring) butteroil.

In dry fractionation cholesterol is reduced in the hard fraction (increased in the soft fraction) and Arul *et al.*, (1988b) observed that this reduction is about 20%. This is not enough to be of any practical value.

Cholesterol Removal

Several technologies to remove cholesterol from milkfat and dairy products are available now or will be available in the near future. Some of these systems are modifications of existing fractionation methods where conditions are selected to maximise the concentration of cholesterol in a given fraction.

Vacuum steam distillation

Vacuum steam distillation methods to remove cholesterol are adaptions of equipment commonly used for solvent recovery from soybean oil (Marshner and Fine, 1989) and fat deodorisation (Deffense, 1990). With anhydrous milk-

Figure 2.

Florentine Vacuum belt filter (Source: Tirtiaux).

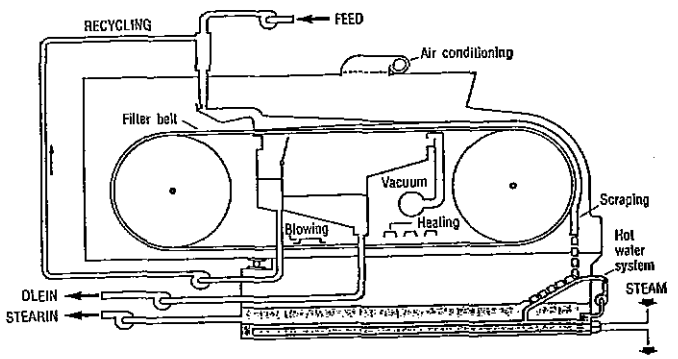


Table 2

Effect of fractionation temperature & milkfat on yield

Fractionation Temperature °C	Summer Milkfat Yield % Hard Fat	Spring Milkfat Yield % Hard Fat
18	-	29
22	39	26
24	33	23
28	23	15

Source: Versteeg (1990).

Table 3

Three-Step Fractionation of a soft milkfat (Spring)

Fractionation Step	Temp. °(C)	Fraction	Yield (%) Last Step	Yield (%) Total	Softening point (°C)
N/A	N/A	Milkfat	N/A	N/A	32
1	18	Hard	29%	29%	43
1	18	Soft	71%	-	21
2	12	Hard	44%	31%	26
2	12	Soft	56%	-	14
3	8	Hard	41%	16%	19
3	8	Soft	59%	24%	5
				100%	

Source: Versteeg, (1990)

fat as the feedstock steam is used to strip the molten fat under vacuum (approx. 1.5 mm mercury) and high temperatures (approx. 250°C) to obtain a fraction which contains most of the cholesterol. However, the flavour is removed and would have to be recovered if required. Two processes are close to being commercially available, one developed by General Mills (Marshner and Fine, 1989) and one from Tirtiaux S.A. Fractionnement (Deffense, 1990). From milkfat 95% of the cholesterol may be removed and generally with this technology product losses are only about 1% (Marshner and Fine, 1989). Probably this method of cholesterol removal will be the most economical method on a large scale.

Short Path Distillation

In short path distillation or molecular distillation the milkfat is distilled under high vacuum (0.2 - 0.001 mm Hg) at temperatures from 160-265°C in a falling film, rotating disc or wiped film evaporator. No stripping steam is used.

When a very high vacuum (<<0.1mm mercury) is available (by the use of a vane pump or similar mechanical device), temperatures as low as 160°C are possible (Bracco, 1978), but when a somewhat lower vacuum is available (steam jet system) the higher distillation temperatures appear to be necessary (Arul *et al.*, 1988a). Depending on the system and conditions, 80-90% of the cholesterol can be removed with product losses of 5-12%. A normal milk evaporator is not suitable for this task and special equipment is required. Commercial scale molecular distillation equipment is very costly (Marschner and Fine, 1989).

Supercritical Carbon Dioxide Extraction

In supercritical carbon dioxide extraction, carbon dioxide is used under high pressure (about 20 bar) and at a temperature of about 80°C to extract cholesterol from milkfat, butter or 80% fat cream (Bradley, 1989). Prior to cholesterol extraction, flavours may be extracted at lower pressures and temperatures and added back later (Bradley, 1989). The initial capital cost for supercritical extraction equipment tends to be high. About 90% of the cholesterol can be removed at a processing cost of A$0.50-A$0.70/kg milkfat (Bradley, 1989). Converted to products this results in about $0.25 to $0.35 per 500g pack of butter or about $0.08 - $0.11 per pack of 500g cheddar cheese (Bradley, 1989).

Enzymatic conversion

Enzymes can be used to convert cholesterol to other compounds. For instance, cholesterol can be oxidised by cholesterol oxidase (Buckland *et al.*, 1976; Ferreira and Tracey, 19S4; Aihara *et al.*, 1988), or converted by a reductase to coprostanol (Sadzikowski *et al.*, 1977; Brinkley *et al.*, 1982; Beitz *et al.*, 1990). In cold pasteurised homogenised milk, the cholesterol concentration can be halved in about 24 hours by the use of cholesterol oxidase (Xiansheng *et al.*, 1990), thus providing a means to reduce cholesterol in a factory or a retail pack situation. Unfortunately, the cholesterol oxidation products themselves may be atherogenic (Addis *et al.*, 1989; Hubbard *et al.*, 1989) and at this stage enzymatic reduction to coprostanol or another enzymatic degradation process may be the only alternative. The commercial availability of cholesterol oxidases is better than the availability of reductases at present, but no doubt supplies of reductases would become available if the demand could be demonstrated. The lack of affordable enzymes combined with the requirement for further nutritional studies of some of the conversion products make enzymatic processes unlikely to be commercially feasible in the short term. The long term prospects are good because most likely the milkfat flavour will not be affected and the technology can be applied in milk products and in milkfat. Generally, enzyme processes or additions can be performed on any scale and with relatively small capital investments.

Adsorption Processes

Cyclodextrins have been demonstrated to remove cholesterol from milkfat (Courregelongue and Maffrand, 1988). In a batch process, melted milkfat is stirred with about 0.5% cyclodextrin. Some of the cholesterol is encapsulated by the cyclodextrin which is removed by the addition of water and subsequent separation. In one step about 26% and in three steps about 40% of the cholesterol is removed. It is claimed that in a continuous process it would be possible to remove 80% of the cholesterol (Courregelongue and Maffrand, 1988).

Similarly, using undisclosed compounds in a batch or

column process, it is possible to remove 80-90% of the cholesterol from milk and cream (Sidhu, 1989; Davidson, 1990). The process can be applied at low temperature (4°C) and the flavour of the milk and cream is preserved (Davidson, 1990). Of course, if milk is treated, then any cholesterol reduced dairy products can be made in the normal manner. For commercial implementation, especially if traces of the cyclodextrins or other compounds can be detected in the product, the compounds will need to be approved food additives.

Nutritional aspects

Dry Fractionation

Dry fractionation has a limited effect on the fatty acid composition of milkfat. The soft fractions are enriched in short chain and unsaturated fatty acids and the hard fractions are enriched in saturated fatty acids. (Table 4).

If a milkfat is fractionated, the fatty acid composition of the fractions fall within the range of natural variation of milkfat. Table 4 gives the fatty acid composition of some milkfat fractions and the natural range (Black, 1988). This is remarkable because the softening points of the fractions (43°C and 5°C) fall clearly outside the range for normal milkfat (35°C-32°C, Dixon

Table 4.

Fatty acid composition of some milkfat fractions[1] and the seasonal variation[2] of fatty acid composition.

Fatty acid	Milkfat (Sept '89) before fractionation	Hard fraction of 1st fractionation step (at 18°C)	Soft fraction of 3rd fractionation step (at 8°C)	Lowest value in low 1975-76	Highest value in 1975-76
4:0	3.3	3.2	4.3	3.4	5.7
6:0	2.0	1.9	2.5	1.9	3.0
8:0	1.3	1.1	1.2	0.9	1.7
10.0	2.6	2.8	4.1	1.8	3.7
12:0	3.2	3.1	3.5	2.1	4.2
14:0	9.5	10.5	9.1	8.0	11.6
14:1	1.6	1.5	1.6	1.4	2.4
15:0	1.4	1.2	0.9	1.2	2.0
16:0	21.9	25.3	19.6	21.9	28.4
16:1	2.6	2.3	2.7	2.4	3.4
17:0	0.8	1.1	0.8	1.0	1.5
18:0	12.2	15.7	8.8	10.5	15.5
18:1	27.9	22.0	31.6	22.1	30.3
18:2	1.7	1.6	2.0	1.3	2.2
18:3	1.9	1.7	2.1	1.3	2.6
Other	6.2	5.1	5.2		

[1]Versteeg, 1990

[2]Black, 1985

1964). However, it would appear that the nutritional properties are unchanged by the treatment.

Cholesterol Removal

There are many papers on the subject of cholesterol and vascular or heart disease and it is outside the scope of this paper to give a comprehensive assessment. A brief overview covering some of the range of opinions is given.

There appears to be little doubt that high plasma cholesterol is correlated with the risk of cardiovascular diseases (McNamara, Stehbens, 1988b) and an elevated plasma cholesterol level is considered by many as one of the major risk factors, the others being high blood pressure, obesity and cigarette smoking. (McNamara, 1987; Taylor *et al.*, 1987).

The effect of dietary cholesterol on plasma cholesterol is still being debated. There is clear experimental evidence that when challenged with a 'modest' increase in dietary cholesterol (750 mg of cholesterol or three eggs a day), most individuals (70%) are able to compensate by reducing the cholesterol adsorption and/or the endogenous cholesterol synthesis and maintain the balance of cholesterol in the body (McNamara *et al.*, 1987). However, the statistical basis of such studies has been questioned and it has also been found that individuals reacting in one way in one year might react completely differently in another year (Katan, 1990).

Dietary saturated fats have a greater effect on blood cholesterol than dietary cholesterol (McNamara *et al.*, 1987; Katan, 1990), although not all saturated fats are the same in this respect (McNamara, 1987). There is evidence that the effects of dietary cholesterol and dietary fats are independent (McNamara *et al.*, 1987), but also that they reinforce each other's effects (Katan, 1990).

Dietary means to reduce plasma cholesterol for the population as a whole are on the average only of marginal benefit for one's life expectancy. According to Taylor *et al.* (1987) (assuming that there is a causal relationship between plasma cholesterol level and the risk of heart disease and that there is no risk associated with lowering one's blood cholesterol) a lifelong adherence to the 'prudent diet' would result, on the average, in a 6.7% reduction in plasma cholesterol and would increase the life expectancy by three days to two months for low risk individuals and by 18 days to 12 months for those at high risk. The benefit of lowering blood pressure was calculated to be about four times greater and stopping cigarette smoking about eight times greater (Taylor *et al.*, 1987). The people with a very high plasma cholesterol level (>300mg/dl or about 7.7mmol/l) were excluded from the statistical model because some of the persons in this group would have genetic disorders.

A correlation between blood cholesterol levels and the incidence of cardiovascular disease does not prove a causal relationship, as pointed out by Stehbens (1988a, 1989), and lowering blood cholesterol by dietary means may not be effective in prolonging one's life. In several of the major intervention studies to lower blood cholesterol, total deaths have not been reduced (Sabine, 1989).

Whether the effect of cholesterol in the diet is scientifically proven or not remains of academic interest for the dairy industry if official dietary guidelines and popular information sources recommend a reduction of cholesterol intake for the population as a whole. The media are flooded with negative information about dietary cholesterol and cardiovascular diseases and this health concern has contributed to the decline of consumption of fat-containing dairy products such as butter, cream, cheese and full cream milk. (Lieb, 1988).

In many countries official guidelines recommended reduced cholesterol intake for all people (Truswell, 1983) and in my opinion this is not going to change in the near future.

Therefore it appears that there is a compelling reason for the dairy industry to offer low cholesterol products. However, a complicating factor is the food labelling legislation which is reviewed and changed regularly. If no claims can be made on the label about the reduced cholesterol content, then there is no marketing advantage and the added processing costs can not be recouped. For instance, other criteria may have to be met, such as: typical serving size, saturated and unsaturated fat content and the percentage of energy derived from fat. If, for instance, 'low cholesterol' can only be claimed when there is less than 2g of saturated fat per serving (as has been put forward in some proposals for the

food standards), whole milk can not be made 'low cholesterol'.

Properties of Milkfat Fractions

The most important physical properties of milkfat are softening point and the percentage of solid fat as a function of the temperature. Sometimes other properties like plasticity and creaming are important as well. Also, in blends with non-dairy fats, the physical properties and compatibilities of blends with milkfat fractions differ from blends with unfractionated milkfat.

Softening point

The fractionation process allows the production of milkfats with softening points between 5° and 44°C. Table 3 gives some examples but many more possibilities exist by varying the fractionation temperature and by blending. The fractionation temperature does not affect the softening point of the hard fraction very much and softening points are generally between 42° and 44°C. But any softening point between that of milkfat (about 33°C) and that of the hard fraction can be made by blending the hard fraction with normal milkfat.

The softening points of the soft fractions are close to the fractionation temperature. For instance fractionation at 28°C gives a soft fraction with a softening point of about 28°C and fractionation at 22°C gives a softening point of about 22°C. At lower temperatures and in multi-step fractionation, the relationship becomes somewhat less predictable. Table 5 gives examples of how the softening points are affected by the fractionation temperature.

Table 5

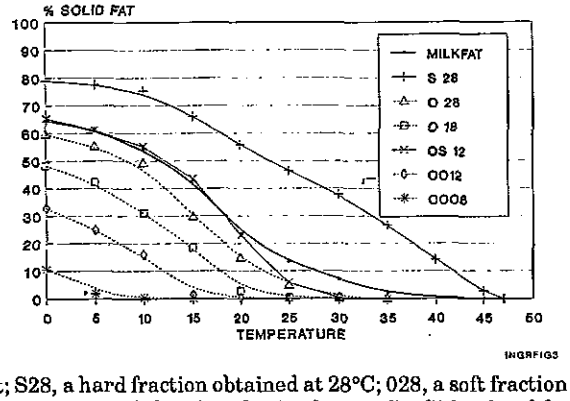
The fractionation temperature and the softening points of the hard and soft fractions[1])

Fractionation temperature (°C)	Softening Points: Hard Fraction (°C)	Softening Points: Soft Fraction (°C)
1st fractionation step		
28	43.2	28.6
26	42.2	25.4
24	42.3	24.2
22	42.0	22.2
20	41.1	21.9
18	41.2	20.4
2nd fractionation step[2]		
15	26.6	17.2
14	26.5	14.4
13	26.3	14.1
12	26.0	13.2
11.5	25.8	12.0

[1] Versteeg, 1990
[2] Using the soft fraction obtained at 18°C fractionation

Figure 3.

MELTING PROFILES OF MILKFAT AND SOME MILKFAT FRACTIONS



Milkfat; S28, a hard fraction obtained at 28°C; 028, a soft fraction obtained at 28°C; 018, a soft fraction obtained at 18°C; 0S12, a hard fraction of a two-step fractionation at 12°C; 0012, a soft fraction of a two-step fractionation at 12°C; 0008, a soft fraction of a three-step fractionation at 8°C.

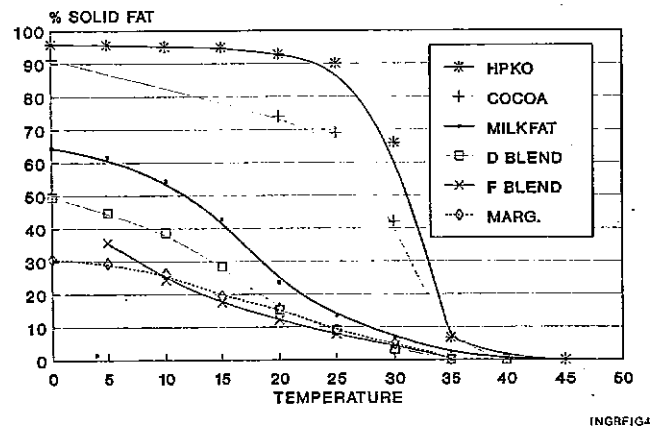
Melting Profiles

The percentage of solid fat as a function of the temperature or melting profile of a range of fractions is illustrated in Fig. 3. As with softening points, a wide range of melting profiles can be obtained, which can be further expanded by blending. Although fractionation provides a much greater range and flexibility, there are still limitations. For instance, the hardness of hydrogenated palm kernel oil (HPKO) cannot be attained and the melting profile of a polyunsaturated margarine can only be approached (See Fig. 4) by using milkfat fractions. To approach the melting profile of a polyunsaturated margarine, seven parts of the soft fraction of a two or three step fractionation (with a softening point of below 10°C) has to be blended with three parts of the very hard fraction of the first step. This milkfat blend can form the basis for a spreadable butter or half-fat butter (Deffense, 1987).

A similar softening point does not necessarily mean a similar melting profile. The softening point of the soft fraction of a one-step fractionation may be similar to that of the hard fraction of a two-step fractionation (Table 5). The melting curve for the latter is much steeper (Fig 3) and this fraction can be used for special puff pastry products which do not give any impression of a fatty mouthfeel, because all the fat is melted well below body temperature. This fat is reported to have excellent plasticity between 15 and 22°C (Deffense, 1988).

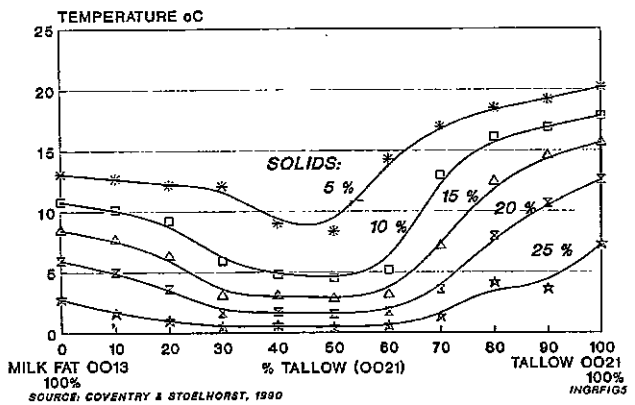
Not only the fat itself, but also the method of crystallisation affects the plasticity.

Figure 4.



HPKO, hydrogenated palm kernel oil; Cocoa, cocoa fat; Milkfat; D Blend, dairy blend which is a blend of 75% butter and 25% vegetable oil; F Blend, milkfat fractions blend (Source: Deffense, 1988); Marg, polyunsaturated margarine.

Figure 5



'Milkfat 0013' is the soft fraction obtained in a two-step fractionation of milkfat at 13°C and 'Tallow 0021' is the soft fraction obtained in a two-step fractionation of tallow at 21°C (Source: Coventry and Stoelhorst, 1990).

The hard fractions are very suitable for puff pastry, croissant and Danish pastry, but only after they have been plasticised. This can be performed in scraped surface heat exchangers using technology developed in the margarine industry (Pederson, 1988, 1989).

Blends with other Fats

In blends with less expensive fats, milkfat is used to improve flavour, for example in blends with palm oil products for shortenings. (Idris *et al.*, 1987; Idris *et al.*, 1988). When fractions are available, the range of options for blending with other fats increases enormously. For instance, soft fractions in pourable frying oils or hard fraction in vanespati (vegetable ghee) can be considered and a whole new range of products is possible. For fractionation to be commercially successful, applications are needed for all the fractions. Some European suppliers offer more than 10 different fractions and blends of milkfat as ingredients to the food industry.

The soft fraction contains more milkfat flavour than normal milkfat (Ricci, Rossi and Deffense, 1984)) and is more effective as a flavour enhancer although, according to a New Zealand report, this advantage is only about 10% (Norris, 1989).

Blending of fats and fractions may give interesting interactions. As shown in Fig 5, a blend of 50% soft fraction of a two step fractionated milkfat with 50% of the soft fraction of a two step fractioned beef tallow is more liquid than either fraction. (Coventry and Stoelhorst, 1990). Whereas in blends of normal tallow and milkfat this is not the case (Timms, 1989).

Chocolate is a product where the milkfat flavour is not a primary consideration. Milkfat is already used in 80% of all chocolate sold worldwide and this is the only application where it displaces a more expensive fat (Timms, 1989). Therefore, there is great interest in maximising the amount of milkfat in chocolate. The hard fraction is more compatible with cocoa butter than normal milkfat and more milkfat may be used (Badings *et al.*, 1983).

Conclusions

There are considerable opportunities to improve milkfat utilization by selecting the appropriate melting properties and other functional attributes for various existing and new food applications. The fractionation technology to do this is available now and is well established overseas. Fractionation enables milkfat to be considered as a well defined natural food ingredient instead of a commodity. It is not unrealistic to expect that a market for 10-20% of total butter production or 10,000 to 20,000 tonnes of fractionated milkfat could be developed in Australia.

The nutritional 'issues' will remain for the foreseeable future and must not be ignored in determining product/market opportunities and threats. Fortunately in the very near future, it will be possible to remove cholesterol from milk products and milkfat and there will be a market for low cholesterol products for several years to come. However, care has to be taken because labelling constraints may prevent the ability to take full marketing advantage of the cholesterol removal.

Acknowledgments

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Milkfat as a Food Ingredient

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Introduction

This paper looks briefly at the chemical and physical properties of milkfat, its good and bad points, and health issues associated with saturated fats and cholesterol. This background leads into the opportunities for milkfat which include using the Tertiaux physical fractionation plant. These milkfat fractions can be used in table spreads and a range of baking industry products.

What is Milkfat?

Structure

Milkfat like all other oils and fats is composed of fatty acids orientated around a molecule of glycerol (Figure 1). Each fatty acid can have from 4 to 24 carbon atoms and can be saturated or unsaturated up to a level of six double bonds. These highly unsaturated fatty acids mainly occur in marine oils. Table 1 shows the fatty acid composition of milkfat and other edible fats and oils. Milkfat has more of the low molecular weight fatty acid than most other oils and fats except for coconut and palm kernel oils.

Table 2 and Figure 3 give an indication of the degree of softness and melting profile of milkfat and polyunsaturated margarine at various temperatures (measured by pulsed NMR spectrometry). It is obvious that milkfat does not have a favourable profile for spreadability at refrigeration temperatures.

Morphology

Milk fat behaves similarly to beef oleo and crystallises in the alpha, beta prime and beta depending on the manner in which it is crystallised.

So what is unique about milkfat? In one word: flavour - Mother Nature bestowed this unique property to milkfat. Apart from that, milkfat is an extremely expensive animal fat, as is illustrated by the selling prices of refined and deodorised oils and fats in Table 3. This may seem a harsh statement to people in the dairy industry who have grown up with butter. The international flavour houses have invested millions of research dollars in trying unsuccessfully to copy the natural product and for this fact alone the dairy industry should be thankful.

The introduction of polyunsaturated margarines in the sixties with the advantages of spreadability, price and perceived health benefits spelt the beginning of the end for butter. Figure 3 illustrates the sales trends of butter and margarines over the past five years.

Health Issues

Milkfat and other animal fats have suffered in sales from the association of lipids and cholesterol with heart disease. This needs no elaboration. There is, I believe, a trend which indicates the pendulum may be starting to swing the other way. I think we should not become too polarised in either direction but be aware of all research that is going on and should keep a balanced perspective.

Opportunities for Milkfat

Spreads

a) Low and Reduced Fat

Presently there are reduced fat products which the market has been slow to respond to. I accept that this often happens

with new products and I predict within several years sales of these products representing 10-15% of the yellow fats market. Milkfat oleo will be able to be used to improve the spreadability while maintaining a 100% dairy component. This will help extend the sales of milkfat by eliminating the use of soft vegetable oils.

Low fat spreads with a fat content of less than 40% will appear on the Australian market within the next two years, although it is technically feasible to produce them today. They are more difficult to produce because of emulsion stability problems as these products usually exist as water in oil emulsions. They are not presently as acceptable as the reduced fat spreads with respect to flavour and texture which tends to be slightly rubbery.

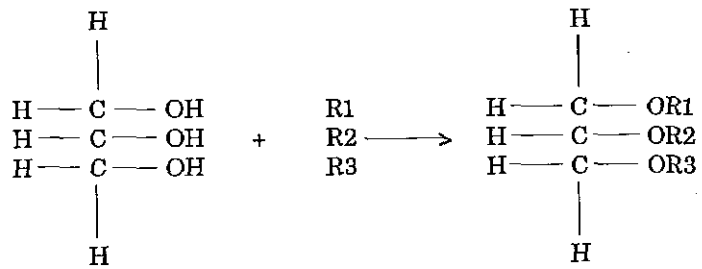
A typical formulation for a low fat spread is illustrated in Table 4. The aqueous and oil phases are prepared separately and mixed together to form, normally, water in oil emulsions although it is not uncommon for oil in water emulsions to be formed and inverted during the chilling process. The emulsion then is pasteurised and passes through a series of chilling tubes with scraped surfaces.

The chilled product is passed through a series of working tubes where the crystallised mass is worked and latent heat of crystallisation is released. The chilled, worked product usually passes through a resting tube where it firms up sufficiently to pack into either tubs or wrapped products.

Figure 1

The Chemistry of Fats & Oils

Chemically they consist of a tri-hydric alcohol, glycerol and fatty acids.



Glycerol Fatty Acids Fat or Oil Triglceride

The fatty acid radicals may be saturated, unsaturated or polyunsaturated, depending on the number of double bonds in the fatty acid chain. A saturated fatty acid is one which contains the maximum possible number of hydrogen atoms. An unsaturated fatty acid contains one double bond, ie, it is deficient in two hydrogen atoms. A polyunsaturated fatty acid is one in which there are two or more double bonds, ie. deficient in four or more hydrogen bonds.

b) Blends

Typically these products contain a maximum of 25% vegetable oils of the total fatty matter or 20% of the finished spread. This enables a slight improvement in spreadability.

When new legislation is approved it will permit a higher proportion of vegetable oils and fats to be added which will result in spreadability equal to that of the polyunsaturated margarines while still maintaining the flavour of butter. These products offer enormous potential for the dairy industry. Obviously the aim is to minimise the amount of vegetable oils but to maximise their advantages. Milkfat oleo could also be used to maximise spreadability and flavour while maintaining the maximum dairy input.

Blends are normally processed by adding the vegetable oil to the cream and processing through conventional butter making machines (Figure 4).

Higher levels of vegetable oils will necessitate employing the type of equipment used in the manufacture of reduced and low fat spreads.

Fractionated Milk Fat

Figure 5 illustrates the typical nmr solids of fractionated milkfat stearine, oleo and double fractionated oleo.

It is thus virtually possible to tailor-make a product from any of these fractions to obtain a product which best suits the proposed end use.

We now look at specific applications for the baking industry.

Puff Pastry

A ready market exists for croissants made from milk fat stearine which can exhibit the same functional properties as its margarine counterparts.

To elaborate, during the manufacture of puff pastry the fat has to withstand the rolling and folding process without softening and melting.

It is for this reason that milkfat is unsuitable because of its low melting point. Milkfat stearine also offers a potentially better mouth feel if formulated correctly.

Again, milkfat's main advantage is its flavour. It would also be possible to blend any of the milk fat fractions together with animal fat or palm oil fractions to tailor make specific products (Table 5).

Figure 6 shows typical melting profile for Australian bakery fats and Figure 7 for European bakery fats incorporating fractionated milk fat.

The European pastry products have generally better eating qualities than the Australian equivalents by virtue of the fact that Australian fats have to be higher in melting point because of the warmer climatic conditions.

Table 1

Typical Fatty Acid Composition of Milkfat & Other Oils & Fats.

Fatty Acid	Weight X					
	Milkfat	Coconut Oil	Beef Tallow	Palm Oil	Sunflower Oil	Marine Oil
4:0	3.7	trace	—	—		
6:0	2.2	0.4	—	—		
8:0	1.3	8.0	—	—		
10:0	2.8	6.5	—	—		
12:0	3.4	47.6	—	—		
14:0	11.8	17.3	3.3	1.4		5.5
14:1 15:0	2.6	—	1.5	—		0.4
16:0	31.3	8.5	25.5	40.1	5.9	17.7
16:1 17:0	2.4	—	4.9	—		7-7
18:0	12.7	2.7	21.6	5.5	4.7	3.0
18:1	21.8	6.4	38.7	42.7	23.4	18.1
18:2	1.90	2.1	2.2	10.3	66.0	4.3
18:3	1.1		1.1			3.4
18:4						1.8
20:1						1.2
20.4						3.4
20:5						5.9
22:1						2.8
22:5						3.3
22:6						13.3

Table 2

Typical NMR Solids of Milkfat & Polyunsaturated Margarine

	Milkfat (Summer)	Milkfat (Spring)	Margarine (Polyunsaturated)
Melting Pts (°C)	35	35	35
NMR Solids 5°C	65	56	30
10°C	60	50	25
20°C	30	18	10
30°C	10	5	4
40°C	0	0	

Other Bakery Products
The soft fraction can be used as a pourable frying oil and blended with the stearine fraction for shortpastry, cakes and biscuits, where the bake-through flavour of milkfat is sufficient to warrant the price. Fractionation essentially enables milkfat to match the previously unattainable superior physical properties of industrial margarines and shortenings.

