Lecturer's Handbook

on whey and whey products

First Edition

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Publisher

European Whey Products Association
14, Rue Montoyer
1000 Brussels, Belgium

Production

Cover: Hunterskil Howard
Eindhoven, Netherlands
Printed in July 2001.

Ordering

The Lecturer's Handbook CD-ROM
can be ordered from the publisher.

PREFACE

Increasing interest is being focussed on whey and whey products as functional ingredients in food and pharmaceutical applications, and as nutrients in dietetic and health foods. The time is past when whey was considered as waste material and the nutritional value of this product as animal feed has been appreciated for a long time now. Nowadays over 25% of the whey production in the European Union is utilized for human consumption, and this proportion is more than 50% in the USA. The demand for whey products has increased faster in the food sector than in the feed sector, and forecasts indicate that human applications of whey (products) may surpass its utilization as feed in the near future.

Modern developments in biochemistry, microbiology and more sophisticated technologies are integrated in the whey industry and allow the manufacturing of high quality and safe food products. Information on composition, manufacturing and applications of whey and whey products has increased impressively in recent years. Publications on whey ingredients appear in different specific fields such as nutrition, pharmacy, medicine, process technology and various journals on food applications. This prevents instructors of professional colleges in food and dairy technology from obtaining a complete survey of existing knowledge and new developments of whey and whey products.

In writing this book I have tried to combine all these aspects in an accessible way as background information for teachers of middle and higher professional schools. Pictures, tables and flow sheets, suitable for overhead presentations are the leading thread running throughout the text of this book. The basic approach is a discussion on the origin, manufacturing processes and applications of whey products and ingredients in the context of technology and its related chemistry. Sometimes a more fundamental appraisal of the underlying science is involved. The comprehensive amount of information in these fields only allows to make selections and short descriptions of processes and applications. More general information is provided in books and reviews indicated in the reference list at the end of the book. Specific information can be obtained from representatives of the "European Whey Product Association" (EWPA), and specialists from dairy and/or related food industries.

It is hoped that this handbook will stimulate the interest of teachers, students, and people within and outside the food industry in the functional and nutritional capabilities of whey and whey products.

February 2001 Dr. J.N. de Wit

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1. INTRODUCTION

Whey is the liquid remaining after the production of cheese or the removal of fat and casein (80% of the proteins) from milk. All mammals produce milk to feed their young, the cow is the most widely used animal for the production of milk for other purposes. Other animals are for that purpose are buffalos, camals, goats, sheep, and horses. We have restricted our discussion to whey derived from cow's milk. The worldwide production of whey is estimated to be over 100 billion (100 thousand million) kilograms per year. About 50% of this amount was produced in the European Union (EU) in 1997. Only 8% of this amount is produced directly as a by-product from skimmed milk during the production of casein or fresh cultured cheese. Most of the whey (92%) is recovered as cheese whey, the liquid remaining during the production of cheese. A rule of thumb is that the amount of milk used for the production of cheese equals almost the amount of whey recovered. Whey still contains about 50% of the nutrients present in milk, comprising milk sugar (lactose), serum proteins (whey proteins), minerals, a small amount of fat, and most of the water soluble minor nutrients from milk such as vitamins. Whey and whey products are used by the food industry in a wide variety of applications on the basis of their excellent nutritional and functional properties. This book reviews information on the origin, composition, processing, and properties of whey and whey products in a wide variety of food applications.