Spray dried milk fat fractions also offer opportunities for bakery products.

Summary

I believe that milkfat can have a promising role in the Australian food industry - with the right efforts. I would suggest this strategy:

a) Milkfat fractionation can open the door for utilisation in low and reduced fat spreads and blends where spreadability is now attainable to match those properties previously exclusive to margarine.

b) Manufacture of bakery products where again the once unattainable desirable properties of industrial margarines are now attainable and the flavour attribute of milkfat is maximised.

c) Extensive market research should be undertaken to fully ascertain the public perception of cholesterol and saturated fats.

d) Vigorous promotion of milkfat as a natural healthy product highlighting the latest nutritional evidence that milkfat in moderation is not harmful.

FIGURE 2 Milkfat and Polyunsaturated Margarine typical NMR Solids

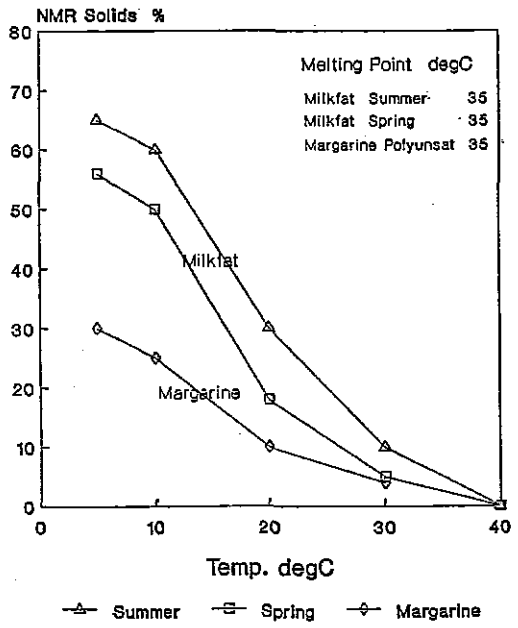
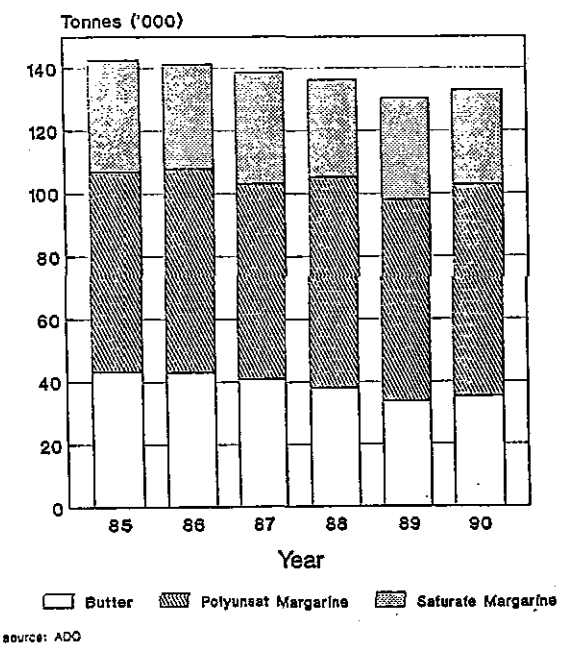


FIGURE 3 Australian Retail Tablespreads Market



e) A realistic pricing structure for milkfat needs to be set up such that it is cost-effective and competitive in the market place.

f) The dairy industry should fund nutritional research on milkfat in relation to saturated fats and cholesterol.

Acknowledgements

I gratefully acknowledge the Dairy Research and Development Corporation for making available the Tertiaux pilot plant fractionation unit to the Australian dairy industry and to the Tertiaux company for permission to adapt information for publication of this paper. I would also like to thank Mr Peter Gross and Mr Jeff Dolbey for their assistance in putting this document together.

Table 3

Typical Market Prices for Milkfat & Refined, Bleached, Deodorised Oils & Fats

Anhydrous Milk Fat	2800
Tallow	680
Beef Oleo	815
Palm Oleo	655
Coconut Oil	858
Sunflower Oil	980
Soybean Oil	959

Prices are in Australian dollars and will vary depending on availability.

Table 4

Table Spreads - Typical Formulation

	Butter	Dairy Blend	Reduced Fat Spread	Low Fat Spread	Poly Marg.
Oil Composition					
Milkfat	80	60	variable	variable	
Veg.oils & fats		20	variable	variable	80
Total Fat	80	80	30-60	< 30	80
Water	16	16	variable	variable	16
Salt	1-2	1-2	1-2	1-2	1-2
Non Fat Milk Solids	1	1	variable	variable	
Protein			+	+	
Colour			+	+	+
Flavour			+	+	+
Vitamins		+	+	+	+
Emulsifiers			+	+	+
Anti-oxidant			+	+	+

Figure 4

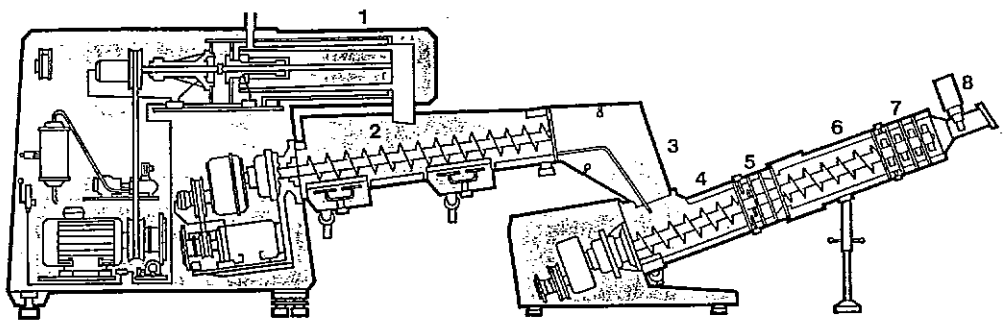


Fig. 4 Buttermaker

1 Churning cylinder
2 Separation section
3 Squeeze-drying section
4 Second working section
5 Injection section
6 Vaccum working section
7 Final working stage
8 Moisture control unit

FIGURE 5 Fractionated Milkfat typical NMR Solids

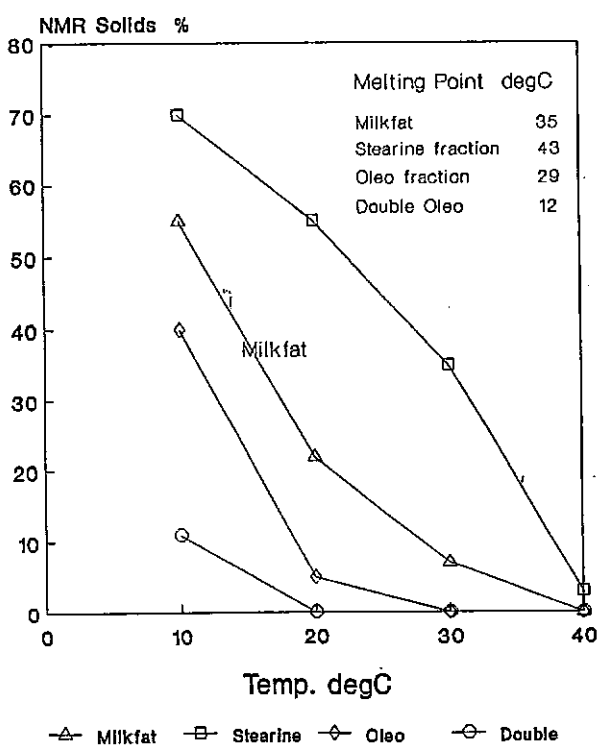


Table 5

Typical NMR Solids of Animal, Vegetable & Milkfat Fractions

Fats	NMR Solids % at 10	20	30	40 (°C)	Melting Point °C
Beef Tallow	51	37	20	6	45
Beef Stearine	77	69	53	38	51
Beef Oleo	32	17	5	0	35
Palm Oil	48	24	8	3	39
Palm Stearine	68	50	29	15	46
Palm Oleo	34	3	0	0	22
Milkfat	55	22	7	0	35
Milkfat Stearine	70	55	35	3	43
Milkfat Oleo	40	5	0	0	28

FIGURE 6 Australian Bakery Fats typical NMR Solids

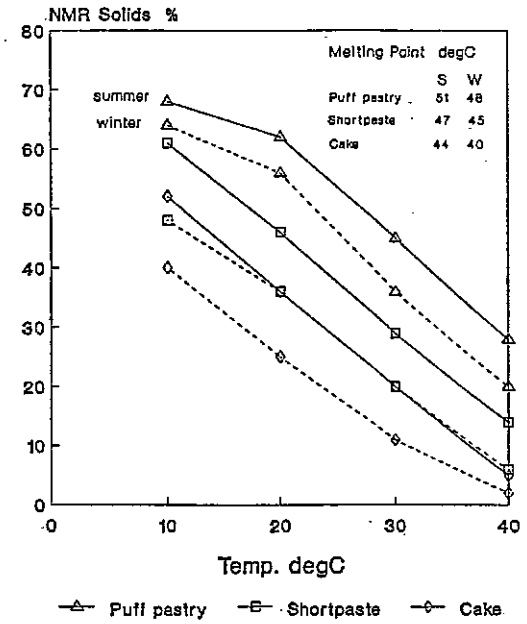
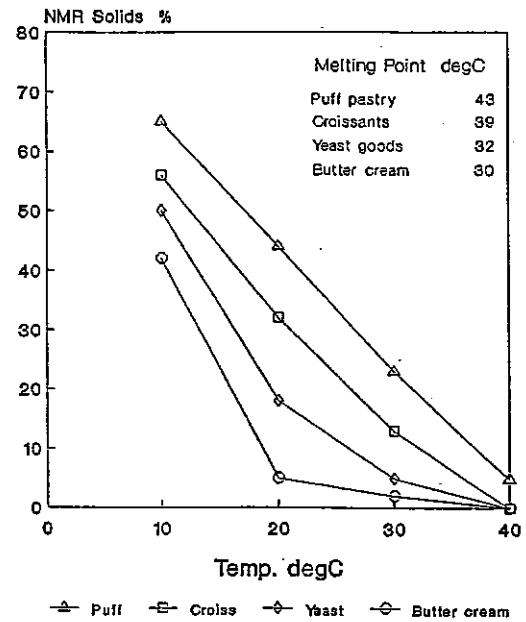


FIGURE 7 European Bakery Fats containing Fractionated Milkfat



Butter Flavour in Food Systems

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Introduction

Butterfat serves both as a precursor of flavours and as a solvent for flavours from the aqueous phase of milk (Urbach, 1991). This helps to make its flavour unique.

Flavours from precursors in the fat

Butterfat contains many hundreds of different fatty acids in its triglycerides (Figure 1). This distinguishes it from all other fats and oils. Triglycerides can be broken down into glycerol and fatty acids by chemical or biochemical means in a process called lipolysis. Heat, lipolysis and oxidation release flavours from their triglyceride precursors. The following are important classess of flavour compounds derived in this way.

Lactones

On heating, prolonged storage or lipolysis, hydroxyacids in triglycerides form gamma- and delta-lactones (Figure 2). The gamma-lactones have a sweet, raspberry- like flavour and the delta-lactones are reminiscent of coconut, apricot and peach. The lactones are major contributors to the flavour of heated butterfat.

Methyl ketones

On intense heating, as would be encountered in frying, or on lipolysis, beta–ketoacids in triglycerides form methyl ketones, many of which have flavours reminiscent of blue-vein cheese (Figure 3).

Low molecular weight fatty acids

Butterfat and coconut fat are the only fats which contain low molecular weight fatty acids but these acids are much more abundant and varied in butterfat than in coconut fat (Figure 4). They are liberated from the triglycerides by intense heat or lipolysis and generally have a flavour reminiscent of Italian cheeses.

Oxidation products

Butterfat also contains unsaturated acids which oxidise to various aldehydes and ketones (Figure 5). Slight oxidation actually enhances the flavour of butter. For example, the compound hept-*cis*-4-enal imparts a creamy flavour to butter at a level of one part in a thousand million (Haverkamp, Begemann and Koster, 1964) whereas at one in a hundred million it is reminiscent of the cold-storage defect (Badings, 1965).

Flavours due to solvent action of the fat

Badings and Neeter (1980) isolated 114 compounds with flavour significance from low temperature pasteurised milk. A large proportion of these compounds are likely to be largely dissolved in the fat phase and hence contribute to the flavour of butter. The most important of these compounds are probably diacetyl, the character impact compound of cultured butter, and dimethyl sulphide; but it is the totality of all contributing flavours, both from the aqueous and the fat phase, which impart to butter its unique flavour.

Effect of diet

Although most of the flavours and flavour precursors of milk

fat originate via the biosynthetic processes of the cow, the diet of the cow can have a strong effect on flavour (Table 1). Thus Dumond and Adda (1978) found sesquiterpenes in mountain cheese from summer milk but not from winter milk from cows grazing on high altitude pastures. Wilson (1989) isolated six terpenes from New Zealand but not from Finnish milk fat and showed that one part per million of D-limonene was responsible for the green/grassy flavour present in New Zealand milk fat at certain times of the year. The Japanese particularly dislike this flavour. Wilson also showed that Finnish milk fat had higher levels off two gamma-dodecalactones than New Zealand milk fat and he suggested that the sweeter flavour of European cheeses as compared with Australian and New Zealand cheeses was due to these compounds. In milk fat the content of precursors for flavours such as lactones, methyl ketones and low molecular weight fatty acids is strongly influenced by feed (Urbach, 1990) (hence season), as well as state of lactation and breed. As a consequence, the flavour (and also the hardness) of butterfat in Australia varies with season and place. This is a specific problem of pasture fed animals as opposed to lot fed animals as in the USA. On the other hand, the milk from lot fed animals tends to oxidise much more readily than the milk from pasture fed animals. This is ascribed to a lack of the natural antioxidant, tocopherol, in lot feeding. The variability of our butterfat creates a problem in the export market, particularly to Japan.

Figure 1

Figure 2

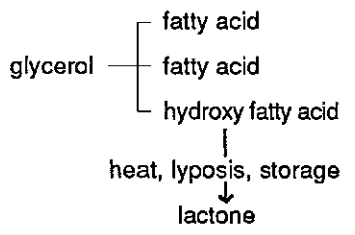


Figure 3

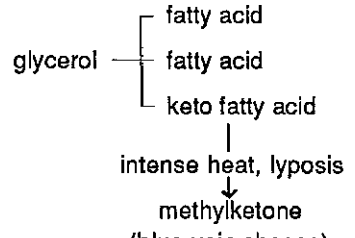
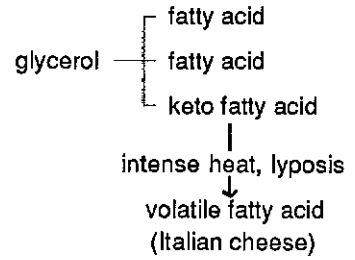


Figure 4



Are butter & anhydrous milk fat equivalent as ingredients?

Butter and anhydrous milk fat are usually heated when they are used in a food, as in baking or frying. I am not aware of any research which has aimed to distinguish between the flavours of foods based on butter as compared with anhydrous milk fat, although I suspect that cooks and bakers are well aware of any differences which may exist. The effect of heat on anhydrous milk fat is well documented but nothing appears to have been reported on the flavour compounds in heated butter.

The most commonly used form of heated butter is the product which is known as ghee in India. Traditional (Desi) ghee is prepared by fermenting whole milk to curd, churning the curd to butter and boiling down the latter to give ghee. The degree of heating depends on the local taste, but, in general, 118°C is regarded as the optimum (Ganguli and Jain, 1973; Rangappa and Achaya, 1973). Commercially, ghee is made by heating either cream or butter to remove the water. More flavour is produced if the cream or butter have been cultured. From its method of manufacture it is to be expected that ghee contains all the compounds produced by the action of heat on butterfat as well as the products of the Maillard reaction (see later) between the components of the serum and the butterfat.

Maillard reaction

The Maillard reaction occurs between amino acids and carbonyl compounds including sugars and is responsible for

flavours produced by cooking (Figure 6). The products of the Maillard reaction depend upon time, temperature and cooking medium as well as on the particular amino acid and carbonyl compound taking part in the reaction. A host of flavours can be produced by the Maillard reaction (Salter, Mottram and Whitfield, 1988). This also means that butter incorporated in a food will not necessarily produce the same flavours as butter subjected to the same conditions an its own. The effect of butter serum on the flavours of food could be substantial, but has been largely ignored. However, Unilever recently has taken out a patent for the preparation of a butter-like concentrate from a mixture of milk fat, partially hydrolysed soya lecithin, dried whey concentrate, glucose and water (Doornbos *et al* 1987). When this mixture is heated to 110°C and the solids are removed, a sweet buttery flavour concentrate is obtained; further heating to 135°C for ten minutes in a closed vessel produces a more pronounced baked, butter-like flavour.

I do not think that we necessarily need to know the exact chemical nature of what occurs when butter serum is incorporated into a food, but a few culinary experiments on the possible difference in flavour produced by whole butter as opposed to anhydrous milk fat might be in order. I would also like to see various ghees included in such experiments. As I mentioned before, the flavour of ghee (Figure 7) is due to three factors:

a) The flavour produced by culturing the milk

Figure 5

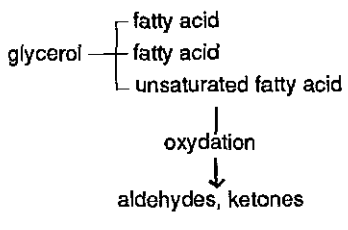


Table 1

Effect of diet

Sesquiterpenes in mountain cheese

	Butterfat	
	NZ	European
Terpenes (grassy)	+	—
Gamma-lactones (sweet)	—	+

Figure 6

Maillard reaction

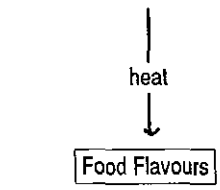


Figure 7

Flavour of Ghee

- Culturing
- Action of heat on serum
- Action of heat on fat

b) The effect of heat on the components of the butter serum in an essentially all-fat environment

c) The effect of heat on the butter fat itself.

Even without heat, the effect of culturing produces a butter with a distinctive flavour quite different from that of our sweet-cream butter; cultured butter should be compared to sweet-cream butter for its effect on products.

Effect of butter quality on foods

Butter does not necessarily need to be of the highest quality to produce a good food product. In fact, a certain amount of oxidation or lipolysis of the butterfat may produce a better food product. Unilever have actually taken out a patent for oxidised milk fat to impart butter flavour to foods (Haring, 1989). Badings *et al.* (1975) found that when butterfat from oxidised butter with a fishy flavour was heated for one hour at 80°C with a small amount of hydrogen sulphide, the fishy off-flavour was replaced by the pleasant smell of frying. Fishy butter may become quite attractive after treatment with casein (Pokorny, 1976). In the USA, chocolate containing partially lipolysed butterfat is actually preferred to chocolate with unlipolysed butterfat (Martin, 1987). Pregastric esterases, ie, enzymes originating from the mouth tissues of calves, lambs and kids, are used to produce cheese flavour, each species' source of pregastric esterase producing a characteristic cheese flavour

(Huang and Dooley, 1976). These enzymes are specific for short-chain acids in the alpha-position of triglycerides and it is assumed that it is these short-chain acids which are responsible for certain charactistic cheese flavours. It is claimed that, with very low additional levels of pregastric-esterase-modified butterfat, a sensation of richness is imparted without any detectable free-fatty-acid-flavour character. As additions are increased, the flavours imparted resemble cream or butter. Lipolysed butterfat is added to shortbread to increase its buttery flavour. When amounts added are relatively high, the flavour imparted suggests cheese. Pregastric-esterase-lipolysed butterfat is relatively free of soapy and bitter notes which occur in other lipase-modified butterfat, since other lipases presumably liberate higher fatty acids (Paulet *et al.*, 1974).

Fractionated butterfat

When butterfat is fractionated flavours are preferentially fractionated into the lower melting fraction. This makes the low melting fraction particularly useful for applications where high flavour intensity is desirable.

Use in frying

Butter oil is used in France and elsewhere in Western Europe for shallow frying where it is prized by professional cooks for its distinctive flavour.

In deep frying, butter fat has the advantage over vegetable oils in that it has superior flavour and oxidative stability. It contains protective agents which contribute to its own stability and, in blends, protect other less stable oils during deep frying (Augustin, 1989).

Conclusion

The advantages of butter over other fats are its flavour and its stability in frying. The flavour of butter can be further enhanced by culturing, by the action of heat and by the action of lipases. Products need to be developed which make use of butter with enhanced flavour.

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Casein-Sugar Reaction Products as Antioxidants

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Introduction

Lipid Oxidation

The storage life of many high fat products such as full cream milk powder is limited due to the development of objectionable flavours and odours as a result of lipid oxidation. Some of the main methods of limiting lipid oxidation include the use of physical barriers to exclude such factors as light and oxygen, and the addition of synthetic chemicals or food components possessing antioxidant activity (Lundberg, 1962).

With few exceptions, current Australian food legislation does not allow the protection of food against lipid oxidation through the use of chemical means such as the addition of antioxidants (National Health and Medical Research Council, 1990). As a result, industry has largely utilised physical methods and changes in manufacturing practices to extend the shelf life of foods susceptible to deterioration by lipid oxidation. Some of the methods currently employed by industry include:

a) the use of light impermeable packaging

b) exclusion of oxygen, e.g. flushing with nitrogen or vacuum packaging (Sanderson, 1978)

c) elimination of metal ions e.g., copper and iron

d) use of fresh materials in processing (Greenbank, 1948) and

e) storage at cool temperatures (Kieseker *et al*, 1984).

Butter and full cream milk powder are among the dairy products which are most susceptible to oxidation.

Although a problem for many years, rancidity in butter has largely been overcome by the replacement of copper processing equipment with stainless steel, thus eliminating copper ions which have been found to accelerate the development of oxidative rancidity.

With full cream milk powder, almost all of the above mentioned measures are required for stability against lipid oxidation (Webb *et al.*, 1974).

Antioxidants

In some cases the available methods of protection do not give sufficient shelf life extension before oxidative rancidity flavours are detected by the consumer. One possibility of overcoming this problem is to use an antioxidant in the food as a means of slowing oxidation and extending shelf life. As many synthetic antioxidants are not permitted for use in most foods susceptible to lipid oxidation, the use of natural antioxidants for such products is of particular interest. Some of the known natural antioxidants include:

a) ascorbic acid

b) tocopherols

c) thiol groups

d) phenolic plant extracts

e) amino acids

f) protein hydrolysates, and

g) proteins (Eriksson, 1982; Dugan, 1980).

This list is by no means complete and in some cases various members of a group (e.g. the amino acids) have been found to be pro-oxidative dep-

ending on conditions such as concentration and pH (Taylor and Richardson, 1980a).

Maillard Reaction Products (MRP) as Antioxidants

One group of compounds that has shown antioxidant potential but are neither totally synthetic or totally natural are the Maillard Reaction Products (MRP) formed by the heat induced reaction of a reducing sugar, such as fructose or glucose, with an amino acid (Hodge, 1953). Yet the Maillard reaction may be considered natural in the sense that it occurs to some extent in almost all manufacturing processes utilising heat when sugar and free amino groups are available. The overall reaction is exceedingly complex and produces a wide range of compounds eventually forming dark brown pigments known as melanoidins (Hodge, 1953). Antioxidant activity has been identified at almost all stages of the Maillard reaction with colourless early stage products (Eichner, 1980), through to the long chain dark melanoidins (Yamaguchi *et al*, 1981), all showing antioxidant potential.

In many instances, experiments investigating the Maillard reaction for antioxidant potential have only involved one type of amino acid and one reducing sugar in a model system. Lingnert and Eriksson (1980a) examined a range of amino acid-reducing sugar combinations, and noted that many combinations exhibited antioxidant activity in a model system containing methyl linoleate. Kirigaya *et al.* (1969), utilising nondialisable material from various amino acids and reducing sugars, found a strong inhibition in the formation of peroxides in a mixture of linoleic and linolenic acid. In a similar system to Kirigaya *et al.* (1969), Tomita (1971) examined MRP formed by heating mixtures of glucose and various amino acids at 120°C for one hour, and found several combinations, notably histidine-glucose, possessed strong antioxidant potential.

Pure amino acids are not the only source of amino groups for the Maillard reaction. Several investigations have also utilised either whole proteins, or protein hydrolysates, as the source of amino groups for the Maillard reaction. Lingnert and Eriksson (1980b) examined MRP from the hydrolysates of malt sprouts, brewers' grains and haemoglobin reacted with D-glucose, and found a considerably improved antioxidant effect over that of the hydrolysates alone. Whole proteins have been investigated by Vandewalle and Huyghebaert (1980) who reacted lactose and ovalbumin and noted substantial protection against oxidation in a soya oil model system.

One difficulty with food systems is that the Maillard reaction occurs to some extent in a wide variety of processed foods and there may already be an antioxidant effect in many food products from the MRP produced during normal processing. This has been shown by Josephson and Dale (1945) who heated butter and found a protective influence against oxidative rancidity. A similar effect has been noted for full cream milk powder receiving a high heat treatment prior to drying (Boon, 1976). Toasting of whole cereals by Anderson *et al.*, (1963) showed an improved oxidative stability of wheat, oats and corn. Zisper and Watts (1961) have demonstrated that 'overcooked' sterilised beef is also less sensitive to lipid oxidation than beef receiving a normal heat treatment prior to sterilising.

Whilst they are efficient antioxidants, there are a large number of factors that have a pronounced effect on the formation of MRP. The type of sugar (Ashoor and Zent, 1984; Lingnert and Eriksson 1980a, Pomeranz *et al.*, 1962), type of amino acid (Ashoor and Zent, 1984; Lingnert and Eriksson, 1980a), source of amino acid (Lingnert and Eriksson, 1980b; Wolf *et al.*, 1977), initial pH of the system prior to heating (Fox *et al.*, 1983; Lingnert and Eriksson 1980a; Wolfrom *et al.*, 1953), water content of the system (Fox *et al.*, 1983; Wolfrom and Rooney, 1953; Labuza *et al.*, 1970), time and temperature of heating (Fox *et al.*, 1983) as well as several other minor factors (Kato *et al.*, 1981; Bohart and Carson, 1955; Song and Chichester, 1967; Yoshimura *et al.*, 1969) may all influence the Maillard reaction and, as a consequence, the antioxidative effectiveness of the MRP produced.

Antioxidant efficacy of MRP from the casein-sugar system

Taylor and Richardson (1980b) found casein to be antioxidative and also found that casein, heated in the presence of lactose, has a greater antioxidant effect than casein alone. Studies on the antioxidant potential of casein and heated casein-lactose mixtures in model systems have been carried out at this laboratory, and confirm

the findings of Taylor and Richardson (1980b). This has been extended further to the examination of the antioxidant potential of heated casein-glucose mixtures (McGookin and Augustin, in press).

One of the major limitations of the model system is that it is not a food system. This means that any findings regarding the efficiency of the MRP can not be assumed to directly apply to a food system as the MRP may act in a different manner in a food system. It is therefore of paramount importance to test the MRP in a food where it may find practical usage. Studies on the effect of incorporation of MRP on the oxidative stability of full cream milk powders have indicated that MRP products can retard fat oxidation and increase shelf life of these powders (McGookin, unpublished results).

Considerations for Use of Casein-Sugar MRP in Foods

Given that the MRP from casein-sugar reactions have been shown to be effective oxidants, there are several factors to be considered regarding the use of these MRP in foods. Perhaps the most important of these is the question as to whether there is any possibility of a toxic or mutagenic effect of the MRP from this type of system. Although compounds formed in some Maillard reaction systems appear to be mutagenic, in many instances this question is still not resolved (O'Brien and Morrissey, 1989). In a recent study by Hosono *et al.*, whole casein was shown to be antimutagenic at a pH similar to that used in the model system in this laboratory. Whilst heating the casein caused a loss of antimutagenic activity, Hosono *et al.*, did not find that the heated casein had developed any mutagenic activity.

Another factor to be considered is the flavour characteristics which may be contributed to the food by MRP. As the Maillard reaction can not be truly arrested, many products where MRP are used may continue to brown over time. However the rate of browning can be made negligible by such factors as sufficiently lowering the water activity of the system (Labuza *et al.*, 1970) or the addition of sulphites (McWeeny *et al.*, 1969). A further consideration is the necessary chemical characterisation of MRP and the need to have the material approved for food additive use.

Conclusions

It has been found that MRP derived from the reaction of casein and glucose are effective antioxidants in both model systems and full cream milk powder. However, there are a number of questions both economic and manufacturing in nature that must be answered before this type of MRP may be safely and correctly used as an antioxidant in foods.

Acknowledgement

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Bacteriocins as Food Preservatives

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Introduction

Tagg *et al.* (1976) defined a bacteriocin produced by gram positive bacteria as an 'essential biologically active protein moiety' possessing 'a bactericidal mode of action', i.e. bacteriocins are small bacterial proteins or peptides with bactericidal properties. Bacteriocins are produced by both gram positive and gram negative bacteria and vary widely in their molecular weight, mode of action and host range. They are generally active against bacteria closely related to the producing organism and probably function in nature by giving producer strains a growth advantage over strains which are sensitive to the bacteriocin. This review will concentrate on bacteriocins produced by lactic acid bacteria. This class of bacteria is widely used in food fermentations and it is likely that bacteriocins produced by these bacteria would be suitable for use in the food industry. Bacteriocins produced by lactic acid bacteria could be used to inhibit the growth of pathogenic gram positive organisms such as clostridia, staphylococci, bacilli and listeria in various foodstuffs.

The bacteriocin could be added directly to the food as a purified product or, alternatively, bacteria used in the production of the food (e.g., cheese or fermented meats) may produce sufficient of the bacteriocin to prevent the growth of spoilage organisms.

Nisin

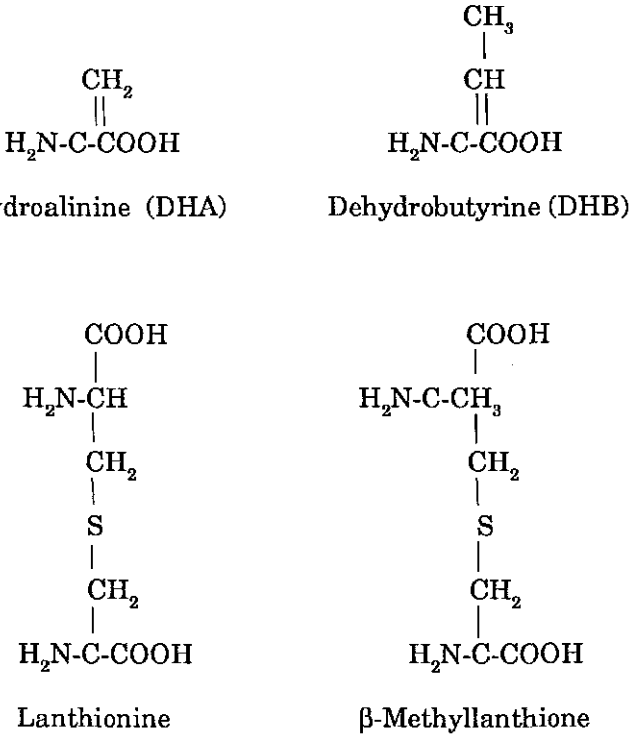
The best known and studied bacteriocin produced by lactic acid bacteria is nisin. The mature nisin molecule is a peptide of 34 amino acids, which is produced by some strains of the cheese starter organism, *Lactococcus lactis* subsp. *lactis* (formerly known as *Streptococcus lactis*). Nisin is synthesised in the cell as a preprotein, which contains an additional 23 amino acids at its amino terminus. This leader peptide region is cleaved from the remainder of the molecule, presumably during secretion of the molecule from the cell. The mature nisin molecule also contains a number of unusual amino acids not normally found in proteins. These unusual amino acids are produced by modification of serine, threonine and cysteine residues in the pre-nisin molecule (Ingram, 1970; Buchman, *et al.*, 1988). The unusual amino acids are lanthionine, methyl lanthionine, dehydroalanine and dehydrobutyrine (Fig. 1). It has been suggested (Gross and Morell, 1967, 1971; Gross, 1975, 1977; Liu and Hansen, 1990) that at least part of the antibacterial activity of nisin is due to the interaction of the dehydro residues of dehydroalanine and dehydrobutyrine with sulphydryl residues on the bacterial surface.

Specificity of nisin action

Nisin is active against a wide range of gram positive bacteria including streptococci (groups A, B, E, F, G, H, K, M, and N) staphylococci, *Micrococcus lysodeikticus*, pneumococci, bacilli, clostridia, corynebacteria, mycobacteria, lactobacilli and actinomyces (Mattick and Hirsch, 1947) and *Listeria monocytogenes* (Benkerroum and Sandine, 1988). Of particular interest regarding

its use as a food preservative is the ability of nisin to inhibit the outgrowth of *Clostridium* and *Bacillus* spores and its activity against *Listeria monocytogenes*. Moreover, the use of nisin with other food preservation techniques (such as heat and nitrite) allows the severity of these treatments to be reduced yet still maintain the preservative quality of the product (Eapen *et al.*, 1983; Tsai and Sandine, 1987). The use of nisin producing strains of *L. lactis* subsp. *lactis* has also been used to prevent the clostridial 'blowing' of swiss type cheeses (Hirsch, 1951; Hirsch *et al.* 1951). The use of nisin as a preservative can therefore be by addition of nisin to particular products or by the use of bacteria which produce the bacteriocin in the foodstuff itself.

Figure 1.
Structure of unusual amino acids present in nisin.



Properties of nisin

The solubility and stability of nisin is pH dependent, with both solubility and stability being greater at pH2 than at pH5 (Hurst, 1981). At pH2, nisin can be boiled without loss of activity. At pH values greater than 7, nisin is inactivated, even at room temperature. Nisin is generally considered to be non-toxic to humans and is degraded by α-chymotrypsin, an enzyme produced in the pancreas and released into the small intestine. These properties have lead to the extensive use of nisin as a food preservative, particularly dairy products and in some canned foods.

Other bacteriocins produced by lactococci

Kozak *et al.* (1978) identified a number of bacteriocins, termed lactostrepcins, which inhibited the growth of other strains of lactococci, group A, C and G streptococci and selected strains of *Lactobacillus helveticus, L. citrovorum* and *L. paracitrovorum*. None of these lactostrepcins exhibited inhibitory activity against a broad range of gram positive bacteria. Geiss *et al.* (1983) screened 280 strains of lactococci for their bacteriocin producing potential. Fifty six of the strains inhibited the growth of at least one indicator strain in an agar test. Sixteen of these strains excreted proteinaceous inhibitory substances into a liquid growth medium. On the basis of their chemical properties and inhibitory spectra, the bacteriocins were divided into eight types. Most of these types showed narrow range inhibition of gram positive organisms. However, one class of bacteriocin could be considered for use as a food preservative as it inhibited a range of gram positive organisms including *Clostridium* spp.

Bacteriocins produced by lactobacilli

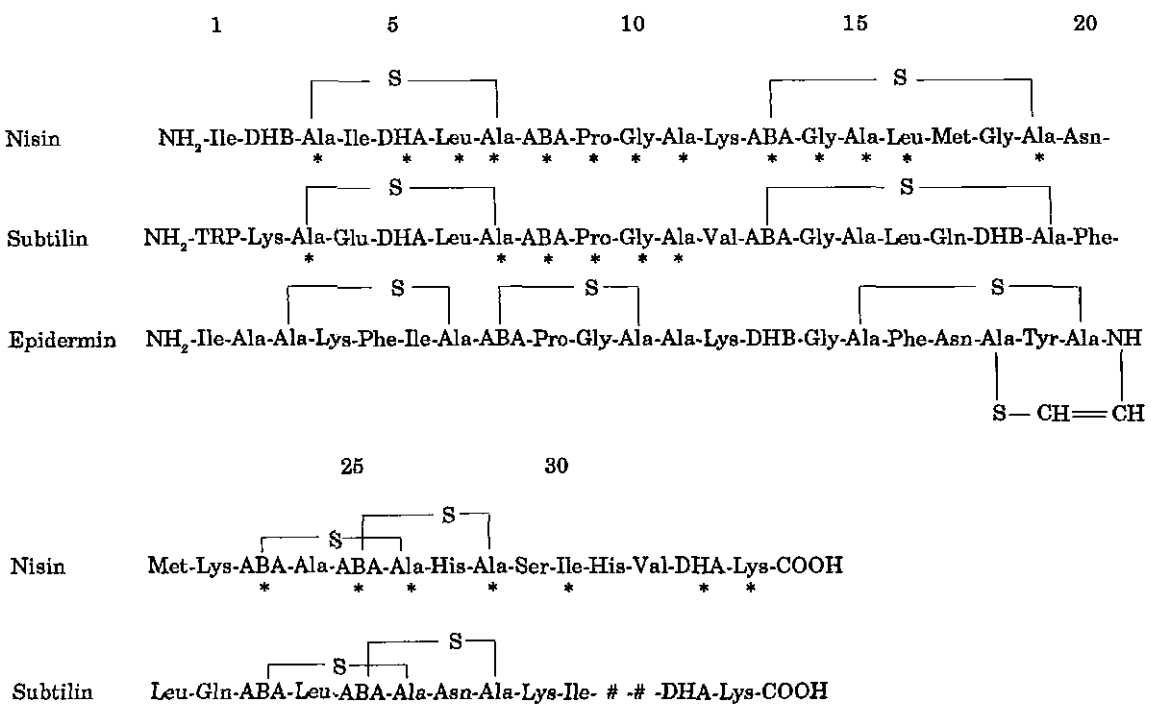
In general, the bacteriocins that have been characterised from lactobacilli exhibit only a narrow range of activity again-

st closely related species within the *Lactobacillaceae* and are therefore, at this stage, unlikely to be of much use as preservatives in the food industry. However, Schillinger and Lucke (1989) in a survey of 221 strains of *Lactobacillus* isolated from meat and meat products identified six strains which produced bacteriocins. The bacteriocin produced by *Lactobacillus sake* Lb706 was shown to inhibit the growth of *Listeria monocytogenes*. Similarly, a strain of *Carnobacterium pisciola* (formerly *Lactobacillus carnis)* was shown to produce a bacteriocin which is active against enterococci and *Listeria monocytogenes*.

Bacteriocins produced by pediococci

Pediococci are found as saprophytes on vegetable material and are used in the fermentation of vegetables and meat. Bacteriocins exhibiting bactericidal activity against a wide range of gram positive bacteria have been isolated from *Pediococcus acidilactici* (Gonzalez and Kunka, 1987; Pucci *et al.* 1988) and *P. pentosaceus* (Daeschell and Klaenhammer, 1985). The bacteriocins from both of these organisms are active against *Listeria monocytogenes* (Klaenhammer, 1988; Pucci *et al.*, 1988) and

Fig. 2. Primary structures of nisin, subtilin and epidermin. The structures of nisin and epidermin are from Gross (1977) and that of epidermin is from Allgaier *et al.* (1986). ABA, aminobutyric acid; Ala-S-Ala, lanthionine; ABA-S-Ala, ß-methyllanthionine.



* indicates identity between corresponding amino acids.

the pediocin A isolated from P. pentosaceus is active against *Clostridium* spp. Pucci *et al.* (1988) studied the effect of bacteriocin PA-1 isolated from *P. acidilactici* on the growth of L. *monocytogenes* inoculated into cottage cheese, half and half cream and cheese sauce. The addition of bacteriocin PA-1 caused a rapid decrease in the number of viable listeria in all the foods. In non-acidic foods, (cheese sauce and half and half cream) the numbers of listeria increased within a week. However, this increase was not observed in the acidic (pH5.1) cottage cheese.

Future directions

There is world wide interest in isolating from lactic acid bacteria, bacteriocins which are active against a wide range of pathogenic bacteria. In addition to screening programmes aimed at identifying new bacteriocins, various researchers are looking at (i) altering the specificity of existing bacteriocins, (ii) increasing the level of bacteriocin production in cells and (iii) procedures to introduce bacteriocin production and immunity into previously non-producing, bacteriocin sensitive cells.

Nisin belongs to a group of bacteriocins termed lantibiotics (Schnell *et al.* 1988) which also includes the bacteriocins subtilin (Gross *et al.* 1973), epidermin (Schnell *et al.* 1988), cinnamycin and duramycin (Gross, 1977) and gallidermin (Kellner *et al.* 1988). These lantibiotics all have similar size and structures and are characterised by the presence of the unusual amino acids lanthionine, B-methyllanthionine and dehydroalanine described earlier (Fig. 2). These bacteriocins have quite different target species. It is likely therefore that the host range of bacteriocins such as nisin can be altered by selective mutation of particular amino acids within the nisin molecule.

Modern genetic techniques could also be used to create strains of bacteria which overproduce the bacteriocin. These strains could then be used in the manufacture of natural products (eg, cheese) or to increase the yield of bacteriocin in fermentations designed to produce the purified bacteriocin. In the latter case, an alternative to increasing the yield of bacteriocin per cell would be to increase the yield of bacteria per volume of fermentation medium.

Finally, genes encoding nisin resistance and production can be transferred between different species and genera of bacteria by conjugation (Gasson, 1984; Gonzalez and Kunka, 1985; Tsai and Sandine, 1987). Indeed, as genes encoding bacteriocins are often located in plasmid DNA, it may be possible to transfer genes for bacteriocin production and immunity to commercially useful strains. For example, it may be possible to introduce genes encoding pediocins into cheese starter bacteria to help prevent the growth of *Listeria* in that product.

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Trends in the Production & Utilisation of Dairy Protein Products: Functional Properties & Utilisation

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The utilisation of dairy protein products as food ingredients is dependent on their physicochemical and functional properties, therefore a brief overview of some of the important functional characteristics is included here. More extensive reviews on these topics include Fox and Mulvihill (1983), Kinsella (1984), De Wit (1989a) and Mulvihill and Fox (1989).

Solubility

A typical solubility-pH profile for casein shows that close to its isoelectric pH, ie, pH 4.0-5.0, the acid form of casein is completely insoluble, while at pH values >5.5, it is converted to the cationic salt (Na, K, NH_3) and is completely soluble. Solutions containing 10-15% of these latter caseinates can be readily prepared at pH 6.0-7.0. At pH <3.5 casein is also soluble but at this pH it is more viscous than at neutral pH values and gel-like systems are formed.

When rennet casein is dispersed in water, the natural pH of the dispersion is 7.0, however, rennet casein is insoluble because of the high calcium content. It can be solubilised by either raising the pH above 9.0 or by adding calcium chelators, normally food-grade polyphosphates and/or citrates. Sodium forms of conventional 'co-precipitates' are also somewhat insoluble at pH 6.0-7.0, but the sodium forms of casein-whey protein co-precipitates prepared from milk heated at alkaline pH values (i.e. SLP and TMP) have solubility characteristics similar to caseinates.

Calcium caseinates and medium and high calcium co-precipitates form coarse colloidal dispersions rather than solutions.

Na-, NH_3- and K-Caseinates are remarkably heat stable, eg, a 3% (w/v) solution of sodium caseinate, pH 7.0, may be heated at 140°C for 60 minutes without coagulating. Calcium caseinate is less stable and a 1% (w/v) solution gels at 50-60°C. Whey proteins are unique among the proteins used in food applications as in their native form they are soluble at low ionic strength over the entire pH range required in food applications. However, being globular proteins, their solubility decreases at high salt concentrations due to salting out and they are susceptible to thermal denaturation at temperatures >70°C. Solubility at pH 4.6 is widely used as an index of the extent of denaturation caused by processing and storage of protein-rich whey products. The level of denaturation and subsequent insolubility at pH 4.6 depends on heating temperature and time, whey pH and ionic calcium concentration (Donovan & Mulvihill, 1987; Mulvihill & Donovan, 1987).

Gelation & Coagulation

Gels are systems in which a small proportion of solid is dispersed in a relatively large proportion of liquid but have the property of mechanical rigidity or the ability to support shearing stress at rest (solid properties). Milk undergoes gelation when subjected to one of several treatments and usually casein is the gelling component involved.

Gelation or coagulation occurs when milk is subjected to limited proteolysis by acid

proteinases, eg, rennet, which hydrolyse the micelle-stabilising κ-casein producing para-κ-casein-containing micelles which coagulated at the level of Ca^{2+} in the milk serum. This forms the basis for the manufacture of rennet casein and most cheese varieties. On mixing equal volumes of milk and 80% (v/v) ethanol, the casein micelles are destabilised and gels or precipitates are formed.

Acid (isoelectric) gelation/coagulation of milk is exploited in the manufacture of fermented milks, acid cheeses (Cottage and Quarg) yoghurt, and acid caseins. Depending on the pre-heat treatment of the milk, acid gels may or may not expel whey (synerese).

The viscosity of caseinate is much higher at low pH (2.5-3.5) than at neutral pH and gel-like structures are formed with >5% protein at temperatures <40°C, which may be exploited in the preparation of milk protein-containing fruit gels.

Concentrated Ca-caseinate dispersions (>15% protein) gel on heating to 50-60°C. Gelation temperature increases with protein concentration from 15-20% and with pH in the range 5.2-6.0. The gel liquefies slowly on cooling but reforms on heating; calcium caseinate is the only milk protein system reported to exhibit reversible thermal gelation.

Although thermal sensitivity is undesirable when one is seeking to prepare a soluble whey protein-enriched product, this property can be exploited in the production of thermal gels from whey proteins, which have excellent thermal gelling properties. The minimum protein concentration and heating regime required for gelation and gel characteristics such as opacity, strength and elasticity or brittleness depend on characteristics of the whey protein product, such as method of production, contents of protein, total ash, selected minerals and other non-protein components, the extent of whey protein denaturation during production of the whey protein product, solution conditions such as pH, ionic species present, other non-protein components added and the presence of reducing agents. Whey protein concentrates (WPCs) and isolates with a range of gelling properties can be produced by selection of whey type and variations in processing conditions during manufacture.

Hydration Properties

Many of the functional food applications of dairy proteins depend on their ability to hydrate and thus bind or entrap water. In this context water binding or hydration is defined as the grams of water associated with or occluded by 1g dry protein. Hydration values for casein micelles calculated from voluminosity data ranged from 1.4-6.4g H_2O/g. Hydration values for 68 caseinate samples calculated from viscosity data ranged from 0.7-3.8g H_2O/g. Hydration of acid casein was reported to be relatively independent of temperature while hydration of Na-caseinate decreased from 3g/g at 25°C to 0g/g at 80°C.

The level of hydration of proteins is strongly influenced by the level of available water and it is common to relate degree of hydration to the relative humidity of the environment to which the protein is exposed. A plot of bound (sorbed) water as a function of relative humidity, P/P_o or a_{wl}, yields a water sorption isotherm which gives useful information on the water binding or hydration characteristics of proteins. Isotherms for sodium caseinate and acid and micellar caseins show that the hydration of acid casein is higher than that of ultracentrifugal (micellar) casein; the differences are small when aW<0.6 but at aW>0.6, acid casein sorbs much more water than micellar casein. High hydration values for Na caseinate at high a_w values reflect swelling and solubilisation.

Hydration values determined for individual native whey proteins ranged from 0.32-0.60g H_2O/g depending on methods used for determination. However, when whey protein solutions of sufficient protein content and suitable solution conditions (pH, ions, etc) are heated thermal gels result and the water holding capacity of such gels makes a significant contribution to the texture and rheology of a number of processed foods.

Using a method based on water uptake by flour doughs to which various milk protein products were added, the water absorption capacity of several milk protein products have been determined by Knightsbridge and Goldman (1975); the value reported ranged from 0.96-3.45g H_2O per g product.

Viscosity

Owing to hydration, swelling and polymer-polymer interactions, caseinates form highly viscous solutions at concen-

trations >15% and even at high temperatures, the viscosity of solutions containing >20% protein is so high as to make them difficult to process. Spray-dried sodium caseinate therefore has a low bulk density.

The effects of solution conditions on the viscosities of caseins/caseinates have been extensively investigated. The viscosity of sodium caseinate is strongly dependent on pH, with a minimum at pH 7.0. The viscosity of casein is much higher at low pH (2.5-3.5) than at neutral pH and, as already noted, gel-like structures are formed with >5% protein at temperatures <40°C. The viscosity of sodium caseinate is logarithmically related to concentration, while there is a linear relationship between log viscosity and the reciprocal of absolute temperature. Caseinates exhibit pseudoplastic rheological behaviour and are thixotropic at high shear rates. The cation present has a significant effect on the viscosity of caseinates, but this in turn is dependent on pH, temperature and protein concentration.

Limited proteolysis by indigenous milk proteinase reduces the viscosity of caseinate solutions and may explain the low viscosity of caseinates produced from late lactation milk, which has a high level of indigenous proteinase. The viscosity of caseinates can also be reduced by treatment with disulphide-reducing and/or sulphydryl blocking agents.

Calcium level influences the viscosity of caseinate; the viscosity of caseinate containing 1% Ca was reported to decrease sharply in a curvilinear fashion from 30-38°C, then remain constant up to 57°C, above which the solution gelled at pH 5.4 but not at higher pH values. The shape of the viscosity-temperature curve was strongly dependent on protein concentration, pH and $[Ca^{2+}]$. Low levels of Ca increased the viscosity of Na caseinate >pH 7.0 but at <pH 7.0 viscosity decreases due to micelle formation.

The effects of various manufacturing conditions on the viscosity of casein/caseinates have also been studied. Excessive heating of milk prior to casein manufacture of casein curd during drying leads to increased viscosity of the resulting caseinates. Precipitation at lower than normal pH values (eg, 3.8) and especially at higher pH values (eg, 5.05) also increased the viscosity of caseinates. The viscosity of roller dried caseinate is higher than that of spray dried caseinate. Solubilised conventional co-precipitates are more viscous than sodium caseinate and their viscosity increases with increasing calcium concentration. Solutions of total milk proteins have viscosities intermediate between those of sodium caseinate and conventional co-precipitates.

Due to their compact globular shapes, undenatured whey proteins form much less viscous solutions than caseinates. They exhibit minimum viscosity around the isoelectric point (pH 4.5) and relative to water their viscosity decreases between 30-65°C, thereafter it increases because of protein denaturation. WPC solutions containing 4-12% w/v protein were reported to exhibit Newtonian flow while at higher concentrations flow became more pseudoplastic and at 18-20% yield values were observed.

Surface Active Properties

The strongly amphipathic nature of proteins, arising from the mixture of polar and non-polar amino acid residues, causes them to concentrate at interfaces. Because milk proteins have been available in pure form and have good surface activity, the surfactant properties have been extensively studied (for review see Mulvihill & Fox, 1989).

Sodium caseinate is a more effective interfacial tension depressor than whey protein, blood plasma, gelatin or soy protein. It diffuses more quickly to an interface and on reaching the interface absorbs more quickly than the other proteins, probably because of direct and rapid anchoring of freely available hydrophobic segments. The order of surface activity reported for the individual milk proteins is β-casein > monodispersed casein micelles > serum albumin > α-lactalbumin > α_s-casein = κ-casein > β-lactoglobulin > euglobulins.

The effectiveness of whey proteins as surface-active agents is enhanced by partial heat denaturation. The surface activity of whole and individual caseins may be modified enzymatically; dephosphorylation or treatment of sodium caseinate with plasmin (to produce y-caseins and proteose peptones) greatly increased its surface activity. γ_2/γ_3-caseins are small and very hydrophobic peptides and thus have increased surface activities.

Surface films of Na caseinate or β-casein are much more flexible and less viscoelastic at both oil/water and air/water interfaces than films of β-lactoglobulin, α-lactalbumin or bovine serum albumin.

Emulsifying & Foaming Properties

In studies on the emulsifying and foaming properties of milk proteins as reported in the literature, a wide range of apparatus type and environmental conditions (pH, ionic strength, temperature, protein concentration) have been used to prepare emulsions and foams in model and pilot scale studies. Also, different terms were used to express the results of these studies. Terms commonly used in relation to the emulsifying properties of food proteins are:

- Emulsifying capacity (g oil emulsified/g protein)
- Emulsion stability (rate of creaming, globule coalescence, flocculation)
- Emulsifying activity index (area of interface stabilised per unit weight of protein, m^2/g)
- Interfacial area (m^2/ml emulsion)
- Protein load (mg/m^2)

Soyabean oil emulsions prepared in a valve homogeniser and stabilised by sodium caseinate were found to have lower creaming stabilities than similar emulsions stabilised by either whey protein concentrate or soy isolate. The emulsifying properties of highly dispersed sodium, ammonium and low calcium caseinates and more aggregated high calcium caseinate and ethanol precipitated and ultracentrifugal (micellar) caseins have been studied (Mulvihill & Murphy, 1991). Although the highly dispersed caseinates had higher emulsifying capacities than the more aggregated caseins/ caseinates, emulsions formed using the aggregate caseins/ caseinates were more stable than those formed by the highly dispersed caseinates. Fat surface area formed on emulsification increased (ie, globule size decreased) as the power input during emulsification was increased for all the proteins and the extent of the increase was inversely related to the degree of aggregation of the emulsifying caseins/ caseinates. The protein loads (mg/m^2) of the emulsions formed using aggregated caseins/cas-

Table 1

Food uses of dairy protein products

Bakery	Biscuits, bread, cakes, pastries.
Dairy	Processed cheese, cheese analogues, coffee creamers,yoghurts, milk shakes, imitation milks, dairy spreads.
Beverages	Milk based beverages, fruit juices, soft drinks, cream liqueurs, wine aperitifs.
Desserts	Ice creams, mousses, whipped toppings, frozen juice bars.
Pasta	Macaroni, pasta, noodles, imitation pasta.
Confectionery	Toffee, caramel, fudges, meringues, sponge-type cakes.
Meat	Comminuted meats, injection brines for whole and cured meats.
Dietary, Pharmaceutical, Medical	Infant formulae, dietary preparations for weightreduction, enhanced athletic performance, therapeutic needs and for infants with special dietary needs, intravenous feed solutions, drugs for control of sleep, hunger and insulin secretion, cosmetic and therapeutic creams, toothpastes.
Convenience	Gravy mixes, sauces, dry and hydrated soups, salad dressings.
Textured	Snack foods, meat extenders.

einates were greater than for the dispersed caseinates and protein load was directly related to emulsion stability. In general, milk protein products and especially caseinates are very good fat emulsifiers and are widely used in emulsifying applications in foods.

In relation to foaming properties,important characteristics are foam volume (overrun) and foam stability. Caseinates generally give higher foam overruns but produce less stable foams than egg white solids or whey protein concentrates. Whey protein enriched products are widely used in foaming applications in food and factors such as protein concentration, level of denaturation, ionic environment, preheat treatment and the presence of lipids all influence whipping properties.

Food Uses of Dairy Protein Products

Details of many of the food uses of dairy protein products are proprietary information used by food processors and not reported in the literature. However, reviews on the food use of dairy proteins include Southward and Goldman (1978), International Dairy Federation (1982), Southward and Walker (1982), Hugunin (1987), de Wit (1989b) and Southward (1989). The following are brief outlines of some reported food applications of dairy protein products (Table 1).

Bakery Products

Milk proteins do not have properties close enough to those of wheat gluten to enable them to completely replace the latter protein in bakery products. However, their use as a nutritional supplement in cereal based products has considerable potential. The limiting amino acid in most cereal proteins is lysine and since caseins are particularly rich in lysine they make excellent supplements for cereals. Only about 4% casein in a casein-wheat flour mixture is required to increase the lysine content by 60%. The protein efficiency ratio (PER) of white wheat flour is only 1.1 compared with 2.5 for casein and on mixing casein and wheat flour to give a 75% wheat protein and 25% casein protein containing mixture, the PER is increased to about 1.8. Another important functional characteristic of dairy protein products in bakery applications is water binding, which affects dough consistency.

Casein/caseinates are added to breakfast cereals, milk biscuits, protein-enriched bread and biscuits, high protein bread and cookies as a nutritional supplement and to frozen baked cakes and cookies as an emulsifier and to improve texture. The type of casein/caseinate has to be carefully chosen to be compatible with the particular bakery applications. Co-precipitates are used in pastry glaze to improve colour; in milk biscuits, cake mixes for diabetics, high protein biscuits and cookies as a nutritional supplement and in fortified bread to improve dough consistency, sensoric properties and to increase volume and yield.