1.1 Origin of milk nutrients

Milk is synthesised by the cow following the vegetation of grass and plants in a natural cyclical process as illustrated in figure 1. Vegetation grows by using the energy of the sun, carbon dioxide, water and some elements from the earth. As this happens, incidentally, the grass and plants release oxygen into the atmosphere; an essential gas used by humans and animals to breathe. Grass is not a suitable feed for consumption by newborn calves and can not be digested by human beings. The cow digests, modifies and filters the nutrients from grass

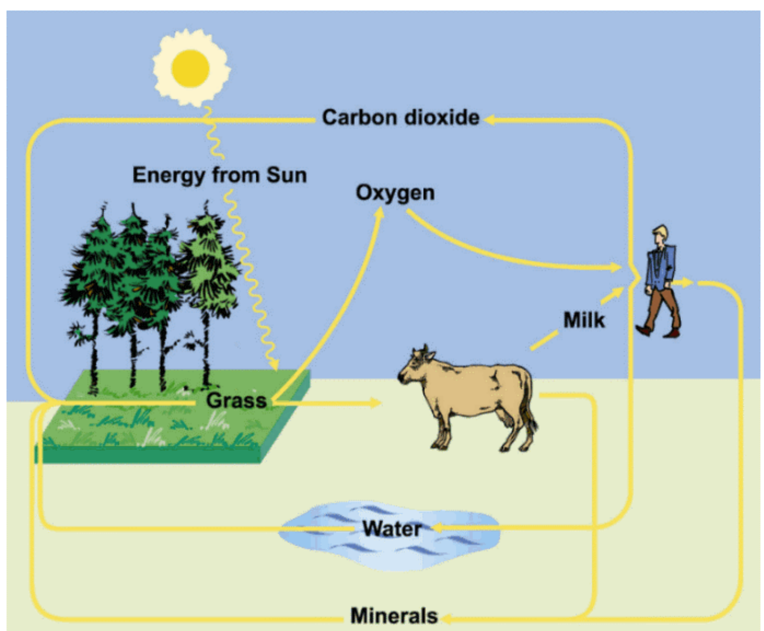

Figure 1. *Milk is generated in a cycle of natural elements, stimulated by the sun. Author Dr. J.N. de Wit*

for growth, maintenance and the production of milk. Waste products such as faeces and urine are raw materials that sustain grass and plants. Cow's milk is a complete food for new-born calves during their first weeks. Well-known components of milk are specific proteins for growth, easily digestible fats, lactose (as energy source), minerals (for bone formation), vitamins and minor components that protect against infections. Cow's milk is also a highly nutritive food for human beings.

1.2 Production of cow's milk

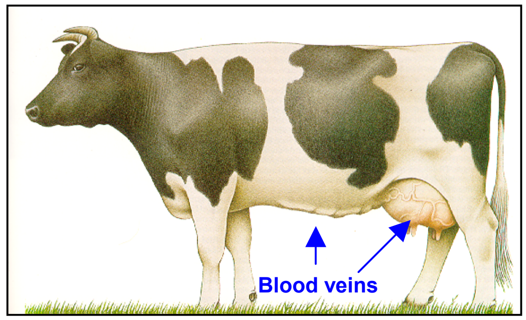

Figure 2. *Milk cow showing thick blood veins on udder and belly for transport of much blood per day. Adapted from reference 21*

A primitive cow produces about 1,000 litres of milk per lactation period; a quantity needed by her calf during the first period of its life. The cow starts the secretion of milk shortly before calving and this continues for a period of about 300 days. Selective breeding of dairy cows has resulted in an average milk production of more than seven times the amount produced by primitive cows. Milk is synthesised in the udder of the cow from nutrients supplied by the blood. A milk cow has about 35 litres of blood that circulates frequently between the heart and udder. It takes 400 litres of blood to pass through the udder to make one litre of milk. So a cow producing 25 l/day requires 10,000 litres of blood to pass through the udder, which requires large blood veins for transportation, as shown in figure 2. The composition of cow's milk is shown in figure 3 involving water, proteins, milk fat, minerals, and lactose as main nutrients. Most of these components are also available in whey, except for the caseins and most of the milk fat.