Whole whey protein products generally have a loaf volume depressing effect which has been associated with proteose peptone components. When whey is concentrated by ultrafiltration the depressant appears to be removed as dough fortified with 1% UF-whey protein concentrate resulted in only a small loaf volume depression. The concentration of whey lipids during UF also contributed to good baking characteristics.

Replacement of eggs by whey protein in cake manufacture would have economic and nutritional advantages. However, simply replacing whole eggs by WPC in madeira-type cakes results in poor quality cakes but much better results are obtained when the fat and WPC are pre-emulsified.

Various types of WPC have been used in convenience type breakfast bakery products like muffins and croissants to increase their nutritional value.

Dairy Products

Dairy protein products are widely used to supplement the protein content and enhance sensory characteristics of conventional processed dairy consumer products and are also used in the production of a range of imitation dairy consumer products. Imitation cheeses (cheese analogues) are made from vegetable fat, caseins, salts and water and are used in pizza, lasagne and sauces and on burgers, grilled sandwiches, macaroni, etc, at a significant cost saving compared to the use of natural cheese. The functional properties of casein which favour their use in imitation cheese include, fat and water binding, texture enhancing, melting properties, stringiness and shredding ability. While caseins (both acid

and rennet) and caseinates have been used most commonly for cheese analogues, co-precipitates also have potential in this area.

Sodium caseinate is used in powdered coffee creamers, which also contain vegetable fat, a carbohydrate source and added emulsifier and stabilisers. These creamers are cheaper, have a longer shelf life and are more convenient to use (eg, they require no refrigeration) than fresh coffee creams. In these products, sodium caseinate acts as an emulsifier/fat encapsulator and whitener, it imparts body and flavour and promotes resistance to feathering (i.e. coagulation of cream in hot coffee solutions).

Sodium caseinate is used to increase gel firmness and decrease syneresis in yoghurts and is added to milk shakes for its emulsifying and foaming properties. In the manufacture of imitation milks the principal ingredients used are caseins/caseinates, vegetable fat and carbohydrate, such as corn syrup. The main advantages associated with imitation milk products are the low cost and the absence of lactose to which some people are intolerant. There is also interest in the fortification of liquid milk with casein products such as sodium, calcium and potassium caseinates and co-precipitates.

Sodium caseinate is used as an emulsifying and fat encapsulating agent in the manufacture of high fat powders for use as shortenings in baking or cooking. Dry whipping fats or whipping creams contain casein products. A number of butter-like dairy spreads are manufactured using milk and/or vegetable fat and various casein products. In these applications casein acts mainly as an emulsifier and in the case of dairy spreads, it also enhances texture and flavour.

Whey protein products are widely used in yoghurts and various cheeses to improve the yield, nutritional value and consistency. Up to 20% of the casein in Quarg cheese can be replaced with thermally modified WPC, resulting in an increase in the yield and nutritional value. The use of sweet UF-WPC in Ricotta cheese manufacture increases the cohesiveness of the curd. Emulsions prepared using heat-denatured whey proteins and fat are used as a protein base for formulated cream cheeses and cream cheese spread.

The viscosity and stability of yoghurts are improved by fortification with WPC to replace skim milk solids. Sliceable and squeezable cheese-type products, based on the emulsifying and gelling properties of whey proteins have been produced by heat treatment of skim milk and WPC solids dispersed in an emulsion of milk fat in WPC. Whey protein concentrates are also used in cheese filling and dips as they tend to complement cheese flavour and produce a soft end product.

Beverages

Casein products are used as stabilisers or for their whipping and foaming properties in drinking chocolate, fizzy drinks and fruit beverages. There is also a large market for sodium caseinate as an emulsifier in cream liqueurs and to a lesser extent in wine aperitifs. Cream liqueurs typically contain 16% (by weight) milk fat, 3.3% sodium caseinate, 19% added sugar and 14% ethanol. Trisodium citrate is also added to inhibit calcium-induced age gelation. Casein products have also been used in the wine and beer industries as fining agents, to decrease colour and astrigency and to aid in clarification.

Fruit juices, soft drinks or milk based beverages supplemented with whey protein concentrates are highly nutritious products. For use in soft drinks, defatted WPC with a low ash content, good solubility at pH 3.0 and a bland flavour are required. The WPC must also be resistant to physical deterioration or flavour changes on storage of the product and it must not mask the typical soft drink flavour via protein-flavour component interactions. WPCs are added to milk-like flavoured drinks to impart viscosity, body and colloidal stability and they have been included as protein supplement in powdered orange beverages and in frozen orange juice concentrates.

Dessert Type Products

Sodium caseinate is used in ice cream substitutes and frozen desserts to improve whipping properties, body and texture and to act as a stabiliser. It is also extensively used in mousses, instant puddings and whipped toppings for similar reasons and also because it acts as an emulsifier and film former. The basic ingredients of whipped toppings are vegetable fat, sugar, protein (sodium caseinate), emulsifier, stabilisers and water. After blending the ingredients together at 38-46°C, the mixture is pasteurised and

homogenised and then either cooled rapidly to below freezing point or spray-dried.

In the manufacture of ice cream, up to 10% of the skim milk solids can be replaced by whey powder. A higher level of replacement (up to 25%) may be possible by using delactosed, demineralised whey powder or UF-WPC with no adverse effect on flavour, texture or appearance. WPC has also been used in frozen juice bars and in compound coatings, especially chocolate coatings, for frozen desserts.

Pasta Products

Milk protein products are often incorporated into the base flour for pasta manufacture for the purpose of enhancing nutritional quality and also to improve texture. Products fortified by addition of sodium or calcium caseinate, low calcium co-precipitate or WPC prior to extrusion include macaroni and pasta.

Undenatured whey protein products produce a strong final cooked noodle which is also more freeze-thaw stable and is suitable for microwave cooking. 'Imitation' or 'synthetic' pasta-type products containing a substantial proportion of milk protein have also been manufactured.

Confectionery

Caseins are used in toffee, caramel and fudge as they form a firm, resilient, chewy matrix on heating. WPCs have limited use in these products as they result in a softer coagulum and the high lactose content tends to cause crystallisation during storage. However, whey proteins are very suitable for use in aerated candy mixtures and are incorporated as a frappe which is a highly aerated sugar syrup containing the whipping protein. Egg white replacement by WPC in the manufacture of meringues only results in acceptable products when defatted WPCs are used while acceptable sponge cakes manufacture requires fat containing WPCs rather than defatted WPCs.

Meat Products

Milk proteins are used mainly in comminuted meat products rather than prime cuts. However, they are also used in injection brines for uncomminuted products like cooked hams.

Caseins in comminuted meat products contribute to fat emulsification, water binding and improved consistency as they release meat proteins for gel formation and water binding. While sodium caseinate is the preferred additive in meat applications, various types of co-precipitates have also been used.

In frankfurters and luncheon rolls up to 20% of the meat protein may be replaced by whey proteins. In these systems whey proteins are used to prepare pre-emulsions of part of the fat and to support network formation, via gelation, during subsequent cooking.

Soluble, low viscosity whey protein concentrates are suitable for use in injection brines for fortification of whole meat products. Fresh and cured meats fortified with 10% whey protein solution may increase by as much as 30% in weight.

Dietary, Pharmaceutical & Medical Applications

Since milk protein products are high quality proteins, they are extensively used in dietary preparations for people who are ill or convalescing, for malnourished children in developing countries on a therapeutic diet and for people on weight-reducing diets. Caseins are used in special preparations to enhance athletic performance and have been incorporated into formula diets for feeding astronauts.

While casein products are not generally used in infant formulae they are used extensively in specialised preparations for infants with specific nutritional problems. Caseinates and co-precipitates are used in low-lactose formulae for lactose-intolerant infants while various types of caseinates have been used in infant foods with a specific mineral balance, eg, low sodium infant formulae for children with specific renal problems. Casein hydrolysates are used in specialised foods for premature infants, in formulae for infants suffering from diarrhoea, gastroenteritis, galactosaemia and malabsorption. A special casein hydrolysate, low in phenylalanine, has been prepared for use in formulae for feeding infants with phenylketonuria. Casein products are also added to various children and infant foods and drinks as a nutritional supplement.

Modified low mineral whey powders are used to produce improved infant formulae which have a whey protein-to-casein ratio close to that of human milk. Hypoallergic, peptide based formulae have

been developed based on whey protein hydrolysates. Selected individual caseins and whey proteins have been proposed as possible ingredients for the 'next generation' of improved infant formulae.

Milk protein hydrolysates are used for intravenous nutrition for patients suffering from intestinal disorders, protein metabolism disorders and for post-operative patients. Special casein preparations have been used as food for patients suffering from cancer, pancreatic disorders or anaemia.

Specific drugs have been produced from casein; β-casein is used as raw material for production of β-casomorphins, penta- to heptapeptides which can regulate sleep, hunger or insulin secretion. Sulphonated glycopeptides prepared from casein have been used for the treatment of gastric ulcers. It is claimed that the use of casein in toothpaste prevents dental caries, in cosmetics it conceals facial wrinkles and in special therapeutic creams it heals wounds.

Convenience Foods

Dairy protein products are widely used in convenience foods, ie, foods which require a minimum of preparation by the consumer. Gravy mixes use either skim milk powder or whey/caseinate blends as whitening agents. Whey solids are used in dehydrated soup mixes and sauces to impart a milky or dairy flavour, as flavour enhancers and to provide emulsifying and stabilising effects. Caseinates are used as emulsifying agents and viscosity controllers in canned cream soups and sauces and for preparation of dry emulsions for use in dehydrated cream soups and sauces. Gravies and sauces containing whey proteins are reported to be less prone to cook-on to utensil walls, require minimum agitation and have stability in freeze-thaw cycling. In some convenience foods caseinate-whey protein blends are used as cheap replacements for skim milk powders. Whey protein products have potential as a replacement for egg yolk in salad dressing and modified whey protein based products, with potential to replace lipid in a variety of convenience foods, have been developed. Milk protein products have been proposed as texture, stability and flavour enhancers in microwaveable foods.

Textured Products

Textured milk protein based foods in the form of cheeses have been manufactured from milk for thousands of years. However, milk protein enriched products have been used in the production of textured foods only recently. Rewetted acid caseins or acidified rennet casein or co-precipitate have been mixed with carbonates or bicarbonates of alkali metals or alkali earth metals and extruded to produce puffed snack foods while caseinates have been co-extruded with wheat flour to produce protein enriched snack type food products.

Meat-like fibrous structures formed from caseins by fibre spinning techniques have been produced for use as extenders in comminuted meats. Whey proteins may be co-spun with the casein to produce stronger fibres than those containing casein alone. Meat-like structure can also be formed from casein or co-precipitates by renneting followed by thermoplastic extensions which involves a combination of heat treatment and extrusion or working. Microwave heating of whey protein solution results in simultaneous expansion and gelation to give textured products with possible applications in comminuted meats.

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Applications for Cheese Whey Protein Fractions

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Introduction

Proteins act, or show activity, in a manner which is a direct consequence of their structures. Activities such as enzymatic catalyses or the provision of structural networks as in skin or tendons are readily recognised and in recent years the relationships between structure and function of such proteins has, in many cases, been well demonstrated. The activity of proteins as food ingredients should also be clearly related to the 'functional properties' they may display. Unfortunately for food technologists, the protein science associated with such functional activity is poorly developed; only in a minority of systems can food protein structures be directly related to their specific functional properties.

The reasons for this deficiency are largely twofold. Firstly, functional properties are diffusely defined (Pour-El, 1981) relative to specific reaction catalysis. Secondly, the majority of food protein systems represent a mixture of proteins operating in a complex environment permitting interactions between proteins and non-protein components. The consequences of such interactions may be advantageous as in egg white where the foam stability of ovalbumin is enhanced by other egg white proteins (Stadelman and Cotterill, 1986) or disadvantageous as in whey protein concentrates (WPC) in which the presence of a complex mixture of proteins appears to reduce certain functional performance levels and hence the applicability of these whey protein products as food ingredients.

Against this background, studies at our laboratory are attempting to:

- Establish methodology for evaluating functional properties;
- Establish techniques for manufacturing whey protein products with improved functional properties;
- Develop and demonstrate applications for whey protein products.

For this paper, emphasis will be placed on the first and last of these objectives.

In assessing protein products as food ingredients the question may be asked: why do more than evaluate functional properties? Surely application studies are for end-product manufacturers? The distinction must be drawn between 'applications development' and 'product development'. Perhaps this is best demonstrated by an example.

It is well known that egg white protein is used to produce a stable foam. This functional property may be modulated by variation of factors including pH, temperature, inorganic environment and methodology. Similar functional activity may be demonstrated for certain whey protein products. Such an egg white foam may be used to aerate a cake batter containing flour. One might expect a similar use for the whey protein foam but experimentation has shown that interaction between whey proteins and, presumably, flour proteins results in loss of foam stability and reduced cake volume. Thus, functional property data may suggest a food application but demonstration of the required functional activ-

ity in a system containing all the normal components of the food type and assembled in the normal manner, that is application development, is also essential. By contrast, manufacture of a specific product with defined colour, flavour and textural qualities, that is product development, is not essential.

Whey Protein Fractions

That it is the presence of a mixture of proteins in WPC that limits its value as a functional food ingredient, may be concluded from previous studies on isolated or partially purified whey proteins which have been shown to be more functional than WPC (Wit (1984), Amundsen *et al.* (1982)).

Thus, improvements in the functional properties of whey protein have been sought through whey protein fractionation. Two distinct protocols have been recently described and compared (Maubois *et al.*, 1987, Pearce, 1987, Modler and Jones, 1987). Nevertheless the whey protein fractions resulting are broadly similar. Three major fractions are produced, namely 'enriched beta-lactoglobulin', 'enriched alpha-lactalbumin' and 'enriched lipoproteins'. Specific terminology for these products is still lacking and for this paper only terminology associated with the Australian process will be used and applications for Australian products described.

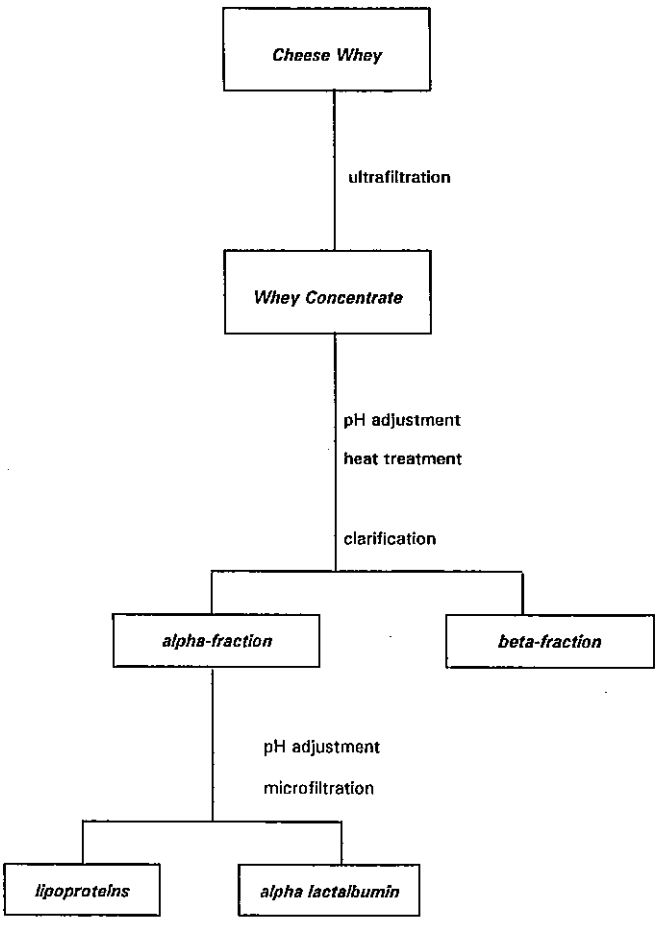
Figure 1 depicts schematically the technology used for producing whey protein fractions. Since the emphasis in this paper is on applications for products, only the products arising need to be identified. A product containing principally beta-lactoglobulin and casein derived peptide (CDP) (glycomacropeptide from κ-casein) is termed 'beta- fraction'. The co-product, 'alpha-fraction', contains principally alpha-lactalbumin and lipoproteins and is subfractionated into 'enriched alpha-lactalbumin' and 'whey lipoproteins'. Functional properties and product applications for each of these whey protein fractions continue to be investigated.

Specialised Applications for Whey Protein Fractions

Whey powder and WPC continue to be used widely as ingredients in foods not requiring special functional properties of the whey product. In the

Figure 1

Schematic depiction of methodology used to prepare whey protein fractions from cheese whey



following examples of special product applications being developed for whey protein fractions, specific functional properties are demanded of the whey protein product. These functional and other demands will be considered together with an assessment of the degree to which existing whey protein products and novel whey protein fractions meet these requirements.

Example 1. Protein-fortified fruit juice-based or fruit flavoured acidic beverages.

Objective: To provide enhanced nutritive value to existing types of fruit juice-based or flavoured acidic beverages.

Whey-based beverages have been described extensively in the published and patented literature. In these essentially flavour is added to whey to make it more palatable.

For the application described here the aim is to provide the enhanced nutrition with minimal change to the appearance, flavour or texture of the existing beverage. This places stringent functional demands on the whey protein product ingredient. The special requirements of the protein are listed in Figure 2.

It may be seen that existing commodity whey protein products such as whey powder and WPC-75 do not meet a number of the functional demands, nor do the 'enriched alpha-lactalbumin' or 'whey lipoprotein' fractions. The novel, enriched beta-lactoglobulin fraction, beta-fraction, meets these most stringent demands because of the special functional properties of the constituent major proteins. The casein derived peptide (CDP) is highly soluble over a wide pH range and by virtue of its non-globular form is highly heat stable, but it has some nutritional shortcomings. However, beta-fraction protein derived from cheese whey is about two-thirds beta-lactoglobulin which is nutritionally very high quality protein and thus compensates in this respect for the CDP. Beta-lactoglobulin is an albumin, a globular protein presenting high solubility over a wide pH range but it is unstable to heat treatment, being denatured at about 71°C (Ruegg *et al.*, 1977). In its denatured state beta-lactoglobulin shows insolubility over quite a wide pH range around

Figure 2

Summary of special requirements for whey protein products to be utilised as ingredients in protein fortified acidic beverages

Special requirements for food applications as protein fortified acidic beverages	*Whey Protein Product Options*			
	Whey Powder	*WPC - 75*	*beta-fraction*	*alpha-fraction*
1. Nutritional value	x	✓	✓	✓
2. Complete solubility at low pH	x	x	✓	x
3. Stability to pasteurisation/sterilization at low pH	x	x	✓	x
4. Absence of free fat (no fat ring on standing)	x	x	✓	x
5. Clarity in solution (specific applications)	x	x	✓	x
6. Stability to carbonation (specific applications)	✓	✓	✓	✓
7. Bland flavour in prepared beverage	x	x	✓	x
8. Acceptable mouth feel of prepared beverage	x	x	✓	x

its isolectric point (pH 5.2) but fortunately it is completely soluble below pH 3.7 even in its denatured state (Jelen and Buchheim, 1984). Thus beta-fraction protein is 'stable' (non-coagulating) to pasteurisation and sterilisation at the pH of fruit juice-based and flavoured acid beverages usually having pH values about 3.5.

The unsuitability of whey powder and WPC in this role is explained in terms of the accentuated unsuitability of the other whey protein fractions. Briefly, alpha-lactalbumin is unstable to heat at temperatures greater than 55°C and especially at pH values less than 4.5, when it aggregates due to partial denaturation associated with loss of the structurally essential calcium ion. Similarly, the whey lipoproteins aggregate at low pH and with gentle heat treatment as used in the whey protein fractionation protocol.

Thus, purified beta-lactoglobulin or beta-fraction appears to bring all the functional properties necessary for a protein-fortified acidic beverage applications, but what of their behavior in actual or model product formulations?

Beta-fraction at appropriate concentrations and pH has been formulated, both separately and combined, with levels of citric acid, sugar and pectins likely to be encountered in potential products. Formulations have been subjected to UHT sterilisation and evaluated spectrophotometrically and visually as shown in Figure 3a and 3b. It was found that clarity was highly pH dependent (as anticipated) and that UHT treatment in most instances resulted in improvement of clarity relative to the unheated sample, presumably due to greater solubility of denatured beta-bactoglobulin. Results showed that it was advantageous to start with a well clarified beta-fraction solution. Increasing the concentration of protein from 1 to 4% w/w resulted in increased absorbance values, as expected. Comparison of the data in Figure 3a with visual assessment of the same samples in Figure 3b suggested that on the basis of the stability of beta-fraction in solution acidified with citric acid, formulations containing perhaps 1-2% protein in the pH range 3.2 to 3.5 might be appropriate for acidic beverages fortified with beta-fraction.

However, for such an application, other components needed to be considered in model formulations. Addition of sucrose enhanced clarity a little as shown in Figure 3a. A low level of pectin improved the clarity of the formulation considerably prior to UHT treatment, but in this instance heating resulted in reduced clarity. Combinations of both sucrose and pectin yielded data comparable to that from pectin addition, but in the absence of sugar.

Figure 3a

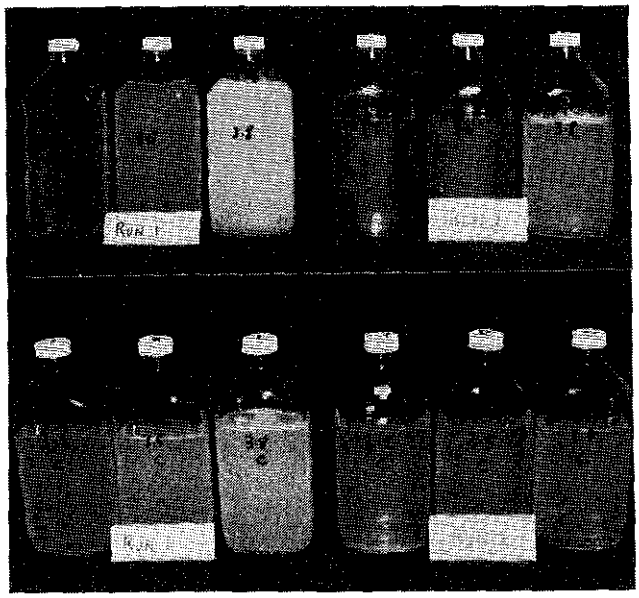
Evaluation of formulations containing beta-fraction for acidic beverage modelling with UHT sterilisation-spectrophotometric assessment

	Absorbance at 400nm		
	pH 3.2	**pH 3.5**	**pH 3.8**
1% Protein			
Unclarified/unheated	0.797	0.998	1.11
Unclarified/heated	0.335	0.648	1.37
Clarified/unheated	0.371	0.410	0.423
Clarified/heated	0.161	0.254	0.536
4% Protein			
Clarified/unheated	0.886	ND	ND
Clarified/heated	0.632	ND	ND
+5% sucrose			
Unheated	0.815	ND	ND
heated	0.485	ND	ND
+0.1% pectin			
unheated	0.160	ND	ND
heated	0.464	ND	ND
+5% sucrose+01.% pectin			
unheated	0.174	ND	ND
heated	0.525	ND	ND

Figure 3b
Evaluation of formulations containing beta-fraction for acidic beverage modelling with UHT sterilisation/visual assessment

A. Unclarified/heated

B. Clarified/heated



C. Unclarified/unheated

D. Unclarified/heated

Note: each sample treatment at pH values 3.2, 3.5 and 3.8

Figure 4. Summary of special requirements for whey protein products to be utilised as ingredients in cold- and heat-stabilised aerated foods

Special requirements for food application in aerated products	*Whey Protein Product Options*			
	Whey Powder	*WPC - 75*	*beta-fraction*	*alpha-fraction*
High foam expansion (overrun/foam capacity)	x	x	✓	x
High foam stability at low temperature	x	x	✓	x
High foam stability at high temperature	x	x	✓	x
Foam stability in the presence of a high sugar concentration	x	x	✓	x
Foam stability in the presence of sugar at high temperature	x	x	✓	x
Foam stability in protein stabilised emulsions	x	x	x	x
Foam stability in the presence of flour	x	x	x	x

Subsequent trials including fruit-juice concentrates and flavours have proven that beta fraction at concentrations up to 2.5% protein w/w is ideally suited to protein fortification of fruit-juice-based and flavoured acidic beverages.

Example 2. Protein stabilised aerated foods

Objective: To provide a protein stabilised foam, stable to cold set and heat set conditions (egg-white replacer).

Proteins have been used widely to stabilise aerated foods. Foaming products used as ingredients have included caseinates, non-fat milk powders, WPC and egg white. The functional demands on proteins for these types of foods are high as shown in Figure 4.

A simple functional test for foaming or whipping capacity may include the use of a mechanical beater to incorporate air vigorously into an aqueous suspension of the protein product under defined conditions and followed by the determination of overrun. Subsequently a test of the stability may include measurement of the rate of breakdown of the foam back to liquid suspension. Figure 4 shows that with the exception of whey powder, most whey protein products will foam to varying degrees of capacity and stability. WPC may sometimes fail to foam if free fat was inadequately separated from the original whey. Similarly most whey protein foams show enhanced stability at sub-ambient temperature indicative of their potential application in cold whipped or mousse-like desserts.

However, all finished aerated products are formulated with ingredients additional to protein hence applications models must be evaluated incorporating components likely to be encountered. Many whipped dessert products are substantially sweetened with sugar. Experience has shown that in most whey protein foam systems, addition of sugar results in at least loss of overrun and sometimes complete foam collapse. Conversely non-foaming protein product suspensions may generate a weak foam due to the increased viscosity. The effect of sugar on foam stability is at present unpredictable particularly for WPC.

Such sugar sweetened foams form the basis of meringue-like products produced after heat-setting of the 'sugar foam'. Figure 4 indicates that WPCs are not appropriate for this application. As has been shown by de Wit (1978) and others, the residual liquid containing components (lipo-prot-

Figure 5. Replacement of egg white by beta-fraction from cheese whey in a model meringue system.

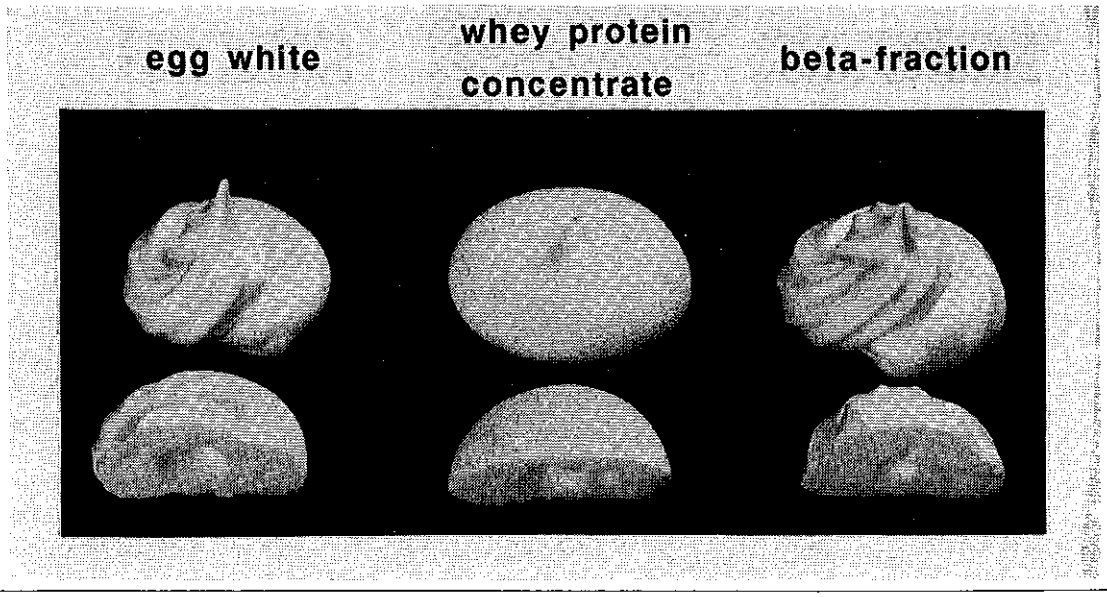


Figure 6.
Summary of special requirements for whey protein products to be utilised in food applications as a thermally set gelling, coating or binding agent.

Special requirements for food application as a thermally set gelling, coating and binding agent	*Whey Protein Product Options*			
	Whey Powder	*WPC - 75*	*beta-fraction*	*alpha-fraction*
Formation of a uniform gel on heating at neutral pH values	x	x	✓	x
Gel breaking strength commensurate with or greater than that of egg white protein	x	x	✓	x
High water binding capacity	x	x	✓	x
High water binding stability (minimal water leakage over time)	x	x	✓	x

Figure 7.
The effect of beta-fraction concentration and non-protein solids content on the breaking strength of heat-induced uniform gels.

Solvent System at pH 6.8	Breaking strength of beta-fraction gels at different concentrations of protein (g)							
Protein Concentration (% w/w)	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Water	0	0	0	112	218	424	632	776
Lactose solution	0	0	0	204	280	458	474	662
Cheese whey UF permeate	51	160	236	425	540	680	746	790

Figure 8.
Amino acid sequence homology in bovine (A)[a] and human (B)[b] alpha-lactalbumins

```
   1
A  H.Glu-Gln-Leu-Thr-Lys-Cys-Glu-Val-Phe-Gln-Glu-Leu-Lys-Asp-Leu-Lys-Gly-Tyr-Gly-Gly-
B     Lys        Phe                    Leu-Ser     *Leu                *Ile-*Asp

  21
Val-Ser-Leu-Pro-Glu-Trp-Val-Cys-Thr-Thr-Phe-His-Thr-Ser-Gly-Tyr-Asp-Thr-Glu-Ala-
*Ile-Ala             *Leu-Ile          *Met                                  *Gln

  41
Ile-Val-Glu-Asn-Asn-Gln-Ser-Thr-Asp-Tyr-Gly-Leu-Phe-Gln-Ile-Asn-Asn-Lys-Ile-Trp-
                 Asp                 Glu                              Ser          Leu

  61
Cys-Lys-Asn-Asp-Gln-Asp-Pro-His-Ser-Ser-Asn-Ile-Cys-Asn-Ile-Ser-Cys-Asp-Lys-Phe-
          Ser-Ser       *Val    Gln      Arg              *Asp

  81
Leu-Asn-Asn-Asp-Leu-Thr-Asn-Asn-Ile-Met-Cys-Val-Lys-Lys-Ile Leu-Asp-Lys-Val-Gly-
        *Asp     *Ile                          *Ala                        *Ile-*Lys

 101
Ile-Asn-Tyr-Trp-Leu-Ala-His-Lys-Ala-Leu-Cys-Ser-Glu-Lys-Leu-Asp-Gln-Trp-Leu-Cys-
                                          *Thr              *Glu

 121   123
Glu-Lys-Leu.OH
```

[a] Brew *at al.* (1970) [b] Findley & Brew (1972)

eins) effectively eliminate the potential heat setting properties of the other whey proteins. Also in Figure 4 it may be seen that the whey protein fraction, beta-fraction, being produced essentially fat-free, now satisfies this demanding functional property of forming stable heat set foams. In meringue model system beta fraction yields products comparable to or better than those produced from egg white as shown in Figure 5. In this type of application beta-fraction may totally replace egg white.

In the preparation of whipped dairy desserts and mousses it is necessary to provide stable aeration to emulsions. Since free lipid has a negative effect on foam stability, fat must be effectively homogenised with protein prior to aeration.

In this type of system clearly the foam destabilising effect of free fat is minimised by coating micro-fat droplets with protein in the formation of the emulsion, since most whey protein products, showing good foaming properties, can be used to manufacture cold aerated emulsions.

WPCs and enriched whey protein fractions may be used satisfactorily but beta fraction is advantageous through consistency of performance since the residual free lipid has been eliminated.

An extension of the aerated emulsion model involves the addition of flour as in the preparation of batters to be baked to produce cakes, sponges etc. The aerated emulsion must accommodate the visco-elastic properties of hydrated flour and subsequently heat set to yield the finished product. Egg white protein is

Figure 9. Summary of special requirements for whey protein products to be utilised as an ingredient in improved infant milk formulations.

Special requirements for food application as an infant milk ingredient	*Whey Protein Product Options*			
	Deminer -alised Whey Powder	*WPC - 75*	*beta-fraction*	*alpha-lactal-bumins*
Alpha-lactalbumins content greater than 85% of total protein	x	x	x	✓
Total solubility at near neutral pH	✓	✓	✓	✓
Bland Flavour	✓	✓	✓	✓
Stability to heat sterilisation at high whey protein to casein ratios	✓	✓	✓	✓
Positive/neutral influence on emulsion stability	✓	✓	✓	✓

most frequently used for this function and on the basis of all other functional properties enriched whey protein fractions might be expected to substitute for egg white protein. However, experiments have shown that the whey proteins in beta fraction appear to interact strongly with flour protein, so that the foam collapses when flour is added to the aerated beta fraction during preparation of the batter.

Example 3. Heat set uniform gels

Objective: To provide an adhesive, continuous proteinaceous matrix with high elasticity and breaking strength and which also has high water binding capacity (egg white replacer).

Egg white protein is used in the meat and fish products industries to achieve desired textured qualities in manufactured meat and fish products. To replace egg white protein stringent functional demands are imposed, as shown in Figure 7.

A simple functional property test is used to provide indicative data on whey protein product suitability for such food structural applications. In this test a suspension of whey protein product under defined conditions of protein concentration and pH is subjected to heating at 90°C for 30 minutes before cooling and measurement of textural properties. In addition, measurements of opacity and colour coordinates provide information on protein organisation and measurements of liquid leakage yield water holding capacity data.

Figure 7 shows that, as might be expected, gel strength increases with protein concentration. However, the relationship is not simple. A critical minimum concentration is required before a uniform protein matrix can form and hold together. Small further increases in protein concentration result in major increases in gel strength.

The effect of non-protein components can also be discerned from Figure 7. By the addition of lactose or cheese whey UF permeate solids a constant total solids content of 12.5% w/w was maintained. The presence of lactose up to 5.5% w/w had relatively small

effect on gel strength, but similar quantities of permeate solids reduced the critical concentration for gel formation and increased the overall gel strength. Since permeate solids are predominantly lactose, clearly minor components can significantly modulate the formation and strength of the resulting heat-set gel.

From Figure 6 it may be seen that, of the whey protein products, only beta fraction satisfies all the functional demands for application as a heat-induced gelling agent for applications such as manufactured meat and fish products. Detailed studies of the gelation of purified beta-lactoglobulin in aqueous buffer were conducted by Mulvihill and Kinsella (1987) who showed that the protein was able to form a uniform clear gel and that gel strength was dependent on mineral content, particularly the concentrations of sodium and calcium ions. Gel strength data obtained using WPC and whey protein fractions reflect this dependency but, in addition, indicate that it is only the beta-lactoglobulin amongst the several whey proteins which contribute positively to the gel strength.

To replace egg white as a gelling agent, comparable gel strength would be necessary. Since egg white contains 9-10% protein and typically yields a gel strength of about 250g, the results in Figure 7 indicate that beta-fraction may demonstrate gel strength as much as three times greater than that of egg white protein at the same concentration.

Consequently, on the basis of functional property evaluation, beta-fraction appears well suited to replace egg white as a heat-induced gelling agent. However, application studies of beta-fraction as a gelling agent are still at an early stage.

Example 4. Improved infant milk formulation

Objective: To provide a whey protein ingredient more closely resembling human whey protein for inclusion in infant milk formulation.

Infant milk formulations based on cow milk have been progressively modified to render the product composition more similar to that of human milk. Thus the current formulation is improved with respect to fat, protein, lactose and minor essential nutrient contents, the balance and levels of minerals and the ratio of caseins to whey proteins. Major differences still exist in the proteins themselves. Human milk casein is predominantly beta-casein; alpha-$_{S1}$ casein represents the largest properties of cow milk casein. Nevertheless, all caseins are present. However, cow milk whey protein contains mostly beta-lactoglobulin whereas this protein is absent from human milk. The predominant whey protein of human milk is alpha-lactalbumin. There is considerable structural homology between human and bovine alpha-lactalbumins as shown in Figure 8. Therefore, highly enriched alpha-lactalbumin fractionated from bovine whey provides an opportunity for significantly further improving infant milk formula. While the ingredient specifications relate substantially to compositional and nutritional compatibility, certain functional properties are also necessary as shown in Figure 9.

The enriched alpha-lactalbumin fraction produced via the thermal fractionation procedure applied to bovine whey followed by microfiltration to remove the lipoproteins, satisfies fully the specification for an ingredient to replace the currently widely used demineralised whey powder. Further advantage is gained through the high protein content of the enriched alpha-lactalbumin ingredient since less lactose and minerals accompany the protein and therefore permits greater scope in formulation. While human milk has a higher content of lactose than bovine milk, a low lactose ingredient containing desirable protein permits special formulations to be prepared for infants with low lactose tolerance, energy being provided from an alternative source such as maltodextrin.

The major functional requirements for infant formulations are total solubility during preparation and after thermal sterilisation to enable bottle feeding. In a milk protein system containing about 60% of whey protein, protein instability is more likely when the majority of the protein is beta-lactoglobulin. While alpha-lactalbumin has a lower denaturation temperature as measured by calorimetry, it has long been recognised that alpha-lactalbumin is more stable than beta-lactoglobulin to heat processing in the presence of casein; that is, it remains more substantially uncomplexed in solution (Shukla,

1973). Thus, enriched alpha-lactalbumin fractionated from bovine whey appears to be well suited for the formulation of improved infant formula in respect of both nutritional and functional properties and for flexibility of formulation.

Conclusion

Cheese whey proteins have intrinsically excellent functional properties, but advanced manufacturing methods are needed to reap their advantages.

Functional properties demonstrated by simple physicochemical procedures provide useful indicators for potential food applications for whey protein fractions. Nevertheless, applications development must follow through evaluation of model systems containing all major components and prepared with appropriate methodology.

Special food applications demand protein ingredients with stringent functional and/or nutritional properties. Whey protein fractions enable the intrinsic value of whey to be realised. Applications enabling more expensive and less versatile egg white protein to be totally replaced have been described together with novel applications unique to whey protein fractions.

Applications development for whey protein fractions as food ingredients is still at an early stage.

Opportunities for new food forms utilising whey protein fractions await food technologists with vision and imagination.

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Casein Macropeptide From Whey - A New Product Opportunity

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Introduction

Casein macropeptide (CM) is one of a number of names for the peptide split off from kappa-casein by the enzyme chymosin (or rennin). This peptide is also known as glycomacropeptide (GMP) or casein-derived peptide (CDP). It occurs in sweet wheys, for example cheddar cheese and rennet casein wheys, at about 0.12-0.15% (1.2-1.5 g/l) and as such comprises between 15 and 20% of the protein in these wheys. This may seem a small concentration but because the production of cheddar type wheys in Australia is so large, about 1,500 tonnes of CM is potentially available per annum.

Work on isolation and characterisation of CM has been in progress at CSIRO Dairy Research Laboratory (DRL) since 1986.

Investigations have centred on increasing the purity of CM prepared using an ion exchange process developed and subsequently patented by Skudder and coworkers (Skudder, 1985; Burton and Skudder, 1987) and on developing alternative processes not covered by this patent. Work on uses of this product initially involved measurement of basic properties such as solubility and viscosity. This work was then extended by examining the effects of incorporating CM into a range of food systems.

Relatively little research has been done on CM. Until recently, only broad features of its composition and properties were known. CM has a molecular weight (MW) of about 7000 and so compared to most peptides, eg, endorphins which have MW <1000, it is quite large. In fact it comprises almost 40% of the kappa-casein molecule from which it is derived, and may therefore be more accurately described as a small protein.

It has long been known that CM is unusually soluble in acids.

Once the amino acid sequence became known (Figure 1, Ernstrom and Wong, 1974), confirmation of the presence of an unusually large number of acidic side chains and relatively few basic side chains was available.

Production of Casein Macropeptide

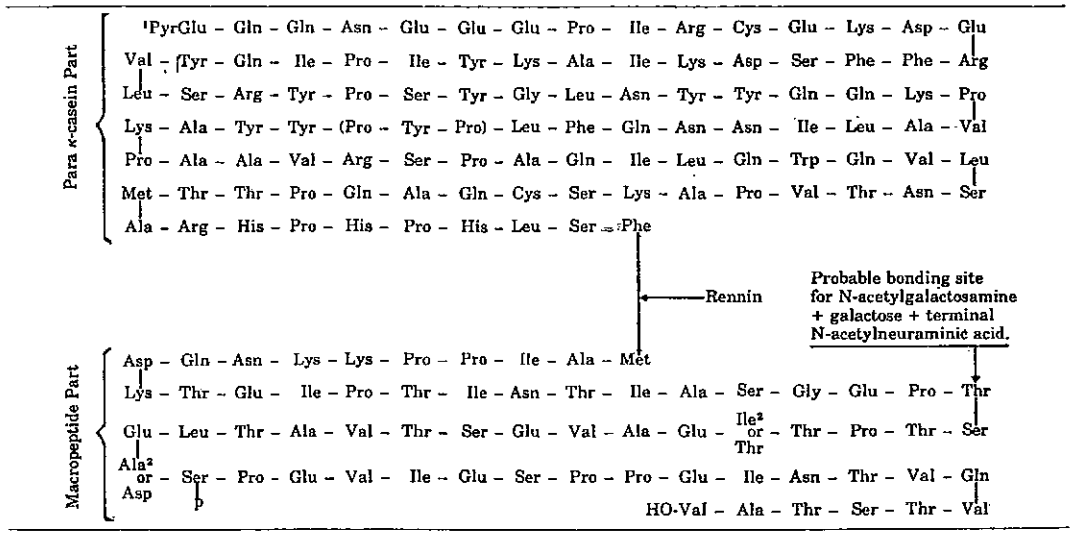
Ion Exchange Process

This process involves the selective adsorption of CM from various forms of whey onto an appropriate anion exchange medium under carefully controlled conditions of pH and ionic strength. Subsequent recovery is achieved by desorption with dilute acid or salt solutions. The preferred ion exchange medium, called 'Spherosil QMA', consists of highly porous silica spheres coated with ion exchangers of strong base functionality. These silica spheres have a number of technological advantages over the more well known organic polymer ion exchange media but are very expensive.

The amino acid profiles of products made at this laboratory using this simple procedure is fairly close to that calculated from the actual amino acid sequence. However, as shown in Table 1, they contain some aromatic amino acids not present in pure CM at concentrations high enough to limit their usefulness in some dietary applications to be dis-

Figure 1.

Amino acid sequence of bovine kappa-casein



[1]Pyrrolidonecarboxylic acid.
[2]Genetic variant κA-casein contains Thr and Asp in residues 136 and 148, κB-casein contains Ile and Ala.
Sources: Jolles *et. al,*[336b] Jolles *et. al,*[337a] Jolles *et. al,*[337b] and Mercier *et. al.*[362a]

cussed later.

Various further purification steps developed at this laboratory have reduced these concentrations of aromatic amino acids to between one-third and one-half of their original values (Table 1) and several further avenues of investigation are being pursued in order to simplify the overall process and to improve the purity of the CM products still further.

Other Processes

CSIRO is actively developing a process not covered by the British patent. This process does not require the use of expensive and specialised ion exchange media and has produced CM of equivalent or better purity. The CSIRO process is now subject to patent action.

Table 1.

Amino acid profiles of casein macropeptide

Amino Acid	% Composition		
	Calculated ex A.A. sequence	CM ex ion exchange	CM ex ion exchange purified
Methionine	1.97	0.95	1.67
Alanine	7.06	4.25	4.94
Isoleucine	10.39	8.59	10.00
Proline	12.16	9.48	10.13
Lysine	5.79	7.50	6.16
Asparagine } Aspartic Acid }	6.99	9.04	7.81
Glutamine } Glutamic Acid }	19.38	21.83	21.94
Threonine	17.30	10.80	12.84
Serine	6.94	7.45	7.10
Valine	9.28	7.18	7.72
Leucine	1.73	5.90	4.19
Glycine	0.99	1.34	1.03
Phenylalanine	0	2.02	1.19
Arginine	0	2.62	2.07
Tyrosine	0	1.02	0.52

Properties of Casein Macropeptide

Nutritional properties

Several features of the amino acid profile of CM indicate its possible usefulness in a number of special dietary applications.

Firstly, six of the twenty common naturally occurring amino acids are absent. In particular all the acids with aromatic side groups, that is phenylalanine (Phe), tryptophan (Try) and tyrosine (Tyr) are missing. CM is therefore a suitable protein substitute for those suffering from hereditary disorders of aromatic amino acid metabolism such as the various forms of phenylketonuria (PKU) (Passmore and Eastwood, 1986). Also CM is rich in amino acids with branched side chains such as valine and isoleucine and is low in methionine. This, combined with the absence of aromatic amino acids, makes CM particularly useful in the management of severe liver disease. Finally CM is rich in some nutritionally important amino acids, especially lysine.

In summary, CM forms the basis of a natural protein source for the treatment of PKU and severe liver disease. It requires only minimal fortification with synthetic amino acids and has the additional advantages of having more acceptable flavour and likely lower production cost compared to the currently available mixtures of amino acids.

Functional properties

The functional properties of CM prepared using the CSIRO ion exchange process were investigated in two ways. First, aqueous solutions of CM were used to determine the foaming and gel forming properties. Then the effects of incorporation of CM into food systems were investigated by preparing a range of food items including meringues, biscuits and fruit jellies. In this work, emphasis was on production of a range of food items containing CM which would be attractive to infants and children, as the effects of untreated PKU are most severe between birth and adolescence.

Gel formation

In their patent, Burton and Skudder (1987) claim that a solution of CM containing 9.3% protein at pH 4.5 would form a gel on standing at 20°C but not on heating to 90°C. Despite numerous attempts it has proved impossible to reproduce the claimed gel formation at 20°C with locally produced CM. At present this major discrepancy in behaviour cannot be explained.

Foaming and foam stability

The foaming and foam stability properties of CM were measured by whipping a 10% protein solution in a domestic food mixer for eight minutes.

Immediately after whipping the increase in volume due to whipping, or overrun, was measured by weighing a known volume of foam. A further weighed portion was placed in a funnel and the drainage after one hour was measured as an estimate of foam stability.

The performance of CM is shown in Table 2 along with results for egg white and a locally produced commercial whey protein concentrate (WPC).

CM gave by far the best overrun but was inferior to egg white in foam stability. The very poor performance of WPC was probably due to the relatively high fat content typical of such products.

Table 2

Foaming & foam stability of proteins

Protein	Overrun %	Foam Stability w/w % drainage after 1 hr
CM	1019	83
Egg white	637	57
WPC	148	100

NOTE: All proteins present at 10% w/w in water at pH 6.0

Meringues

Meringues were prepared using either CM, egg white, or WPC as the protein source. (Recipe details: Table 3.) The stability of the whip before baking and a large number of attributes of the baked meringues were measured, in particular their appearance and density.

The foam stability test was modified by measuring the time taken for 10 ml of drainings to appear because of the much greater stability of the meringue foams. The CM foam in this real system was the least stable (Table 3). In practical terms this was of little significance however because of the very high stability observed. As before the CM gave the greatest overrun which resulted in the lowest cooked meringue density.

All meringues were formed by extrusion of the whipped mixture through a six pointed star nozzle to produce a conical shape with a markedly rippled surface and a sharp peak on top. The appearance of the meringues made with CM and WPC was quite different and generally inferior to those made with egg white after cooking. The egg white meringues maintained their rippled surface and sharp peaks and had a smooth, dry and glossy surface. Both the other types of meringue lost all or most of their ripples and sharp peaks and tended to spread and flatten a little on baking. Surface texture was glossy and smooth but slightly sticky for CM and dry but rough for WPC. Despite these differences the CM and WPC products were instantly recognisable as meringues. No attempt at organoleptic assessment was made, however.

Table 3.
Stability of meringue mixture & density of cooked meringues

Protein	Stability sec/10ml	Density g/ml (cooked)
CM	5,900	0.135
Egg white	>50,000	0.208
WPC	18,000 to 50,000	0.276

MERINGUE RECIPE

Ingredient	Mass (g)
Caster sugar	200.0
Protein	18.0
Plain flour	4.0
Vanilla essence	2.4
Vinegar	4.8
Water	100.0

Table 4.
Viennese biscuit recipe

Ingredient	Mass (g)
Plain flour	146.0
Margarine	119.0
Caster sugar	45.5
Protein (in 12% dispersion)	12.2
Vanilla essence	5.0

Viennese biscuits

The normal recipe for Viennese biscuits is shown in Table 4. Biscuits low in Phe were produced by replacing the plain flour, which contained 11% protein and was rich in Phe, with a mixture of corn starch (cornflour) and CM of the same protein content. Biscuits were also prepared in which the plain flour was replaced with corn starch only or a mixture of corn starch and egg white. After preparation of the different biscuit mixtures the various biscuits were formed by extrusion into a shape similar to the meringues described above. Biscuits containing plain flour, corn starch or corn starch and egg white baked normally, retaining their shape and having the expected soft crumbly texture. However the biscuits containing corn starch and CM completely lost their shape only two minutes after baking commenced, becoming thin discs approximately twice the diameter of the other biscuits. Their texture was hard and brittle. Although the CM biscuits in no way resembled traditional Viennese biscuits they were considered to be a not unattractive product, a little reminiscent of the well known brandy snaps or butternut snap type biscuits.

Apple gel

Most fruits and fruit juices are low in Phe and are acidic and most infants and children will eat fruit jellies with little or no encouragement. Hence fruit jellies fortified with protein low in Phe and having good acid solubility such as CM would appear to be an ideal protein source for juvenile PKU sufferers.

Table 5.

Firmness & appearance of protein-fortified *apple gels*

pH	Energy Requirement for 25% compression mJ	Appearance
3.6	37	Opaque-flocculent ppt.
4.0	42	Opaque-flocculent ppt.
4.5	54	Translucent, yellow
5.0	46	Translucent progressively
5.5	51	Translucent increasing
6.0	20	Translucent brown
7.0	29	Translucent colour
5.0 (no protein)	126	Yellow, transparent

APPLE GEL FORMULATION

Ingredient	Mass (g)
Apple juice	79.5
Kappa carrageenan	0.5
1 % KCl solution	10.0
Sugar	9.0
Protein	1.0

Apple gels were prepared from apple juice using carrageenan as a gelling agent. At the natural pH of apple juice, which was 3.6, relatively poor gel firmness was observed with CM fortified gels, and the CM formed a flocculent precipitate. A range of gels with pH between 3.6 and 7.0 were prepared and their appearance and gel firmness evaluated (Table 5). The best gels were produced at pH 4.5, and these were translucent with a similar colour to gels prepared without protein. At lower pH the protein formed flocculent precipitates and at higher pH the colour of the gels intensified and became progressively more brown.

Attempts to fortify the gels with other proteins such as WPC and whey protein fractions were unsuccessful. All these gels were either completely opaque or contained flocculent precipitates.

The gels fortified with CM were considered to be by far the most acceptable in terms of appearance and would probably only be at a small disadvantage in the market place compared to unfortified gels.

Conclusions

It is possible to produce CM by a process not covered by the British patent of Burton and Skudder. The CM preparations made so far are almost but not quite pure enough to replace synthetic amino acid mixtures in the management of PKU and severe liver disease. However, we are confident that we will be able to produce CM of the required purity in the near future.

By virtue of its protein functionality CM can be presented in a number of interesting food forms, in contrast to synthetic amino acid protein substitutes which are only available in the form of relatively unpalatable beverages.

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New Casein Products: Fresh Opportunities for the Dairy Industry*

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Introduction

The preparation and characterisation of two new casein-derived products are outlined. First, a membrane processing procedure for the preparation of micellar whole casein, as an alternative to acid or rennet casein, is described. The process involves physical separation of casein micelles from the substantially smaller whey proteins and other whey components and is based upon the established principles of ultrafiltration and microfiltration. Physical separation of micelles from whey proteins results in a casein product with properties more reflective of the natural micelle structure. Properties of micellar whole casein, when compared with acid or rennet casein, include improved dispersibility and whitening ability and anticipated increased heat stability and hydration capacity. Second, a membrane processing procedure for the isolation of β-casein, following physico-chemical-mediated fractionation of the total casein protein, is described. The process involves cooling and slight acidification of non-fat milk to encourage dissociation of β-casein from the casein micelle, followed by membrane processing at low temperature. Under these conditions the β-casein-depleted micelles remain in the retentate while the substantially smaller free β-casein appears in the permeate. The β-casein product has the potential to enter the specialised food industry, as an ingredient in improved infant formulae, or the pharmaceutical industry as the source material in the preparation of biologically-active peptides, such as β-casomorphines.

Milk - A Valuable Raw Material

Development of new dairy products, as well as improvement of presently available products, for ever more discerning and competitive local and foreign markets currently provides the Australian dairy industry with many challenges (Cassar, 1989). In order to meet these challenges our research and development must be designed to maximise the efficiency of current processes to improve the quality of established products and to seek out new and innovative ways to utilise the myriad of milk components. The latter objective probably offers the greatest potential rewards.

Work from our laboratory has focussed, in particular, on new initiatives in the utilisation of milk protein components. In this endeavour, we have taken the view that milk, the most basic commodity of the dairy industry, is not merely a consumable but rather a very valuable raw material, rich in a variety of proteins that in various forms of isolation will yield new 'value-added' protein products. These products will have potentially increased nutritional, functional and biological value to the food and related industries and increased commercial value to the dairy industry.

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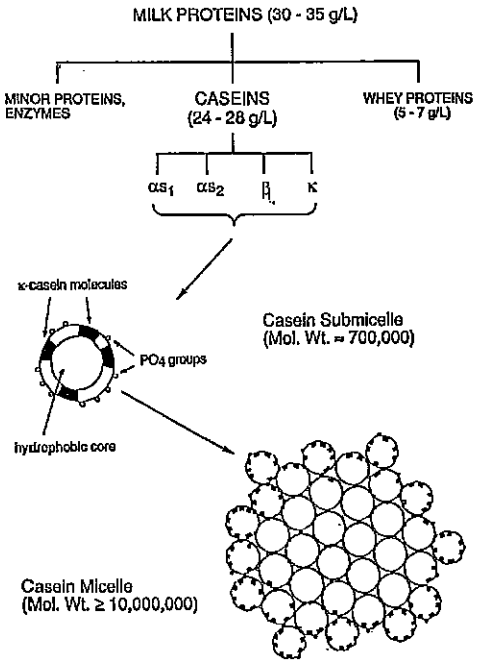
Various protein fractions have been recovered from whole milk since ancient times and are nowadays considered essential constituents of a variety of manufactured food products. The casein proteins have traditionally provided the food industry with ingredients important to the nutrition, structure, texture and appearance of many processed foods and confectioneries. Caseins account for approximately 80% of the total protein in bovine milk and are represented by four primary gene products: αs_1-casein, αs_2-casein, β-casein and κ-casein. These gene products aggregate to form large oligomeric complexes termed submicelles. In the presence of calcium, inorganic phosphate and other minor inorganic components, the submicelles further aggregate into large macrostructures called micelles (Schmidt, 1982). Solutions of these micelles appear 'milk-like' and represent a stable colloidal dispersion. A schematic representation of this structural hierarchy is shown in Figure 1.

Figure 1.
Schematic representation of the structural hierarchy of the casein proteins in bovine milk. The four primary casein gene products (αs_1, αs_2, β and κ) associate to form submicelles (approx. 30 casein monomers), which in the presence of inorganic components further associate to form casein micelles. Partially adapted from Schmidt (1982).



In the absence of disease, essentially all the casein secreted into bovine milk is found associated in the micelles. Thus, as would be expected, functional and biological attributes of casein-derived fractions will be governed primarily by the molecular structure and associated physical and chemical properties of the micelles. Nevertheless, only two basic properties of the casein micelles are currently utilised in the dairy industry to yield protein products for the food and other industries. Specifically, these properties are isoelectric precipitation of the micelles at pH 4.6 and enzyme-induced coagulation of the micelles following proteolytic treatment with rennet (Muller, 1982). Indeed, the commercial methodology associated with the preparation of casein products using these two properties has not changed significantly over the past 20-30 years.

Recent advances in membrane technology for the large-scale manipulation of milk and milk proteins provide a climate within the dairy industry conducive to exploitation of other inherent properties of the casein micelles in the preparation of new casein products with expanded commercial applications.

Micellar Whole Casein Production: Physical Manipulation of Total Milk Protein

Irreversible chemical alteration of the natural casein micelle structure through the action of proteolytic enzymes or acid forms the basis of estab-

lished procedures for the manufacture of edible casein and caseinate from non-fat milk (Muller, 1982). Acid or enzyme treatment of milk induces coagulation of the casein micelles and facilitates their separation as curd material from the soluble whey proteins. By contrast, an alternative procedure for the preparation of edible casein, currently under development in our laboratory, relies upon physical separation of the whey proteins and other whey constituents from the casein proteins in their natural micellar form. Indeed, present-day commercial techniques for the manufacture of casein destroy the casein micelle, while the current processing procedure is designed to maintain the micelle structure along with its unique properties. The new casein-derived product has been termed micellar whole casein.