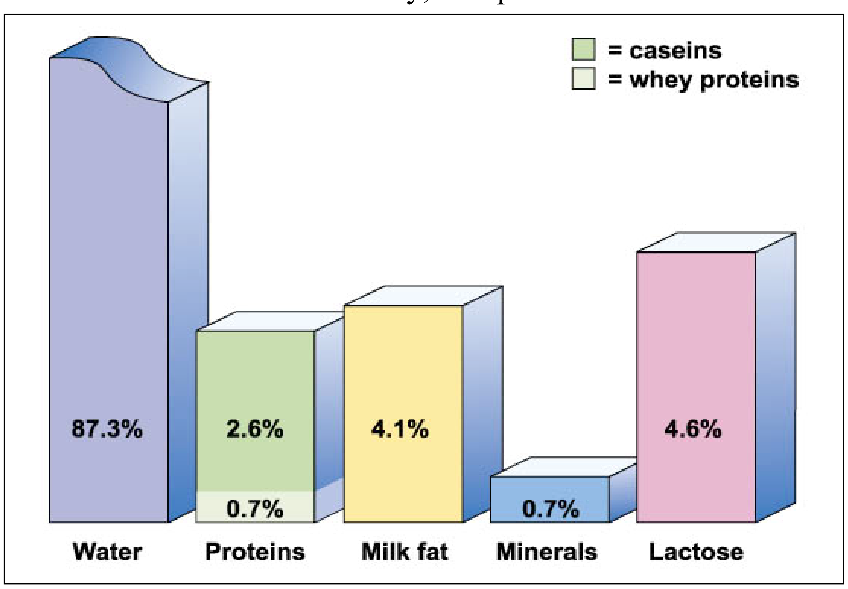

Figure 3. *Main components in cow's milk in weight percentages*
Author Dr. J.N. de Wit

2. FROM MILK TO WHEY

2.1 Pretreatments of cheese milk

2.1.1 Pasteurization

Milk is a nutritional liquid, not only for humans and animals but also for micro-organisms, which may spoil the quality of milk products. Milk is therefore chilled to 4°C immediately after milking and kept at this temperature all the way from the farm to the dairy plant to retard the growth of contaminating bacteria. After arriving at the dairy plant the milk receives a relative mild heat treatment, sufficient to kill the micro-organisms likely to contaminate milk. This treatment is called Pasteurization, after Louis Pasteur, who made studies on the lethal effect of heat on micro-organisms and the use of heat treatment as a preservation technique. The usual pasteurization process involves a heating time of 15 seconds at 72 °C (or combinations with similar effects), which is appropriate to kill 99% of the contaminating bacteria introduced during handling and transport of the milk.

Heating up and cooling down is usually carried out according to a counter-current flow in the so-called plate heat exchangers from which one section is illustrated in figure 4. The plates are corrugated in a pattern designed for optimum heat transfer and compressed in a frame. Supporting points on the corrugation hold the plates apart, thus forming thin channels between them. The incoming milk (cold medium) flows in a counter-current stream with the pasteurized product and is heated up to about 60°C before standardization of fat content (as shown in figure 6). The pasteurized milk (at the other side of the plate) is cooled down in this section to about 45°C, thus economizing on cooling water and energy. In subsequent sections, the incoming milk is heated up to e.g. 72°C in a counter current stream with hot water. An external holding tube is used to ensure the correct length of the heating time at 72°C before the milk returns to the cooling side of the heat exchanger section, as explained in section 2.1.2.

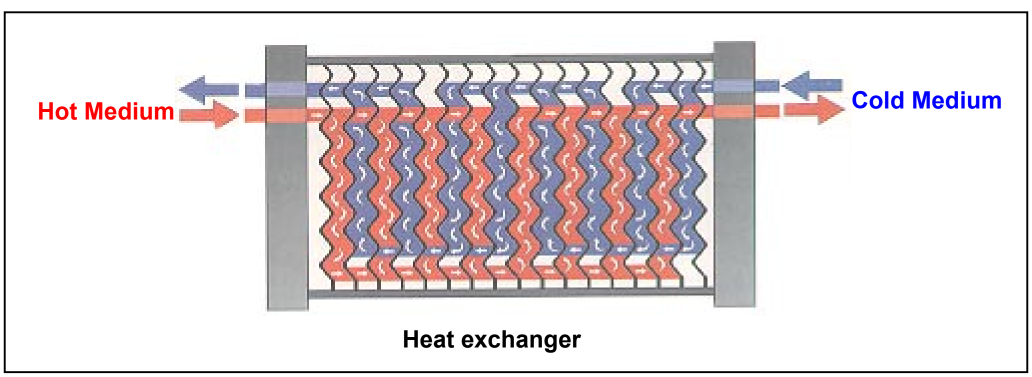

Figure 4. *Diagram of one section from a plate heat exchanger. From Reference 2*

Pasteurization of milk mostly occurs in combination with standardization or separation of milk fat in milk by using centrifuges.