The rationale for the process resides in the stark physical differences between the caseins and whey proteins as they exist in milk (Table 1). Caseins are present as a colloidal dispersion of micelles with molecular weights substantially greater than 10 million (Figure 1, Table 1), whereas the whey proteins exist as much smaller, globular and soluble species. The major whey proteins (β-lactoglobulin and (α-lactalbumin) have molecular weights < 50,000. The process for the preparation of micellar whole casein exploits these differences, particularly the size differential (Table 1) and is based upon the established principles of ultrafiltration and microfiltration, separation of the casein micelles from the whey proteins being effected

Table 1. Some Physical Properties of Caseins versus Whey Proteins as found in Bovine Milk.

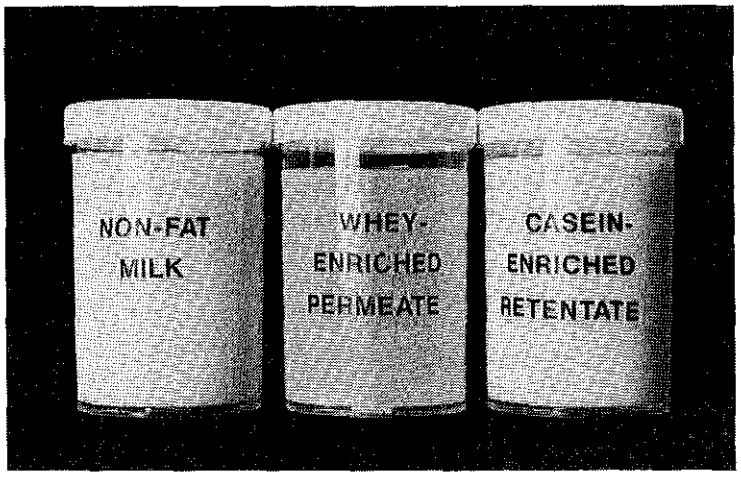
Milk Protein Class	Nature in Milk	Molecular Size (daltons)
Casein	Colloidal micelle dispersion	$\geq 10^7$
Whey	Soluble, globular	$<< 10^5$

Table 2. Chemical Analysis of Dried Products following High Porosity Membrane Processing of Bovine Non-Fat Milk.

Product	Protein	Fat (%, w/w)	Ash
Micellar whole casein	73.2	1.3	8.3
Protein permeate[a]	73.8	0.5	6.1

[a] Prior to lyophilisation the permeate was subjected to diafiltration (3:1) with demineralised water.

Figure 2.
Visual appearance of non-fat feed material and whey protein-enriched permeate and casein-enriched retentate following high porosity membrane processing of bovine



through the use of appropriate 'porous' membranes. This procedure has been termed high porosity membrane processing (HPMP).

Recent trials of the suitability of HPMP in the manufacture of micellar whole casein, using a commercial pilot-scale microfiltration plant have demonstrated that membrane-based physical separation of whey from casein micelles in milk is commercially feasible. The visual appearance of the whey-enriched permeate and casein-enriched retentate following HPMP of non-fat bovine milk using the plant are compared with the feed material in Figure 2. Analysis of both product streams by polyacrylamide gel electrophoresis (Figure 3) indicated that the retentate was highly enriched in casein and substantially depleted in whey proteins; while the permeate was rich in whey proteins, including both major (β-lactoglobulin, α-lactalbumin) (see also Smithers *et al.*, 1990) and high molecular weight minor (e.g., lactoferrin) species (see lane Wl, Figure 3). Casein contamination of the permeate (Figure 3) most likely reflects the presence of some small micelles.

Table 3.
Some Physical Properties of β-Casein versus β-Casein-depleted Micelles from Bovine Milk.

Milk Protein	Nature	Molecular Size (daltons)
β-Casein-depleted micelles	Colloidalmicelle dispersion	$> 10^6$ (?)
Free β-casein	Soluble	2.4×10^4 (monomer)

Table 4.
Some Structural Properties, and Projected Functional Attributes and Applications of Fractionated β-Casein

Structural Properties	Functional Properties/ Applications
Small amphipathic molecule... * 24,000 daltons * polar N-terminal domain * hydrophobic C-terminal domain	Surface active ingredient... * foaming * foam stabilisation
Primary casein constituent of human milk*... * sequence homology between bovine and human proteins	Nutritional ingredient... * 'humanised' infant formulae
Regions of sequence corresponding to 'biologically-active' peptides	Therapeutic product... * morphine-like peptides * immunostimulant peptides * mineral absorption * anti-hypertensive peptide
*see Table 5.	

Utilisation: chemical analysis, functional properties & potential applications

Results of gross chemical analysis of micellar whole casein and the protein permeate coproduct are presented in Table 2. Both products have protein contents in the region of 75%, coupled with low fat levels, particularly the protein permeate powder. The high ash content of micellar whole casein most likely reflects inorganic material (e.g., calcium, magnesium, phosphate) associated with the micellar nature of this product.

Functional properties of both products, as assessed to date, are reflective of the nature of the preparative procedure and the results of chemical analysis (Table 2, Figure 3) and can be used to forecast potential applications. Thus, micellar whole casein should find use as an ingredient in manufactured foodstuffs where the excellent dispersibility and whitening ability (qualitative assessment), good solubility (data not shown) and anticipated heat stability and hydration capacity of the product would be of value. Such foods include low-fat or non-fat coffee whitener, yoghurt, ice-cream and

manufactured meats. The foaming ability of the protein permeate (570% foam overrun) compares favourably with a commercial whipping agent (All Whip™, 580% foam overrun) and reflects the low fat content and high protein level of the co-product (Table 2). Thus, this by-product of the manufacture of micellar whole casein should find application as an ingredient in aerated confections. The protein permeate may also prove a valuable source material in isolation of the individual whey proteins. For example, purified α-lactalbumin will command a high price as the major whey protein ingredient in improved infant formulae (see Table 5).

Fractionated Whole Casein: Beta-Casein

Production: Physico-chemical-mediated fractionation of casein

Intact casein micelles can be manipulated through simple chemical or physical treatments, such as mild acidification or a reduction in temperature or a combination of both (Creamer *et al.*, 1977; Dalgleish and Law, 1988). These treatments disrupt the integrity of the native micelle resulting in dissociation of individual casein constituents and provide a facile and novel approach to casein micelle manipulation and fractionation.

In practical terms, Dalgleish and Law (1988) showed that by simply lowering the pH (5.3 - 5.2) and temperature (4°C) of bovine milk up to 80% of micelle-bound β-casein (and other β-casein-derived species termed γ-caseins) could be solubilised.

The development of a commercial process for isolation of the dissociated β-casein, currently being pursued in our laboratory, has exploited the stark physical differences between free β-casein and the β-casein-depleted micelles (Table 3). While there is doubt as to the exact structural nature of the β-casein-depleted micelles, evidence suggests that these species still exist in micellar form (Creamer *et al.*, 1977) with molecular weights most likely below one million. On the other hand, free monomeric β-casein is a relatively small molecule (Table 3). Exploitation of the substantial size differential between dissociated β-casein and the modified micelles, together with the use of HPMP (see above) at low temperature, has resulted in the isolation of small quantities of a β-casein-enriched whey permeate from non-fat milk.

Utilisation: structural/functional properties and potential applications

The unique structural attributes of β-casein provide an indication of the functional properties and potential areas of application of a β-casein-enriched product, not only as a food ingredient but also in non-traditional dairy protein markets, such as the pharmaceutical industry. Structural features of β-casein and predicted functional properties and areas of application, are summarised in Table 4.

Table 5.
Comparison of the Protein Composition of Bovine and Human Milk[a]

Protein	Composition (g/L)	
	Bovine Milk	Human Milk
Casein	26	3.2
αs_1	10.0	negligible
αs_2	2. 6	negligible
β	9.3	2.2
γ	0.8	
κ	3.3	0.9
β-Lactoglobulin	3.2	negligible
α-Lactalbumin	1.2	2.8
Serum Albumin	0.4	0.6
Immunoglobulins	0.7	1.0
Lactoferrin	≈0.1	2.0
Lysozyme	negligible	0.4

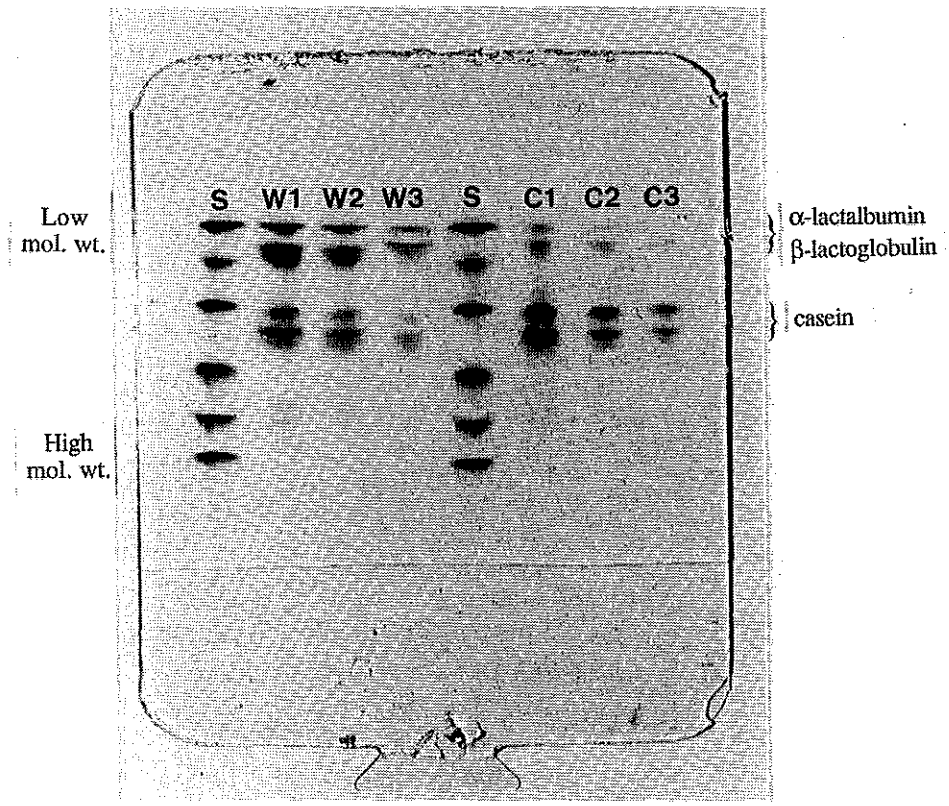
[a] Tabulated from data presented in Jenness (1982) and Farrell and Thompson (1988).

Functional Food Ingredient. β-casein is a small amphipathic molecule containing a highly polar N-terminal domain, distinctly separate from the C-terminal hydrophobic region (Swaisgood, 1982). Such a detergent-like nature confers upon the molecule 'surface-active' attributes. Associated properties, of particular relevance to the food industry, include foaming, foam stabilisation and emulsification (Table 4).

Nutritional Food Ingredient Contrary to popular belief, of the total protein found in human milk approximately 30% is casein (Table 5). β-casein represents the vast majority of this casein protein (70%) followed by κ-casein (27%) with only negligible quantities of α-casein present. By contrast, of the casein protein found in bovine milk approximately 50% is α-casein (Table 5). Thus, efforts to develop a baby food that more closely matches the protein makeup of human milk must not only address the issue of whey protein content (e.g., levels of α-lactalbumin, β-lactoglobulin, lactoferrin), but also the question of total casein content and the relative levels of individual casein constituents (Table 5). Availability of

Figure 3.
Sodium dodecyl sulphate polyacrylamide gel electropherograrn of the whey-enriched perrneate (W) and casein-enriched retentate (C) following HPMP of bovine non-fat milk.

Electrophoresis was carried out using a Pharmacia PhastSystem and a gradient (10 - 15%) PhastGel. Lanes Wl - W3 contained 2.0, 1.0, and 0.5 llg protein, respectively; and lanes Cl - C3 contained 2.4, 1.2, and 0.6 ~g protein, respectively. Subunit molecular weight standards (S) include *a*lactalburnin (14,400), soybean trypsin inhibitor (20,100), carbonic anhydrase (30,000), ovalbumin (43,000), bovine serum albumin (67,000), and phosphorylase b (94,000).



a bovine β-casein product will allow development of 'tailor-made' infant formulae that more closely match the casein makeup of human milk (Table 4).

Therapeutic Product. The primary structure of β-casein is rich in a number of short amino acid sequences that correspond to peptides with established biological and physiological activities (Migliore-Samour and Jolles, 1988; Maubois and Leonil, 1989). For example, various penta-, hexa-, hepta- and octa-peptides, corresponding to regions of the amino acid sequence 60 - 68 in β-casein (Tyr - Pro - Phe - Pro - Gly - Pro - Ile - Pro- Asn), express both opioid (β-casomorphilles) and immunostimulatory activity. In addition, the highly phosphorylated sequence 14 - 20 (Glu -SerP - Leu - SerP - SerP - SerP - Glu) corresponds to a peptide that may play a role in the intestinal absorption of minerals (e.g., Ca^{2+}) and the region 177-183 (Ala - Val - Pro - Tyr - Pro - Gln - Arg) appears to possess antihypertensive activity (Table 4). The availability of a bovine β-casein isolate will not only provide the pharmaceutical industry with a source material suitable for isolation of these peptides, but also the means for a dairy protein to enter a non-traditional market.

Conclusions

The Australian dairy industry can meet the challenges of industry deregulation and increased competition on a national and international level, at least in part, through development of 'value-added' dairy protein products. The bovine casein proteins offer tremendous scope for the development of such products. Rather than depend solely on established casein-derived preparations, such as cheese and acid or rennet casein, the industry now has the opportunity to develop high value, 'tailor-made' casein products with applications not only in the food industry, but in non-traditional dairy protein outlets. Two such products are currently under development in our laboratory. Micellar whole casein, prepared using a process designed to maintain the natural micelle structure, should find use as an alternative to acid or rennet casein. β–casein, prepared using a simple fractionation process, should find use as a functional and nutritional ingredient in the food industry and in the preparation of physiologically-active peptides by the pharmaceutical industry.

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Lactose Utilisation

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Introduction

This paper addresses the use of lactose in a range of foodstuffs. The structure, chemical and physical properties of lactose are discussed and compared with other saccharides. The utilisation of lactose in a range of foods, including infant foods, confectionery, meat, packed goods and biological media, are outlined. Some nutritional aspects are also considered. It is concluded that increased utilisation of lactose will probably be the result of developments in infant food and confectionery, together with its application as a feedstock for the production of lactose hydrolysed products and fermented products.

General Considerations

The utilisation of the lactose in by-product streams from cheese and casein manufacture remains one of the dairy industry's most difficult problems. Until recently, the major source of lactose has been whey from the manufacture of casein and cheese. However, the development of ultrafiltration (UF) technology for the processing of milk and whey is resulting in a rapid increase in the production of UF permeate high in lactose content. This trend is certain to continue as UF technology continues to be more widely applied to cheese making and to the production of whey protein concentrates (WPC). The increased volume of permeate so produced will have important implications regarding the utilisation of lactose.

In the past, the processing of wheys has generally aimed at utilisation of the protein fraction, as this attracts the highest economic return. Thus, WPC manufacture is aimed at maximising utilisation of the protein in whey. To date, the utilisation of the protein-free permeate from the UF of milk or whey has to a large extent been ignored. However, with the increased use of UF in cheese making resulting in the production of larger volumes of permeate rather than whey, increased emphasis is likely to be given to permeate utilisation. Because permeate is virtually protein free, potential returns for the product are significantly lower than for whey and applications within the food industry are more restricted.

The increasing role of UF in the production of permeate has been outlined by Teixeira *et al.* (1983a). These authors reported that whilst the potential market for whey protein concentrates in the USA is about ten times the 15 thousand tonnes used in 1981, by 1986 the demand for lactose would have risen by only about 25% over the 1981 production. They strongly suggested therefore that new applications be developed for the utilisation of lactose permeate from UF.

World cheese whey solids production is currently at least 9,000,000 tonnes per annum. These solids contain about 4,000,000 tonnes of lactose. Currently, commercial utilisation of lactose is about 200,000 tonnes per year. Much

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of the residual lactose is utilised directly in the form of whey - as animal food, in spray dried whey or disposed of on the land or by sewage treatment.

There is little information available regarding the utilisation of lactose by individual countries, or on a world basis. However, it is likely that major users include the manufacturers of infant foods and the pharmaceutical industry, where the ability of lactose to be moulded into tablets and pills is beneficial.

World demand for lactose is considered to be inelastic and thus any significant increase in production would likely result in a sharp reduction in price. For this reason, there has been some tendency for the dairy industry to utilise lactose as a raw material for the manufacture of other more valuable products. However, this approach often requires the injection of considerable capital, as well as the assessment of alternative technologies and the development of new markets.

However, there are still many useful applications for lactose within the food industry and these continue to be developed. Some of these applications are outlined in review articles by Teixeira *et al.* (1983b); Coton *et al.* (1982) and Mann (1984).

Many of the uses of lactose by the food industry rely on its particular characteristics in comparison with other sugars. For example, lactose is a useful carrier for flavour and colours and this has led to its utilisation in products such as sachet wafers, seasonings and baked goods. The confectionery industry uses lactose to obtain desired end products properties, relying on lactose to alter the crystallisation characteristics of other sugars. The reducing nature of lactose, coupled with the fact that it is not fermented by bakers' yeast means that it offers unique properties to the baking industry. The addition of lactose will increase the browning of the crust and, since lactose is not fermented during bread making, any other functional properties conferred by the lactose will not be lost during manufacture. In beer, lactose may be also used as a means for improving organoleptic quality, as it is not fermented by beer yeasts.

Lactose may also be used as a substrate in the production of penicillin, as seed material in the manufacture of concentrated and condensed milks and as a raw material for the production of specialty chemicals and in some fermentations.

Properties of Lactose

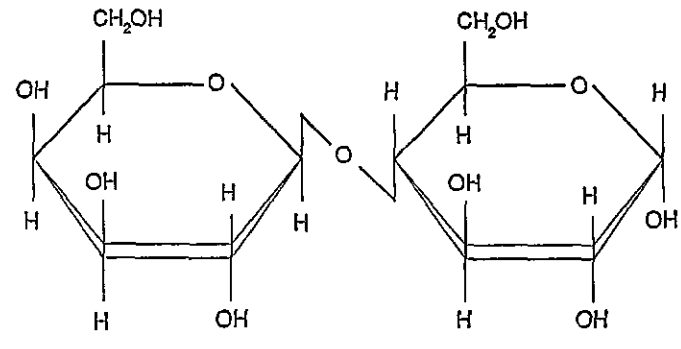
Structure

Essentially, the sole source of lactose is the milk of mammals (other sources are rare, but it is also found as a component in the polysaccharides of some flora). It is a di-saccharide that, on hydrolysis, yields D-glucose and D-galactose. The two mono-saccharides are linked through the aldehyde group of d-galactose; thus the aldehydic portion of lactose is attached to the glucose moiety. The structure of lactose is shown in Figure 1.

Lactose exists in two isomeric forms (anomers), alpha and beta, which differ only in the configuration of the substituents on the number one carbon atom of the glucose residue (Figure 2). The solubility of these two forms is significantly different - the solubility of the alpha form is about 7g/100g at 15°C, whereas that of the beta form is about

Figure 1

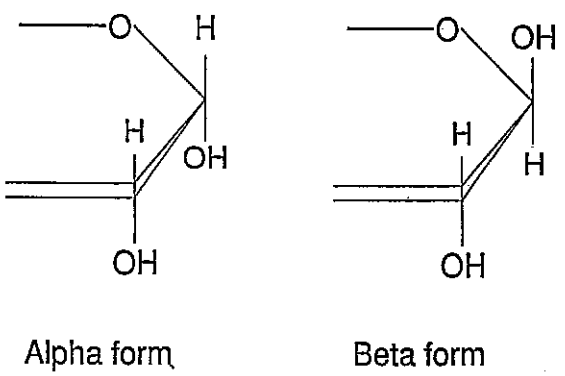
Structure of Lactose



50g/100g. On dissolution of lactose, mutarotation occurs, yielding a solution containing about 63% beta-lactose. On concentration, some alpha-lactose will precipitate and further mutarotation will occur, with conversion of soluble beta-lactose to alpha-lactose. As crystallisation proceeds, this process continues, yielding a product mainly composed of alpha-lactose monohydrate. The composition of the product so obtained will therefore depend on the rate of two competing equilibria, the rate of conversion of soluble beta-lactose to soluble alpha-lactose and the conversion of soluble alpha-lactose to alpha-lactose mono-hydrate crystals.

Figure 2

Alpha & Beta Forms of Lactose



Alpha-lactose crystallises as a hydrate; however, beta-lactose contains no water of crystallisation. When lactose solutions are dried rapidly, there may be insufficient time for crystallisation of the alpha-lactose to alpha-lactose hydrate to occur. The dry lactose is then in a form similar to that present in the liquid. A number of studies have confirmed that lactose in rapidly dried dairy products is in the form of a mixture of beta-lactose, alpha-lactose mono-hydrate and amorphous alpha-lactose. Neither beta-lactose nor alpha-lactose mono-hydrate are hygroscopic. However, anhydrous alpha-lactose is highly hygroscopic and absorbs water from the air, forming the hydrate that occupies more volume than the anhydrous form. This is the cause of the caking and lumping observed in many dried dairy products.

These characteristics need to be taken into account during manufacturing processes if difficulties are to be avoided. Normal procedures for the manufacture of 'non-hygroscopic' dairy products generally involve the conversion of much of the lactose into a crystalline form prior to drying. This can be achieved by holding the concentrate under fixed conditions to allow for the formation of alpha-lactose hydrate crystals. As an alternative, techniques similar to 'instantising' can be employed, where the surface of the product is humidified or the particles dried partially to permit crystallisation of the lactose before final drying.

Sweetness and solubility

Lactose is much less soluble and much less sweet than sucrose. These properties substantially restrict its range of applications in the food industry as an alternative sweetener. The relative sweetness and solubility characteristics of lactose, glucose, galactose and sucrose are shown in Table 1 (Pazur, 1970; Shah and Nickerson, 1978). However, relative sweetness varies with concentration and thus the values shown in Table 1 should be taken only as a guide. The sweetness of lactose increases with concentration more rapidly than does the sweetness of sucrose, although there appears to be little difference in the effect of concentration on the sweetness of lactose, glucose or galactose. It is generally accepted that beta-lactose is sweeter than alpha-lactose, but at low concentrations, it is not significantly sweeter than the equilibrium mixture.

The development of lactose crystallisation in frozen foods may lead to undesirable calcium-protein interactions and instability (Muir, 1985). A number of options to improve freeze-thaw stability of lactose containing frozen products are open to the food formulator, including lactose hydrolysis.

Manufacture of Lactose

It is not my intention to discuss the manufacture of lactose in detail. The principles for the manufacture of lactose were outlined as long ago as 1895 by Zirm (1895) and then by Aufsberg (1910). The principles described by these authors for the manufacture of lactose remain relevant today. Today, the technology for production of lactose can be purchased from a number of experienced equipment supply companies. In general, production of lactose involves protein removal (for example by liming, heat treatment and filtration), concentration of the mother liquor, refiltration, further concentration, induction of crystallisation and removal of crystals by centrifugation. Continuous systems have not been successfully developed to commercial application as yet.

In the batch crystallisation procedures, about 50% recovery of the lactose is achieved and the mother liquor may be sold as delactosed whey powder. It should be noted that permeate from the UF of milk or whey is an ideal raw material for this process, as it does not require removal of protein.

Lactose Utilisation

Infant foods

The only source of carbohydrate in mammalian milk is lactose and lactose is also a major contributor to energy requirements during infancy. Lactose is hydrolysed only slowly in the intestines, resulting in a steady energy supply and a comparatively constant blood glucose level between feedings. The replacement of lactose by glucose (for example) in infant diets would require a greater response from the insulin system, with risks of over secretion of insulin and consequently low blood sugar levels. It is also believed that lactose assists in the development of a favourable environment in the intestine, resulting in development of lactic acid flora, which may inhibit the growth of pathogenic flora and also has a useful effect of calcium absorption.

Some of the differences between human and cow milk are outlined in Table 2 (Visser *et al.* 1986). It is common practice to fortify infant foods based on cow milk with lactose because of the difference in lactose content between human and cow milk.

There is extensive literature available on the formulation of infant foods, including useful reviews by Mann (1977), Mathur and Shahani (1979) and Ulrich (1976). The preparation of a food for premature infants based on whey protein concentrate, lactose, maltodextrin, vegetable oils, glycerol mono-stearate, lecithin and oil vitamin concentrate has been outlined by Lucas and Barr (1985). The process involves clarification, pasteurisation, homogenisation and heating. The food contains more

Table 1

Sweetness and solubility of lactose

	Relative Sweetness[a]	Solubility (g/100g solution)[b]		
		10°C	30°C	50°C
Sucrose	100	66	69	73
Lactose	16	20	30	
D-Galactose	32	28	36	47
D-Glucose	74	40	54	70
D-Fructose	173	—	82	87

[a]Pazur 1970. [b]Shah and Nickerson, 1978.

Table 2

Some attributes of human and cow milk

		Human	Cow
Solids (%)	-Total	12.4	12.4
	-Lactose	7.2	4.6
Calorific Value (kJ/100mL)	-Total	263.7	272.1
	-Lactose	121.4	77.4
Osmotic Pressure (mOsm/L)	-Total	239.0	221.0
	-Lactose	210.0	134.0

Adapted from Visser, Van den Bos and Ferguson (1986).

than 160 microg/100µ riboflavin and may be beneficial to infants undergoing photo-therapy.

Confectionery

The confectionery industry is a major user of lactose (Spurgeon 1976; Riedel and Hansen, 1979; Mann, 1982; Estelmann, 1984). Recent reports have outlined the use of lactose in fondant at Meggle Milchindustrie (Anon, 1984). The incorporation of lactose into fondant (usually comprising sucrose, glucose syrup and water) and the use of microfine lactose in fondant fillings were studied by these workers. Manufacture of a lactose containing fondant was achieved by bringing the lactose and sucrose into solution and crystallising them together. Alternatively, microfine lactose, could be introduced to prepared fondant with further mixing. Inclusion of lactose in fondants resulted in control and reduction of sweetness, intensification of whiteness in fondant and economies in operation. Meggle Milchindustrie (Anon, 1985) have also reported a lactose containing a special ingredient for toffee and fudge.

Boesig and Pritzwald-Stegmann (1981) have described the use of a mixture of sucrose and lactose for sugar coating of cores (e.g. chocolate buttons or hazelnuts). The ratio of sucrose to lactose examined covered the range 90:10 to 50:50. Lactose suppressed sucrose crystallisation allowing the coating to be effected at lower temperatures and reducing the sweetness of the coating.

Baked goods

The applications of lactose within the baking industry are determined to a large extent by the reducing nature of lactose, coupled with the fact that it is not fermented by bakers yeast. The addition of lactose, for example, will increase the browning of the crust, which is often highly desirable. Luksas (1984) has reviewed the applications of lactose-based products in the baking industry. Harper *et al.* (1984) examined the use of whey-based products in breadmaking and concluded that lactose concentration was not related to the loaf depression associated with use of some whey-based products.

Meat

Although the application of lactose in meat products would appear to have considerable potential, there is comparatively little information concerning such uses in the literature. Pinel (1981) has considered various possibilities in a review article. Lauck and Melachouris (1983) have outlined the manufacture of a deproteinised whey-based product containing 40 to 50% lactose which is particularly suitable for addition to comminuted meat products as a flavour enhancing and binding agent. Scharner *et al.* (1981) have described a lactose-containing product which may be added to raw sausage formulations as a carbohydrate source for the starter culture.

Cultures and biological materials

Lactose fractions derived from whey UF permeate have been recommended as an ingredient for a wide range of culture media for bacteria or fungi (Keggins *et al.*, 1984).

The use of milk-based powders for the drying of starter bacteria has been studied by Harju *et al.* (1983). Dried milk products were used to absorb the water and this technique was compared with freeze drying and spray drying. *Propionibacterium freudenreichii* and *Lactobacillus helviticus* were dried successfully by the sorption method, with survival rates of more than 50%. Freeze drying was more successful for *Streptococcus lactus*. Spray drying was unsuitable for all three organisms.