2.1.2 Standardization

The standardization of the milk involves the adjustment of the fat content by separating part of the milk in a separator or centrifuge. Well-known standards are 0.05% for skim milk, 1.5 to 3.5% for consumption milk, and 2.5 to 4% for cheese milk.
A continuous separation of fat from milk takes place in a centrifuge bowl as illustrated in figure 5. The centrifugal force carries the incoming milk outwards to form a ring with a cylindrical inner surface. Milk components will separate radially outwards or inwards according to their density relative to that of the continuous medium (water), under the influence of the centrifugal force. The cream (fat globules with a density of 890 kg/m^3 at 60°C) moves towards the axis of rotation and passes through channels to the cream-paring chamber (yellow flow in figure 5).
Skim milk (having a density of 1017 kg/m^3 at 60°C) leaves the disc stack at the outer edge and passes between the top disc and the bowl hood to the skim milk-paring chamber (light purple stream in figure 5). Heavier solid particles in milk settle outwards; they are collected in the sediment space and discharged at time intervals.
The skimmed or standardized milk, leaving the separator is pumped in-line to the next section of the pasteurizer as shown in figure 6. The cold milk enters the plant via the balance tank [**1**] and is transported by the feed production pump [**2**] to the first section [***A***] of the plate heat exchanger [**4**]. The milk leaving this section at about 60°C passes through the flow control [**3**] before entering the separator [**5**]. The fat content of the cream is usually set at 35 to 40 % but can also be set at other levels depending on its application. Once set, the fat content of the cream is kept constant by the controlling system of flow transmitter [**7**], the density meter [**8**] and the regulating valve [**9**]. The standardized milk flows after adjustment for constant pressure at

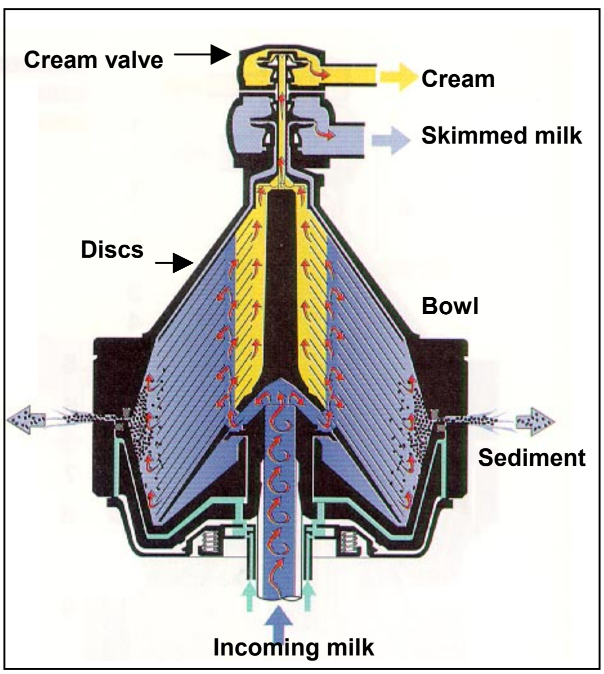

Figure 5. *Flow pattern of streams in centrifuge for separation of fat and sediments from whey. From reference 2.*

valve [**6**] and flow at transmitter [**7**] to the heat exchange sections [***B***] and [***C***] of the pasteurizer. A heat treatment of 15 seconds at 72 °C is legally required and strictly controlled by temperature/time discs on the pasteurizer through pressure control by pump 10. These points belong to the so-called Hazard Analysis Critical Control Points (HACCP) for the effectivity of a pasteurization process.