Miscellaneous

Lactose has been recently suggested for as an ingredient in coffee creamers (Moran and Halstead, 1981), dietetic agents (Kowalsky and Scheer, 1981), edible gel products, (Le Grand and Paul, 1981), food release agents (Noborio and Maeda, 1981), ketchups and sauces (Dordevic *et al.*, 1981), a water miscible starch based product (Gasser and Badertscher, 1981).

The firming of vegetables by addition of lactose was studied by Jelen and Chan, 1981). Blanched carrots, green beans and peas were retorted at 121°C in 2% sodium chloride brine containing O-15% lactose. After 37 and 68 days, hardness of the vegetables was evaluated. Increasing lactose content correlated significantly with average hardness of peas and beans and, to a lesser extent, carrots. All samples from brines containing more then 8% lactose showed higher average hardness than those containing less or no lactose.

The increase was noticeable to an untrained panel.

Eisenstadt (1981) has suggested the use of lactose in di-peptide sweetener formulations to give a product approaching the natural sweetness of glucose and requiring the minimum addition of di-peptide sweetener.

Nutrition

Lactose malabsorption

Lactose malabsorption and its implications for the development of lactose hydrolysed products has been recently reviewed by Hourigan (1984), amongst others.

Calcium absorption

There is much evidence that dietary lactose assists the absorption of calcium (Allen, 1982; Schaafsma, 1983). The enhancement of calcium absorption by lactose is due to increased passive diffusion (Allen, 1982), but beyond that, the mechanism is uncertain. The effect is thought to be due to the metabolic by-product of lactose, lactic acid (rather than lactose itself), as consumption of sour milk also improves calcium absorption. The mechanism may involve a decrease in pH in the intestinal tract as a result of fermentation resulting in increased solubility of calcium increasing transport. Part of the effect may be due to the formation of soluble complexes between calcium and lactose (Renner, 1983). Other work has not supported these suggestions however. Experiments with rats showed that the effect was not due to a lowering of pH by fermentation or to stimulation of intestinal metabolism by lactose (Wasserman and Lengemann, 1960). Further, the suggestion that lactose forms a complex with calcium increasing absorption (Charley and Saltman, 1963) is not supported by the lack of the necessary detailed structure in lactose (Angyal, 1974). It is does remain clear however that milk is the most concentrated and available form of dietary calcium.

Intestinal flora

During digestion, lactose is virtually unhydrolysed in the stomach and little is absorbed in the upper section of the large intestine. However, in the next portion of the intestine it is cleaved by the enzyme lactase and the resulting mono-saccharides provide a useful substrate for the body's flora. The lactic acid so produced results in development of acid conditions believed to be desirable to inhibit the growth of many putrefying bacteria, allowing their replacement with acidophilic flora.

Conclusions

Increasing markets for the utilisation of lactose as such will remain difficult. Its applications are limited by its low sweetness and low solubility and, as such, lactose has little

Table 3

Some options for lactose utilisation

Product	Applications
Acetic acid	Foods
Acetone	Various
Alcohol	Foods, energy
Amino acids	Various
Antibiotics	Medical
Butanol	Various
Citric acid	Foods
Food oils	Animal feeds
Fuel gas	Energy
Galactaric acid	Various
Galatonic acid	Various
Gibberellic acid	Plant hormones
Glucaric acid	Various
Gluconic acid	Various
Hydrolysed lactose	Sweetener, lactose malabsorbers
Itaconic acid	Various
Lactase	Enzyme applications
Lactic acid	Foods
Lactic polymers	Biodegradable plastics, prosthetics
Lactitol	Non-nutritional sweetener
Lactobionic acid	Chelating
Lactose crystals	Food, tablet binder
Lactose foams	Insulation
Lactose polymers	Surfactants
Lactosyl urea	Ruminant feeding
Lactulose	Infant nutrition
Malic acid	Various
Oligosaccharides	Medical
Polysaccharides	Food gums
Single cell protein	Various
Vitamins	Food fortification

in the way of specific advantages to offer to the food manufacturer.

Increased utilisation of lactose is more likely to come about through a development of further applications in the fields of infant foods, confectionery and meats. Other applications are unlikely to be of major significance on a world scale. However, it is more likely that increased utilisation of lactose will be through its application as a raw material for further processing, such as the feedstock for a range of chemical products.

There is extensive literature on the manufacture and utilisation of lactose derivatives. Reviews of particular value include those of Thelwall (1985), Andrews (1986) and Pritzwald-Stegmann (1986). Many of the options available to the lactose processor for conversion of lactose are shown in Table 3. Whilst virtually all of these options are technically feasible, it is probable that many would be uneconomic in practice (Hobman, 1984).

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Uses for Lactose-Hydrolysed Dairy Products

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Introduction

Of the solids in cows' milk, lactose, comprising approximately 39%, is the most abundant. Dairy by-products such as wheys and permeates contain even greater proportions of lactose. To enhance the sale of dairy products the lactose can be converted into its constituent monosaccharides, glucose and galactose (Figure 1). This is particularly true of wheys and permeates which often have limited markets. After lactose hyhydrolysis (LH) wheys and permeates are able to be used as food ingredients due to the properties of the monosaccharides. In the food industry lactose is hydrolysed using the enzyme beta-galactosidase or lactase. Typically, lactase-catalysed lactose hydrolysis shows a nonlinear relationship for lactose conversion versus time, characteristically a rectangular hyperbola. Often a greatly diminishing rate of hydrolysis occurs after 70% conversion is achieved. This translates to greatly increased costs in achieving levels of hydrolysis greater than this level. The kinetics of the enzyme-catalysed lactose hydrolysis reaction will usually depend on the type of feed and the source of the enzyme together with temperature and pH conditions.

Advantages of Lactose Hydrolysis

The advantages of LH products over the non-hydrolysed product can be categorised as functional and nutritional. LH products exhibit improved functional properties due to the increased sweetness and solubility of the monosaccharides, glucose and galactose (Table 1). Many people maldigest lactose due to lactase deficiency. Therefore, after a meal containing lactose they can experience discomfort and pain and the potential nutritional advantages of LH products are a function of the decreased lactose content and an associated decrease in lactose digestive problems.

Costs

This article aims to show a wide range of market opportunities from the many uses for LH products. The price set by the LH product manufacturers will heavily affect market demand. To assist manufacturers in establishing product prices it is useful to know that the likely hydrolysis costs in Australian currency for milk and whey are 1-20c/L for an unconcentrated product (Zadow 1986; Mitchell, Muller and Weinert, unpublished report).

Processing & Storage of LH Products

One of the more economical methods used to manufacture LH products is based on the use of immobilised lactase. CSIRO has assisted in the development of such a process — which is also capable of hydrolysing a wide range of dairy products, including milks, wheys and permeates.

LH milks can be spray dried in conventional dairy driers. However, the greater concentration of monosaccharides in the solids of LH wheys and permeates makes this difficult. For prolonged storage of hydrolysed wheys and permeates, concentration to a syrup of around 70% total solids is more suitable. Hydrol-

ysis of such syrups to 85% conversion would maximise the saccharide solubilities (Bourne *et al.*, 1983).

Uses for Hydrolysed Products

LH products have been manufactured in Australia and uses of these products have included a reduced lactose milk and as a combined humectant and sweetener used by the pet food industry. More detailed uses are now described:

Hydrolysed milks

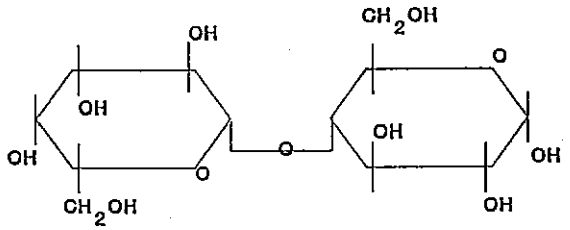
Hydrolysed milks can alleviate the discomfort associated with lactose maldigestion in the lactase deficient person. Hydrolysis levels of 60-70% are necessary for milk to be well tolerated by such people (Hourigan, 1984). An example of a situation where a LH milk would be beneficial is in food aid programs where many of the recipients have a reduced ability to digest lactose and could be subject to deterioration in health if fed normal milk.

Milk can be frozen to increase the shelf life. On thawing, a coagulum can form, giving the milk an unpalatable appearance. Hydrolysed milks show more stable freeze-thaw characteristics which may offer some marketing advantage (Tumerman *et al.*, 1954; Woychik and Holsinger, 1977; Free and Hayes, unpublished data).

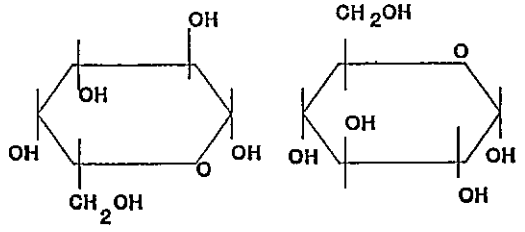
Milk is often flavoured and sweetened to increase its appeal. Hydrolysed milks require less added sweetener than normal milks and this can also be used as a marketing advantage.

Figure 1.

Structural formulae of lactose, glucose & galactose.



α Lactose
Molecular Weight = 342



β D -Galactose
Molecular Weight = 180

α D - Glucose
Molecular Weight = 180

Table 1

A comparison of sweetness and solubility measurements of different sugars.

	Sweetness[a] (comparative)	Solubility[b] (g/100g solution at 30°C)
Sucrose	100	69
D-Fructose	173	82
D-Glucose	74	54
D-Galactose	32	36
Lactose	16	20

[a] Pazur (1970)
[b] Shah and Nickerson (1978)

Note the low sweetness and solubility of lactose compared to glucose and galactose.

Hydrolysed wheys and permeates

LH wheys and permeates can be used as sweeteners. However, the minerals contained in wheys and permeates tend to impart a salty flavour which becomes particularly unpleasant after concentration. Demineralisation is therefore an important adjunct to hydrolysis of wheys and permeates. Concentrated wheys which have been demineralised by 50% have been reported to be without noticeable salty flavours (Salmon, 1981). The use of hydrolysed wheys as fermentation feedstock may also benefit from demineralisation.

Food companies often require a continuous supply of product. Production of hydrolysed whey and whey permeates in Australia would be variable, following the seasonal production of cheese. Storage to even out supply may however be economically unviable.

Ice-cream

When lactose hydrolysis technology is used in ice-cream manufacture the increased sweetness and solubility of glucose and galactose and the reduction in lactose may reduce the body defect referred to as 'sandiness' as well as reducing the amount of added sweetener. The resultant ice-cream is softer which should also appeal to consumers.

It appears possible to manufacture an acceptable ice-cream using LH whey to replace up to 50% of the non-fat milk solids and sucrose. Typically the level of hydrolysis should be 70%. Table 2 is a summary of the effects of lactose hydrolysis on ice-cream

Table 2

Summary of the effects of lactose hydrolysis on ice-cream manufacture

Replacements	Additons	Flavour	Body/ texture	Reference
	Hyd syrup	+ +	+ +	Huse *et al.*
MSNF	WPC	-	+	(1984)
	Hyd-whey	0	+	Patel & Mathur (1982)
MSNF	Hyd/dem. whey	0		Trzecieski (1982)
	lactase	0	0	Miller (1977)
	Hyd-whey	+	+	Bray (1987)
Sucrose			+	Newshawy *et al.* (1988)
Sucrose		+	+	Coton (1979)
	Hyd-whey	+/-	0	Guy (1980)
	Hyd-whey and dem.	0		Martinez and Speckman (1988)
	Hyd-whey	+	+	Gregory (1982)
MSNF/ fat	Hyd-demin. whey			Reissmann (1982)
MSNF	Hyd-whey	0	0	Loewenstein *et al.* (1975)
MSNF	Hyd-whey	0	0	Bhursi *et al.* (1976)
	Hyd-whey		+	Guy *et al.* (1974)

Legend:

Hyd	=	Hydrolysed
MSNF	=	Milk Solids-Not-Fat
WPC	=	Whey Protein Concentrate (The following comments refer to a comparison with the normal product):
0	=	No significant differences reported
+ (+)	=	Hydrolysed product (much) preferred
-	=	Product less preferred
+/-	=	Variable results

manufacture (adapted from Mitchell, 1990).

Yoghurt

The benefits of lactose hydrolysis of the base to be used in yoghurt manufacture are:

- Less sour flavour
- Reduced level of added sweetener required for flavoured yoghurts
- Increased rate of acid production, and
- Wider choice of starters.

The optimum level of hydrolysis is approximately 70%, as at this level the acid production and costs of hydrolysis are optimised. Table 3 is a summary of the effects of lactose hydrolysis in yoghurt manufacture (adapted from Mitchell, 1990).

Table 3.

Summary of the effects of lactose hydrolysis in yoghurt manufacture

Replacements	Additions	Flavour	Body/ texture	Reference
Sucrose	Hyd	+	0	Whalen *et al.* (1988)
	Asp./ Hyd	0	0	Botha *et al.* (1987)
	Hyd	0	0	Kreuder (1987)
	Hyd	+		Hilgendorf (1981)
	Hyd	0	0	Engel (1973)
	Lactase	+	+	Dariana *et al.* (1982)
	Hyd	+		Antila *et al.* (1978)

Legend:

Hyd = Hydrolysed (The following comments refer to a comparison with the normal product):
0 = No significant differences reported
\+ = Hydrolysed product better
Asp. = Aspartame

Other uses

Table 4 summarises some of the other uses for LH products.

Markets

Many dairy companies have the opportunity to utilise LH products 'in-house'. The LH product could be used to replace bought-in sweetener or increase the market appeal of existing products. 'In-house' uses such as replacement of bought-in ingredients would be most economical.

However, it may not be possible to utilise all LH products 'in-house'. Many dairy products are sold as ingredients to general food manufacturers. The marketing of such products may be facilitated by the increased sweetness and reduction in the likelihood of sugar crystallisation conferred by lactose hydrolysis.

Table 4

Examples of uses for hydrolysed wheys and permeates

Use/Product	References
Humectants	
Beverages	Anon, 1982
Breads, cakes and biscuits confectioneries, sweeteners	Bouvy 1975; Holsinger 1976; Gueriviere 1978; Guy and Edmondson1978;Holsinger1978; Moore 1978; Mann 1982; Coton 1980.
Fermentation feedstock, beer production and animal feeds	Brule 1981; Heyneman and Hourigan 1981; Rydar 1988; Coton 1980
Cheese	(Thompson and Brower 1976; Thakar *et al.* 1987; Gyuricsek and Thompson 1976; Anon 1977)

Market advantage may also be gained if the LH product is part of a blended product (Morris, 1985).

Other opportunities may include reduction in taxes or tariffs paid on ingredients. There have been cases where it has been advantageous to replace sucrose in flavoured milks with a dairy-based sweetener. Such opportunities need to be carefully investigated together with the regulatory restrictions that might apply to the use of LH products.

Conclusion

Of the many possible uses for LH products most relate to the increased sweetness. In America and the United Kingdom corn starch syrups are commonly used as sweeteners, but in Australia LH products would be competing with sucrose from cane sugar. The likelihood of successful competition depends on many factors, of which price has major importance. However if LH products confer cost as well as functional and nutritional advantages then profitable returns for LH manufacturers appear possible.

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New Cheese Products As Food Ingredients

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Introduction

Cheese may almost be described as the boom product of the dairy scene, enjoying great popularity. It has an excellent image, being perceived as healthy, natural and nutritious.

Increasingly cheese is being appreciated by consumers for the great interest and variety it adds to the eating experience. Textures range from smooth and creamy to hard and crumbly; flavours from subtle to robust and tastes from mild to piquant.

Cheese consumption is still rising in Australia after two decades of steady growth. In the last year, domestic sales of both Australian and imported cheese varieties rose by 6%, the increase coming principally in the non-cheddar and low fat categories (Australian Dairy Corporation, 1989).

How is cheese being consumed?

Of the 126,600 tonnes of cheese sold in 1989 on the domestic market, 88,200 tonnes went to the retail sector, mostly in portion packs for table use or for food preparation in the home. Approximately 30% of this amount was processed cheese, mainly in the form of individually wrapped or stacked slices. The remaining 38,400 tonnes went to the industry and food service sectors which are growing in importance as outlets for cheese, reflecting greater consumption of pre-prepared meals and convenience foods, and a trend towards more meals being eaten away from home (Australian Dairy Corporation, 1990).

Cheese is thus an important dairy ingredient which has the potential to add sales appeal to many food categories. These include:

- Processed cheeses
- Cheese dips and spreads
- Bakery goods
- Snack foods
- Canned foods

What does cheese offer the industrial user?

Firstly, cheese may be used simply as a source of dairy fat and protein. However, good quality cheese is a fairly expensive way to buy fat and protein. In past years there have, at times, been significant quantities of downgraded cheese, but the amount of low-priced cheese available to reprocessors and other industrial users is presently quite limited, and it will probably become very small in future as modern methods of total quality management take effect.

Secondly, cheese may be the ingredient of choice in order to provide the structural matrix of the prepared food. This is an important function which is brought to all the processed cheese products, as well as to dips, spreads, cheesecakes and other foods containing cheese. For some of these products it may be desirable for the cheese protein to be substantially intact, whereas in others, a significant degree of proteolysis may be required. Some product formulations dictate that the fat and protein of the cheese are present in proportions quite different from those normally found in cows' milk. Satisfying these special requirements can add significantly to the cost of cheese as an ingredient.

Thirdly, cheese offers the food processor a source of flav-

our and taste sensations which can withstand the rigours of processing treatments and give much consumer appeal to the finished product.

Cheese therefore is a convenient and readily marketed food ingredient. However, cheese is an expensive ingredient; it is not shelf-stable; and it may be a somewhat variable ingredient.

Therefore I wish to discuss two relatively new 'cheese' products which may be used in the food processing sector and the cheese processing industry to provide the desirable attributes of cheese with fewer of the drawbacks.

Enzyme Modified Cheese (EMC)

One of the factors which adds to the cost of cheese as an ingredient is the time required for the cheese to develop typical flavour. For some varieties this may be greater than one year. Cheese maturation also carries an element of risk that undesirable flavours may develop. Furthermore, for some cheese types, a large quantity of cheese is needed to impart sufficient of a cheese note to the flavour of the finished food product. The use of enzyme treatment technology to produce controlled, intense cheese flavour concentrates is a comparatively modern innovation which overcomes some of the problems of cheese as a food ingredient.

The impetus for the development may have come partly from the pioneering work of Kristoffersen, Mikolajcik and Gould (1967). They suggested that cheese-curd slurries, incubated under conditions which favoured rapid proteolysis and lipolysis, may provide the flavour component for processed cheese manufacture in a cheaper and more reliable way than afforded by the use of matured natural cheese. Sutherland (1975) extended the work to produce a range of rapidly ripened slurries and demonstrated the potential for positive control over the course of flavour production. These slurries were made from unpressed salted cheddar cheese curd which was macerated with added water and salt to give a finely ground slurry with 40% total solids and 3.2% salt. The slurries were incubated at 25°C as prepared or after addition of rennet, glutathione, a lipolytic enzyme or provision of additional headspace oxygen. Flavour development proceeded differently in each of the slurry preparations, yielding rather intense flavours, some of which were like blue cheese, Italian cheese or unbalanced cheddar. The ripened slurries were used for manufacture of processed cheddar cheese and were found to give most acceptable products when used in combinations of three types at a total addition rate of 10-20% of the processed cheese blend.

Later work by Jameson and Shanley (unpublished) showed that this slurry technique was not sufficiently reliable to be applied directly in industrial practice. However, this basic idea has been taken up by commercial suppliers of enzymes to the dairy industry who have developed proprietary processes for rapid, controlled development of highly flavoured slurries through controlled enzyme curing.

Developments in EMC technology have recently been reviewed by Moskowitz and Noelck (1987) and a considerable amount of utilisation information is available from the present suppliers of enzyme preparations to the dairy/food industry.

EMCs are available with flavours claimed to provide the essential notes of Cheddar (mild to mature), romano, provolone, parmesan, Swiss, gouda/edam, blue cheese and others. The EMCs may be supplied in a cheese-like form or as heavy pastes which are stable under refrigeration for at least six months. Some EMCs are available in powder form which makes them well suited to the bakery and snack food industry. EMCs are more intensely flavoured than the cheese which they replace and so the level of incorporation is correspondingly lower. For example, liquid types of Dariteen cheddar cheese flavours (Miles Laboratories Inc., Elkhart, In, USA) are claimed to have from five times to twenty-five times the cheese flavour of quality cheddar cheese and spray-dried types are claimed to have an eight-fold concentration.

A wide range of cheese-like flavours for food formulation are available from dairy supply companies and food flavour suppliers, some of which are synthetic mixtures but some are 'natural' products, being the result of enzyme treatment of natural substrates such as lipids (of animal or vegetable origin), protein-lipid or protein-lipid-carbohydrate mixtures. These products are considered outside the scope of this review but readers are referred to the review of Kilara (1985).

Over the last ten years or so there has been much research carried out on the use of enzymes to reduce the ripening time of natural cheeses. This work does not seem to have led to any 'new' cheese products at this stage, being more concerned with maintaining trueness-to-type of the cheese variety under study. For reviews of this field see Law (1978) and the reports of the International Dairy Federation Expert Group (IDF, 1983, 1987, 1990).

Utilisation of EMCs

Commercial enzyme modified cheese have a flavour profile which may be quite different from a table cheese and yet, on dilution with a suitable bland or nearly bland base, do provide the cheesey note which is desired in the end product.

The principal usage of EMC is understood to be in the processed cheese industry as a substitute for some or all of the expensive matured cheese component of the blends. As early as 1974 in the USA, EMC became a legally approved optional ingredient for manufacture of processed cheese (40% moisture max., 50% FDM [fat in dry matter] min.), processed cheese food (45% moisture, 45% FDM) and processed cheese spreads. EMC is also used as the flavour source in manufacture of imitation cheese products, a product range with a small but significant niche in the US market.

Other typical applications of EMCs include cheese sauces, spaghetti sauces, soups and dips which require a stronger cheese flavour. As a flavour booster, the inclusion of 1-5% of EMC can increase the total cheese flavour of a formulated food without adding greatly to the cost. A typical recipe for cheese sauce using EMC as 50% replacer for cheddar cheese is shown in Table 1.

Cheesebase

Cheesebase is the generic name for a comparatively new range of cheese products developed specifically as food ingredients and coming from the research activities of the CSIRO Dairy Research Laboratory. The early phase of the research was conducted in collaboration with Professor Tony Ernstrom of Utah State University (Ernstrom, Sutherland and Jameson, 1980) and further development to pilot and commercial scale took place in collaboration with Schreiber Foods Inc. (SFI) of the USA. The process is protected by patents in all major cheese processing countries.

The cheesebase process has been in operation on a large commercial scale (22,000 tonnes per year) at Tempe, Arizona for just over five years and a substantial body of experience now exists with respect to both manufacture and utilisation. The process is now available for licensing to local manufacturers.

While the EMC was developed as a low-cost replacer for the mature cheese component of processed cheese foods, the cheesebase range was developed as a replacer for the mild or young cheese component. The young cheese in

Table 1.

Cheddar Cheese Sauce - Formulations with and without EMC as an Ingredient[a]

Ingredients	Control %	Plus EMC %
Milk	52.30	60.30
Mild Cheddar Cheese	28.00	14.20
Water	8.90	9.90
Margarine	7.20	7.20
Flour	3.00	5.00
EMC[b]	–	2.80
Salt	0.50	0.50
Mustard	0.05	0.05
Cayenne Pepper	0.05	0.05
	100.00%	100.00%

[a] Derived from Miles Technical Bulletin L-406-4

[b] Miles Daniteen NCF 130 - 50% of the mild Cheddar has been replaced by EMC on a ratio of one part EMC to five parts cheese.

processed cheese blends is needed to provide the structural matrix and much of the nutritional value of the finished products.

Manufacture of Cheesebase

Cheesebase products are manufactured using a combination of membrane filtration, fermentation and high-viscosity evaporation. A typical flow sheet for a cheddar cheese replacer is shown in Figure 1.

The raw material for cheesebase is standardised milk, with the fat/protein ratio adjusted to give any desired FDM content in the finished product. The milk is pasteurised on the way to a continuous ultrafiltration plant where it is concentrated from 4.5- to 6-fold (total solids in the range 30-45%). As the concentration proceeds, the lactose/protein ratio of the concentrate is continuously regulated by controlled addition of water to selected stages of the ultrafiltration plant. In this way the pH of the concentrate after fermentation of the lactose can be accurately controlled.

Starter cultures are added to the milk concentrate (retentate) and fermentation proceeds to complete utilisation of the lactose in 12-16 hours. Normally such retentates would undergo an acid coagulation at pH values below about 5.3 but this is prevented by adjustment of the ionic strength, preferably using common salt.

The moisture content of the fermented retentate is then reduced to any desired level (but commonly in the range 35-40%) in a specially engineered swept-surface vacuum evapor-

Figure 1.

Cheesebase Manufacturing Process

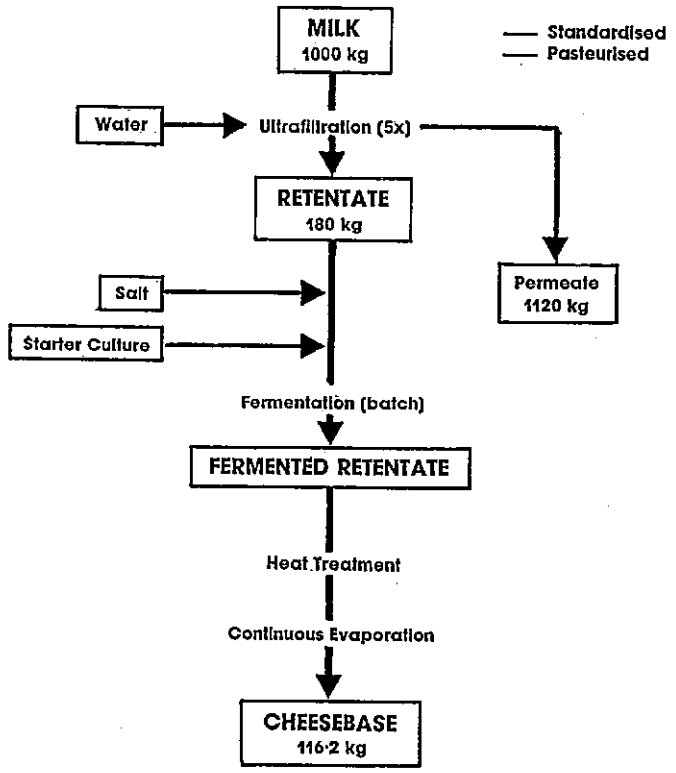

Table 2.

Comparative Retention of Milk Solids - Cheddar Cheese and Cheesebase

Component of Milk	% Retention	
	Cheddar Cheese	Cheesebase
Fat	89	100
Protein	77	98-99
Total Solids	51	60

ator. The high viscosity product is pumped from the evaporator to a packing station where it may be formed into blocks or filled into drums for long-term storage. Alternatively, the cheesebase may be pumped directly to a processed cheese manufacture line for immediate use. On cooling, the cheesebase becomes practically solid and can be stored and handled in the same manner as conventional cheese.

A feature of the process is the ability to vary the functional properties of the cheesebase products by a controlled heat treatment following fermentation and before evaporation. For example, it is possible to produce cheesebases which will yield processed cheese with high or low re-melting properties, a significant factor in acceptability of cheese supplied to major fast-food outlets.

The cheesebase process is one of the highest yielding cheesemaking methods in terms of fat and protein recovery (Table 2). Lactose is the only major milk component which is lost during the process, and the yield advantage over conventional cheddar manufacture is in the range 16-18%.

Composition of cheesebase

By varying the fat/protein ratio of the milk and the production parameters it is theoretically possible to manufacture cheesebase with the composition of practically any known, or imaginable, cheese type. Experience has been gained at commercial scale with a modest range of compositions, e.g. total solids from 32% to 45% and FDM from 45% to 58%. At pilot scale, considerable work has been done to expand the proven range of compositions with FDM levels as low as 5%, total solids in the range 27% to 55% and pH values in the range 4.4 to 5.4. Reduced mineral content cheesebase has also been produced by acidification of the milk prior to ultrafiltration. US research (Anis and Enrstrom, 1984) suggests that the reduction of calcium content may yield a cheesebase with improved functionality for the production of processed cheese with a high re-melt capacity.

Cheesebase variants

Cheesebase may be produced with an increased content of undenatured whey proteins by incorporation of a liquid whey-protein concentrate. This yields a cheese with the capacity to undergo heat gelation.