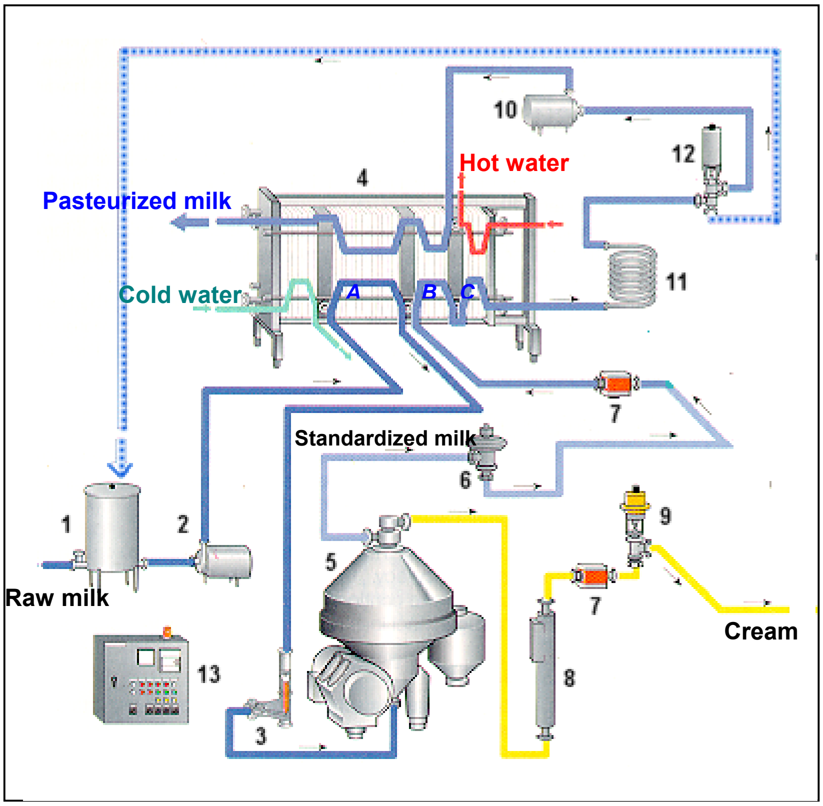

Figure 6. *Production line for standardization and pasteurization of milk or whey. Adapted from reference 2*

The necessary holding time is provided by a separate holding tube [**11**] at the pasteurization temperature, which is recorded continuously. A possible temperature drop is sensed by a transmitter, which activates the flow diversion valve [1**2**]. This valve returns insufficient pasteurised milk to the balance tank. Pump [**10**] increases the pressure of the pasteurized milk for counter-current transport through the heat exchanger and the cooling section. Standardized and pasteurized milk may be used in liquid form as cheese milk of different fat contents. The remaining cream is mostly used for the manufacture of butter.

Whey, the liquid remaining after the production of cheese, is used for further processing. The whey and whey products available on the market are mainly derived from sweet cheese whey. The remaining acid whey is produced during production of casein (casein whey) and fresh cheese.

2.2 Manufacture of whey

2.2.1 Casein whey and caseinates

The manufacture of casein whey goes back more than 3,000 years B.C., when Bedouins carried animal milk in bags on their trips through the desert. The heat in the desert caused acidification and coagulation in milk, resulting in an acid liquid (whey) on top of a milk curd sediment.

Acid precipitation of this curd has been optimized in the past for the recovery of purified casein from pasteurized skim milk, as illustrated in figure 7. Casein and caseinates are produced by acidification of skim milk by either a culture of lactic bacteria at 25 °C or by food grade acids such as hydrochloric acid or sulphuric acid at 45°C. The casein will precipitate around pH 4.6 and is separated from the remaining liquid by using centrifuges or decanters (shown in figure 24), followed by washing. The remaining liquid is the acid or casein whey, which is available for further processing. Casein and caseinates are dried according to techniques discussed later, and applied as indicated in figure 7.