Cheesebase, in standard form, is a storage stable product since the enzymes normally responsible for cheese maturation are inactivated by the heat treatment which follows fermentation. However by reducing the severity of heating during evaporation, or by re-inoculation after evaporation, it is possible to have a cheesebase variant with potential for protein and lipid breakdown and associated flavour formation.

Properties of cheesebase

Cheesebase, in its standard form, lacks the body and texture of conventional cheese. Although it appears solid at temperatures below 1 5°C it is actually a very high viscosity paste which can be readily redispersed in water to a consistency similar to milk. It has a mild lactic flavour and a pleasant smooth creamy mouthfeel.

Cheesebase is a stable form of young cheese solids with the same functional properties in cheese processing as young cheese. Stability in storage of high pre-heat cheesebase has been demonstrated, with the product still acting as young cheese after more than 12 months storage at refrigerator temperatures. This attribute may prove most useful as a means of overcoming the problem of lack of young cheese during the Australian seasonal periods of little or no cheese production.

With its low flavour, lack of a yield point under compression and its tendency to 'dissolve' in the mouth, cheesebase is unlikely to be a consumer product in its own right. Nevertheless, because of the relative simplicity of the process, the excellent compositional control and the favourable economics offered by cheesebase manufacture, there is a considerable incentive to work towards a new family of dairy-based cheese products by such technology. Since the casein in cheesebase is still intact it should be possible to induce structure formation by mechanisms known to generate a protein matrix in other products, e.g. by the rennet reaction. Preliminary research is underway in this area.

Conclusion

In an address to a meeting at the Australian Society of Dairy Technology as long ago as 1976 (Sutherland, 1976), it was proposed that processed cheese products of the future might be made by a combination of a

high-yield base material and cheese flavour concentrates. The technology to manufacture these new ingredients is now available for the enterprising food processor to use in creating profitable new foods.

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Fermented Dairy Products as Food Ingredients

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Introduction

The scope of this topic is too extensive to enable an in-depth review of the total subject. I propose to focus on the market and application aspects of the topic. In particular, this paper will attempt to use the historical context to project a scenario for future development of cultured milk products as food ingredients.

It is proposed that there have been four stages to the adoption of fermented milk products as ingredients in food production. These are presented in Table 1. The four phases represent an evolution of technology reacting to market needs. Each will be dealt with in turn.

Traditional Fermented Dairy Products in Foods

Fermentation of milk to produce different foods, pre-dates history. Traditional fermented dairy products, such as yoghurt, cheese, sour cream and innumerable local variants, were the product of harnessing the coincidental fermentation that occurred on storing milk. With time and experience, the art was mastered and progressively became science, though old hand cheese makers may like to dispute the level of science.

These traditional fermented dairy foods were naturally used as ingredients in home cooking in regions where they were endemic. As food manufacture moved to cottage industry, and ultimately full industrial status, the use of traditional fermented milk products in food processing was a natural consequence of their domestic use.

Today a wide range of food products taken home from the supermarket feature traditional fermented dairy foods in their ingredients lists. Some examples of these are given in Table 2.

The role of these ingredients in the formulation relates principally to flavour and texture, although secondary functionalities (e.g. microbial control) are occasionally important. Nevertheless such uses of fermented dairy products are mere extensions of the domestic use of these ingredients.

Form-Modified Fermented Daily Ingredients

The dairy industry, responding to needs of the broader food processing industry, has developed more convenient forms of traditional fermented milk products, enabling wider use of these as ingredients. Foremost among these are spray-dried powders. Products like cheese powders, yoghurt powder and sour cream powder have entered the ingredient trade as a consequence. A point recognised by the industry, but frequently not by intending users of these ingredients, is that they do not re-hydrate with any of the physical or textural properties typical of their feedstock. Their practical contribution is primarily flavour.

The introduction of these ingredients had two consequences for food manufacturers. Firstly, they have simplified the manufacturing process for some food products based on traditional fermented dairy ingredients. This is a consequence of replacing unstable, biologically active ingredients with dry powders, stable for many months. This has obvi-

Table 1.

Historical phases in fermented dairy products as food ingredients

PHASE	DESCRIPTION	TYPIFIED BY
	TRADITIONAL FERMENTED DAIRY PRODUCTS	USE OF TRADITIONAL FERMENTED DAIRY FOODS (EG CHEESE, YOGHURT) IN FOOD MANUFACTURE.
2	FORM-MODIFIED FERMENTED DAIRY INGREDIENTS	TRADITIONAL FERMENTED DAIRY INGREDIENTS IN MORE STABLE/CONVENIENT FORM (EG SPRAY DRIED.
3	FLAVOUR-MODIFIED FERMENTED DAIRY INGREDIENTS	FLAVOUR INCREASED TO ENABLE LOWER USE RATE, USUALLY THROUGH BIOTECHNOLOGY (EG ENZYME MODIFIED CHEESE).
4	FUNCTIONALLY ENGINEERED FERMENTED INGREDIENTS	TOTALLY NEW PERFORMANCE ATTRIBUTES THROUGH FERMENTING DAIRY SUBSTRATE WITH NON-TRADITIONAL ORGANISMS.

ous benefits in stock management, storage costs and production planning. Less obvious are the gains from using standardised, readily controlled raw materials.

Significant as these gains are, they are over-shadowed by the second consequence of the development of powdered, fermented dairy ingredients. This is the development of totally new consumer products which could not exist without the dried form of the fermented milk products. Examples are cheese-flavoured extruded snacks, powdered sour cream dip mix and yoghurt-coated confectionery.

Table 2.

Traditional fermented milk products as ingredients in processed foods.

INGREDIENTS	FOODS USED IN
HARD CHEESES	PIZZAS, CHEESE SAUCES, BREAD TOPPING, SAUSAGES, PASTA DISHES, MICROWAVE MEALS.
SOFT CHEESES	CHEESECAKES, FLANS, CHILLED DESSERTS.
YOGHURT	SALAD DRESSINGS, FROZEN YOGHURT, ETHNIC FOODS (ESPECIALLY INDIAN), CHILLED DESSERTS.
SOUR CREAM	DIPS, BAKERY PRODUCTS, CHILLED DESSERTS.

The manufacture of dried, fermented dairy products is amply detailed in the literature (Societe Laitier, 1969: Avleson *et al.*, 1979: Noznick *et al.*, 1974.) and little purpose would be achieved in outlining these here. It is notable however that manufacturers are increasingly taking account of the functional demands of such ingredients in specific food systems and optimising these in ingredients tailored to the final application. This approach is enabled by the greater understanding of how manufacturing conditions impact on functional properties of the resulting powder and accelerated by customers who appreciate the value of reliable performance within their process. As a consequence, today's reputable suppliers are likely to offer a range of (say) cheese powders formulated to tight performance specifications rather than using the food ingredient market as the means to dispose of fermented dairy products that failed to meet standards required for direct sale.

Table 3 provides an example of how desirable properties for yoghurt powder differ between two major applications and indeed cannot be optimised for both applications in one product. The fact that one system has a continuous fat phase in which particles are suspended and the other is primarily an aqueous product, determines the essential performance needs.

Flavour Modified Fermented Dairy Ingredients

Recognising that the critical determinant in using a fermented dairy ingredient is its flavour contribution led to the development of flavour-modified dairy ingredients. The primary application of this is enzyme modified cheese (EMC) manufacture. By exposing the cheese to carefully selected enzymes under well controlled conditions, the flavour contribution can be increased dramatically. Claims as high as 50 times the flavour of cheese have been made, but levels between 5 times and 25 times are more reasonable (Moskowitz *et al.*, 1987).

The manufacture of enzyme modified cheese is achieved by enzyme addition at almost any point in the cheese manufacturing process. The resultant product may have a texture similar to that of the cheese it is derived from, or if extensive hydrolysis is encouraged, it may be in paste form. Selection of the extent of flavour development is determined by balancing the contrary aspects of flavour strength (and type) against the loss of texture. The flavour profiles developed in enzyme modified

Table 3.

Desirable attributes for yoghurt powders in two applications.

APPLICATION	IMPORTANT ATTRIBUTE	UNIMPORTANT ATTRIBUTE
CONFECTIONERY COATINGS	LOW LIPASE ACTIVITY EVEN PARTICLE SIZE FLAVOUR SMALL PARTICLE SIZE	SOLUBILITY DISPERSIBILITY VIABLE CULTURE
SOFT SERVE	SOLUBILITY VIABLE CULTURE DISPERSIBILITY FLAVOUR	LIPASE ACTIVITY

cheese are not totally representative of the flavour complexity of traditional cheese but show heightened flavour notes of some aspects of the cheese flavour. For this reason they are generally used as extenders or enhancers for natural or powdered cheese in processed food products such as sauces or snack sprinkles.

The primary benefit of EMC products is economy. The process used allows the production of a product with typically ten times the flavour of the equivalent natural cheese, but in considerably less time than it takes to produce a fully matured cheese. Thus the production economics favour EMC, yielding substantial savings to the users where the application enables its use. Typical usage rates of EMC are in the range of 0.1% to 2.0% of finished food.

Similar flavour effects are to be had by enzyme treating butter fat. Whilst not strictly a fermented dairy product (unless of course lactic butter is the substrate!) enzyme modified milkfat is so closely allied to enzyme modified cheese in its biotechnology and marketing that it ought to be dealt with at the same time.

In both cases the intent is to mimic the biochemistry of flavour development that occurs more slowly in a microbial fermentation and to drive the reaction beyond where it would normally stop. In so doing greater concentrations of the flavour compounds are produced.

By exposing butteroil emulsions to lipase from microbial, fungal or animal sources increased 'buttery' or 'creamy' notes are observed. The flavour concentrate made in this way is heat deactivated and used either in the oil form or in a spray dried powder. Commercial products of this type are used in chocolate, sugar confectionery, popcorn, cooking oils and baked goods to give enhanced dairy notes (Dziezak, 1986).

Functionally Engineered Fermented Daily Products

Whey, the by-product of cheese or casein manufacture, has long been used as the substrate for fermentations for producing food and non-food chemicals. Ethanol and lactic acid have been extensively commercialised, but more exotic materials such as carotene (Friend *et al.*, 1979), Vitamin B12 (Crow, 1988) and microbial oil have been suggested. However these technologies do not, of necessity, require dairy substrates. Nor does the dairy content carry through to the finished product due to purification steps designed to isolate the desired chemical in its purest form.

A more creative approach has been patented, yielding ingredients which (at least in the USA) can be declared as 'cultured whey' or 'cultured non-fat milk solids' yet contain functional chemicals as a consequence of a microbial fermentation. Two examples can be taken here, both recently commercially marketed in the USA and elsewhere.

In the first case an anti-mycotic agent, propionate, is produced by fermenting sweet whey to lactic acid and in turn to propionic acid using appropriate bacteria (Ahern *et al.*, 1987). The resultant broth is dried as is (i.e. without extraction or purification of the propionate) allowing the description 'cultured whey'. When used in baked goods at 0.5% to 3.5% of the flour weight to replace milk solids, shelf life is extended by the anti-mycotic effect.

In the second example, whey is fermented with a specified strain of *Xanthomonas campestris* in order to produce a thickening polymer, xanthan (Schwartz *et al.*, 1984). Again, the total product is dried without purification and the resultant powder used as a food ingredient. Functions of texture improvement and creamy mouthfeel are the major claims for the product, which is recommended for cupcakes, puddings, mousses, soups, sauces and gravies (National Starch, 1989).

An allied product based on the same fermentation, but using skimmilk as the substrate is recommended for ice cream where emulsification and stabilisation are the objectives (Stauffer, 1986).

In each of these cases the raison d'etre for the fermented dairy ingredient is pursuit of a 'clean', that is additive-free, label through providing the functional performance of propionate or xanthan while only labelling 'cultured milk solids' or a similarly friendly declaration. Time alone will determine if this approach is seen as serving the consumer interest, but should it continue to be condoned, further functional additives might be expected to be developed by similar technologies.

Prospects for Fermented Dairy Ingredients in Foods

The current mood of the consumer market is favouring the use of fermented dairy products as food ingredients. As these products, and most notably yoghurt, have moved into the main stream of western food habits, and are seen as 'healthy' rather than 'health' food there is a proliferation of new food products which capitalise on this consumer demand for variants based on these healthy ingredients. A recent issue of a new product monitoring service in the United States recorded 19 new product releases in August 1990, which obviously used a fermented dairy food as an ingredient (Friedman, 1990).

Frozen yoghurt has been the success story of 1990 in the United States. While the product sold now bears little relationship to the early, fully cultured versions which had limited success, the proliferation of frozen yoghurt launches in 1990 confirms the mainstream acceptance of cultured milk-based new food concepts.

The market conditions which have lead to the situation can only continue and are summarised in Table 4. It is fair to say that these market forces are consistent through all developed regions of the world in markets as diverse as Japan, Europe and America. This situation will ensure the growth in opportunities for the first three groups of fermented milk ingredients outlined in this paper. Indeed, there will probably be new opportunities for niche ingredients such as acidophilus milk or kefir-based ingredients as the consumer continues to pursue new interests.

What is less clear though, is what direction the fourth group, the functionally engineered fermented dairy products will take in the future. At this point they appear to exploit a regulation loop-hole which could be closed at a stroke of a pen. This will not be determined in any way by the technology, but by political and moral judgement. Should these products' continued existence be supported by the regulators then products of this type will proliferate. In that environment it is likely that fermentation yielding products of every functionality of food interest will appear. Colours, antioxidants and emulsifiers will appear by this route and the current limited range of stabilisers and preservatives will be added to. There are indications from the scientific literature that this is already an active area of research.

Conclusions

In this paper the historical use of fermented dairy products as food ingredients has been reviewed. Use of fermented dairy products in this way is showing increasing momentum and it is expected that this trend will continue. The future can only be bright for food ingredients manufactured by the fermentation of dairy substrates.

Table 4.

Market forces favouring continuing use of fermented milk products as food ingredients.

MARKET FORCE	EXAMPLES
BROADENING INTEREST IN 'HEALTHY FOODS'	BIOLOGICALLY ACTIVE FOODS REDUCED FATS WILL FLAVOUR YOGHURT
INCREASING INTERNATIONALISATION OF FOOD TASTES	ETHNIC FOODS EXOTIC 'NEW' FLAVOURS
CONTINUING INTEREST IN 'CLEAN' INGREDIENT LABELS	MINIMUM NUMBER OF ADDITIVES POSITIVE IMAGE INGREDIENTS FAVOURED

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Hydrolysed Protein Products As Food Ingredients

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The technology of hydrolysis of milk proteins is gaining in importance with the recognition that technological modification to proteins can assist the human digestive process. The reasons why a consumer might prefer a hydrolysed protein are various. One group of potential customers consists of those who are concerned with rapid and efficient nutrition, such as sports minded people, and those who are concerned with healthy foods. A more challenging group of consumers are those whose ability to utilise proteins is in some way compromised. In recent years foods which are 'hypo-allergenic', particularly those targeted for infants, and foods which are designed for recovery of patients after hospitalisation have been developed and are now being commercialised. These product developments coincide with, and are dependent upon, an understanding of the technology and science of enzymology, the commercial availability of adequately pure enzymes and an understanding of the nutritive impact of protein hydrolysates.

The technology of manufacture of hydrolysed milk proteins appears at first sight to be simple. An enzyme is added to a protein suspension, acts for a while, then is inactivated. The idea is simple but the control of the hydrolysis process in order to obtain repeatedly a precisely defined product can require very sophisticated scientific support. The issues that must be resolved in designing a process include the following:

a) The selection of a raw material

Firstly, the amino acid profile of the final product may be important in a dietary food ingredient. If so, milk proteins are commonly very satisfactory when compared with vegetable proteins.

However, this comparative advantage may not be significant in practice because a manufacturer of hydrolysed protein can add selected amino acids to the 'soup' of peptides which, in its final form, can no longer be distinguished as having the properties of any particular native protein.

Secondly, and perhaps more importantly, the original protein will create characteristic flavours after hydrolysis. Some proteins give rise to flavours described as 'yeasty', 'brothy', 'astringent', and, very significantly for milk proteins, 'bitter'. Casein creates a specially difficult flavour profile because the end peptide of beta-casein, which is quickly released, is intensely bitter. For example, the peptide Arg-Gly-Pro-Pro-Phe-Ile-Val is 20 times more bitter than caffeine. In some foods, bitterness is acceptable, but this is seldom true in foods where hydrolysates are used as ingredients. Technological means to reduce bitterness are available, but are of limited utility (Roy, 1990). Whey proteins tend to be the dairy raw material of choice as a consequence.

b) The Nature Of The Final Product

Those products that will be used for general nutritive purposes can be designed to have a broad range of peptides with a variety of molecular weights. They are comparatively easy to manufacture.

Other products that are designed for convalescent patients usually contain a high proportion of di-peptides and tri-peptides. This requires a thorough hydrolysis which may require a high level of enzyme addition and a long period of reaction. Both of those factors will push up the cost.

Perhaps the most challenging end use is the preparation of a product which will avoid allergic response. This is particularly important in foods designed for infants.

Allergic response is triggered in a number of ways. The mechanism of protein allergy is a response to protein fragments, known as epitopes, which are recognised as 'foreign', so that the immunological system of the body mounts a defence against them. Enzyme hydrolysis which will break up those epitopes will avoid the process of recognition. An extensively hydrolysed protein, with fragments less than six amino acids in length, will likely be safe. Longer peptides may, or may not, cause an allergic response, depending on the sensitivity of the individual. In either situation, hydrolysates need to be checked for clinical response and cannot simply be assumed to be non-allergenic.

At a truly critical level, a response from the intestine in which Immunoglobulin E (IgE) is involved may result in the bodily release of histamines and other reactive compounds initiating shock, which can be life threatening. Fortunately that response is rare, but the manufacturer of products that are labelled 'hypo-allergenic' must ensure that those products will not trigger the IgE response. Very carefully hydrolysed proteins have been defined for this market sector (Knights, 1985). Nutramigen and Pregestimil in the USA and Morinaga's MA1 in Japan are designed to meet these threats to health.

At a less critical level, the body may respond in a generalised way with symptoms developing slowly. It is more likely that the response of the body is Immunoglobulin G (IgG) mediated. These allergies are much more difficult to diagnose (Institute of Food Technology, 1985; Butkus and Mahan, 1986). Consequently, the estimates of incidence of allergy vary widely from 0.3% to 20% of adults. Less completely hydrolysed proteins may be adequately digestible to avoid, or ameliorate, such responses. Nestle's 'Beba HA' in Europe and Carnation's 'Good Start' in USA, are designed to meet the needs of infants with this level of problem.

Other products for sensitive individuals utilising hydrolysed protein are beginning to reach the market and can be expected to provide variable levels of effectiveness depending on the thoroughness of the hydrolysis and the sensitivity of the individual consumer. An alternative for the consumer is to not use milk protein at all. Soy-based formulae are widely available and do help some infants, but soy protein is more foreign to the human infant than cow's milk protein and allergic response to soy frequently occurs. Breast milk is preferable but it too can (though less frequently) carry allergens.

Not all sensitivities are protein related, so while protein hydrolysis will assist many infants, informed supervision of any dietary experimentation is desirable and the use of a protein hydrolysed infant food is not a sure method of avoiding a reaction.

Enzyme modification has also been used to alter the physical properties of a variety of proteins so that the functionality of those proteins in food or technical uses will be enhanced. (Kilara 1985). Modification of solubility, heat stability, pH stability, emulsifying properties, and foaming has been achieved.

c) Enzyme Selection & Process

A wide variety of enzymes, of varying levels of purity, are available. Some have broad specificity and are useful for initial hydrolysis of the total protein molecule. Others specifically hydrolyse individual bonds in the molecule and are useful for precisely controlling the length of the peptides produced. (Loffler, 1986; MAFF, 1982). Peptidases which hydrolyse only the end groups of peptides are offered by many suppliers. Both amino peptidases and carboxypeptidases are available and are claimed to reduce or to eliminate bitterness.

Details of the preparation of trypsin-hydrolysed whey proteins to produce an infant formula ingredient has been published (Pahud, *et al.*, 1985) and the process patented (Jost, *et al.*, 1988).

d) Measurement

The measurement of extent of hydrolysis of proteins can be readily achieved by chemical procedures, such as non-prot-

ein nitrogen, amino nitrogen and degree of hydrolysis. These measurements provide only a gross measure of the progress of hydrolysis and are more useful to control the process than to characterise the product. For hypo-allergenic applications it is necessary to ensure that no lengthy peptide remains which could precipitate an allergic response. Chemical test methods can not provide that level of assurance. Consequently, HPLC methods of determining the molecular weight profile have been developed. While these are helpful in characterising a hydrolysed protein product, they do not guarantee that an allergic reaction will not occur. Confirmation of the success of a hydrolysis requires either animal tests or clinical tests on humans.

Conclusion

If it is to be successfully used, the apparently simple technology of protein hydrolysis requires an intensive level of scientific support. The process conditions, once they have been selected, must be precisely observed in the manufacturing plant and characterisation of the end product must be precise. As an ingredient, a protein hydrolysate is not easily designed and a satisfactory product requires the closest of co-operation between the supplier and the customer.

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Microbiological Considerations in the Production of Dairy Ingredients

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Introduction

The commercial success of new processes developed for manufacture of food ingredients or to improve the efficiency of manufacture of existing products is dependent upon many factors. One factor that is often underestimated is the problem of proliferation of undesirable microbes in the new process. Each food process provides a unique set of circumstances that determines the type and number of microbes capable of proliferation. Proliferation of pathogens renders the food product unsafe for consumption, while proliferation of other non-pathogenic microbes may adversely affect product quality. Control of unwanted microbes in a new process may require:

- The application of new criteria in selecting raw materials.
- The development of new cleaning and sanitation programs to reduce initial contamination of equipment used in the process and.
- Modification of the process in order to control proliferation of undesirable microbes during manufacture of each batch.

Since the effects of undesirable microbes may not become apparent in a new process until after commercial production has commenced, research and developmert in this area is often carried out under crisis conditions. This paper discusses two examples of the problem of proliferation of undesirable microbes in new dairy food processes. The first is in protein-rich whey powders and the second in a new cheddar cheese making process.

Protein-Rich Powders

In addition to the importance of proteins as structural components in many foods, proteins are also used as food ingredients because of their physico-chemical properties and nutritional value (Kinsella, 1976, 1982; Morr 1984). In the USA, 168,000 tonnes of whey powders are used annually as functional ingredients in foods, making whey proteins the major functional ingredient protein in human foods (Table 1).

The potential market for functional ingredient protein is expected to increase worldwide as the food industry increases the trend to formulation of new foods from basic ingredients. In order to satisfy this demand food processors require protein-rich ingredients with consistent functional properties that act in food systems in a reproducible manner.

Unrefined whey powders are used mostly as inexpensive filler ingredients, for example to increase the level of essential amino acids, whereas refined whey powders enriched in protein are marketed for their specific functional properties such as gelling, foaming and emulsifying activities. However, commercial protein-rich whey powders display a highly variable range of functional properties which has been attributed to differences in composition (Morr, 1979; Marshall, 1982; Melachouris, 1984; and Mathews, 1984), variation in the basic composition of the raw milk as influenced by stage of lactation (Morr, 1982), and the quality

of the raw milk as influenced by mastitis and the growth of *psychrotrophic bacteria* (Schmidt *et al.*, 1984).

Research in our laboratory has found high levels of thermophilic bacteria in some commercial preparations of protein-rich whey powders. The bacteria were shown to be predominantly species of *Bacillus* and *Enterococcus* (Dimopoulos, 1990; Solomon, 1990). The presence of thermophilic bacteria might be expected since the membrane processing to enrich for whey proteins is carried out at temperatures of 50°C or greater. Further research was therefore initiated to determine the significance of contaminating microbes in the variation in functional properties of commercial protein-rich whey powders.

The gel strength and foam stability of ten samples of commercial protein-rich whey powders obtained from one manufacturer, containing 570 to 200,000 cfu of thermophiles per gram, were measured in simple model food systems. A log-log plot of the data showed an inverse straight-line relationship between both functional properties, gel strength and foam stability, and the concentration of thermophiles (Solomon, 1990). The observed relationship between lost functionality and the number of thermophiles suggests that the bacteria were capable of changing the structure of the whey proteins, which caused a degenerative effect on functionality. This conclusion highlights the importance of controlling these bacteria if protein-rich whey powders are to be used successfully by the food industry for their functional properties. Consistent functional properties can only be achieved if the number of thermophilic bacteria are kept at a consistently low level in the protein-rich whey powders.

Table 1.

Sources of protein-rich ingredients used in food manufacturing in USA.

Ingredient Source	Estimated Market[1] (tonnes)
Milk	136,000
Whey	168,000
Egg	6,800
Meat	
Fish	?
Cereals	14,000
Oilseeds	145,000
Yeast	1,400

[1]Adapted from Kinsella and Whitehead, 1989.

The thermophilic bacteria isolated from these protein-rich whey powders were shown to be resistant to mild heat treatments applied to raw milk for cheese making and to cheese whey prior to manufacture of protein-rich whey powders. In addition, the typical plant cleaning (1% caustic at 70°C) and sanitation system (200 ppm hypochlorite solution) used by the dairy industry do not remove or destroy all of these bacteria when in contact with stainless steel surfaces (Solomon, 1990). Introducing the use of an acid wash may be required to avoid build up of thermophilic bacteria in whey processing plants (Dimopoulos and Hull, unpublished).

The same species of thermophilic bacteria isolated from protein-rich whey powders have also been isolated from raw milk and from residues present on cleaned whey processing equipment (Dimopoulos and Hull, unpublished).

This result indicates that the source of thermophilic bacteria in protein-rich whey powders originate from raw milk supplies and/or in-process contamination. Kinsella and Whitehead (1989) have pointed out the need for rapid reliable methods to quantify the various protein components and to assess the level of protein denaturation as these are important in determining functional properties.

The finding that thermophilic bacteria have a degenerative effect on functionality points up the need for rapid reliable methods to monitor these organisms in the raw milk supply and in the manufacturing process.

New Cheesemaking Processes

The introduction of new cheese making technologies has led to the continuous operation of cheese/milk pasteurisers and ultrafiltration (UF) plants for periods of up to 22 hours. Continuous operation of dairy food processing equipment allows microbes to multiply to high numbers with possible adverse effects on product quality. For example, Hup *et al.*, (1979) reported off flavours and excess openness in Gouda cheese caused by heat resistant streptococci originating from a pasteuriser that had been operated for an extended period of time without cleaning. A build-up of bacteria in pasteurised milk has been reported after 7-12 hours of continuous operation (Hup *et al.*, 1979; Driessen and Bouman, 1979; Bouman *et al.*, 1982).

Research in our laboratory in collaboration with a cheese manufacturer has shown that the total bacterial count of pasteurised cheesemilk can increase rapidly after 8-15 hours of continuous operation of a commercial cheesemilk pasteuriser. The increase is not observed in pasteurised milk sampled after the holding tube section, but is seen in pasteurised milk sampled after the regenerative section of the pasteuriser (Lehman, 1990; Lehmann *et al.*, 1990).

A miniwash of the pasteuriser after approximately 10 hours of operation, using a 15 minute cold water rinse, a 20 minute 1% caustic solution (70°C) wash and a 10 minute hot water rinse was found to prevent or delay the increase in total bacteria in pasteurised cheesemilk (Lehmann *et al.*, 1990, Figure 3.)

In UF cheesemaking pasteurised milk is fed to a UF plant to concentrate the milk prior to cheesemaking. The UF plant is usually operated at 50-55°C, conditions suited to the multiplication of thermophilic bacteria. The species of thermophilic bacteria most commonly isolated from pasteurised milk and UF concentrated cheesemilk were *Bacillus* species (Solomon and Lehmann, 1990). The source of these organisms was shown to be raw milk supplies (Russell and Lehmann, 1990) and that the two main sites for bacterial multiplication in cheese process plant are the cheese/milk pasteuriser and the ultrafiltration plant (Lehmann, 1990).

Preliminary results of cheesemaking trials, in which thermophilic bacteria isolated from UF concentrated milk were added to UF concentrated cheesemilk, indicate that some can produce flavour defects in UF Cheddar cheese (Lehmann, Mayes and Hull, unpublished). In addition, UF concentrated milk containing high levels of thermoduric bacteria is unsuited for the production of lactic starter culture. The spores of these organisms require very high temperatures to inactivate them and survivors have been shown to be capable of multiplication in lactic starter cultures.

The finding that thermophilic and thermoduric bacteria can have adverse effects on new cheesemaking processes again points to an urgent need for rapid reliable methods to monitor these organisms in raw milk supplies and in the manufacturing process.

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