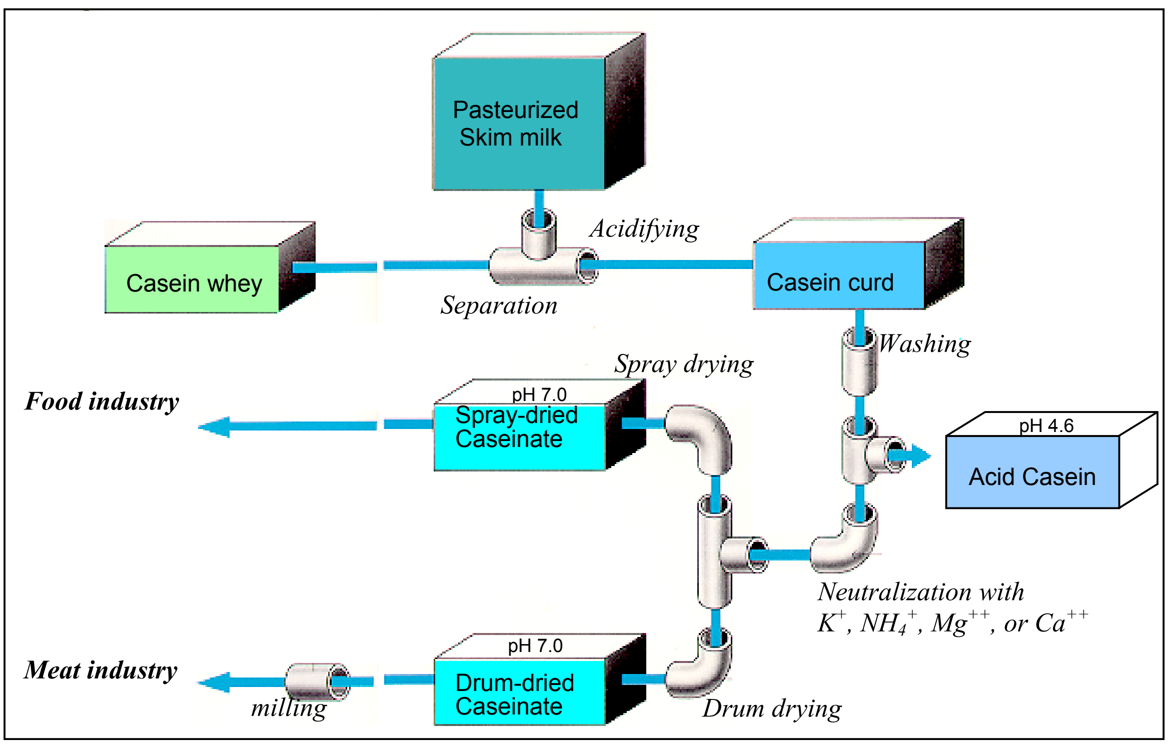

Figure 7. *Flow sheet for the production of casein, caseinates and casein whey. Author Dr. J.N. de Wit*

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2.2.2 Cheese whey and cheese

Historical reports suggest that Bedouins sometimes observed a sweet yellow liquid (whey) on top of a (cheese) curd, when they carried their milk in sacks of dried animal stomachs through the desert. Later studies showed that dried stomachs were able to clot milk proteins, caused by residual activity of enzymes present in the stomach of living animals. This observation has been used for the production of cheese by enzymatic coagulation of casein. Whey, as by-product from the manufacture of cheese, is well known for its main ingredients, e.g. lactose for the pharmaceutical industry and whey proteins for the food industry. Moreover, whey contains many valuable nutrients for use in human foods. During recent years new commercial processes have been developed for the manufacture of these high quality whey ingredients.
Most of the whey (92%) is obtained from the production of various types of cheese, which show small differences in their preparation procedure. Figure 8 illustrates the procedure for making semi-hard cheeses, which generates whey that is representative for most types of

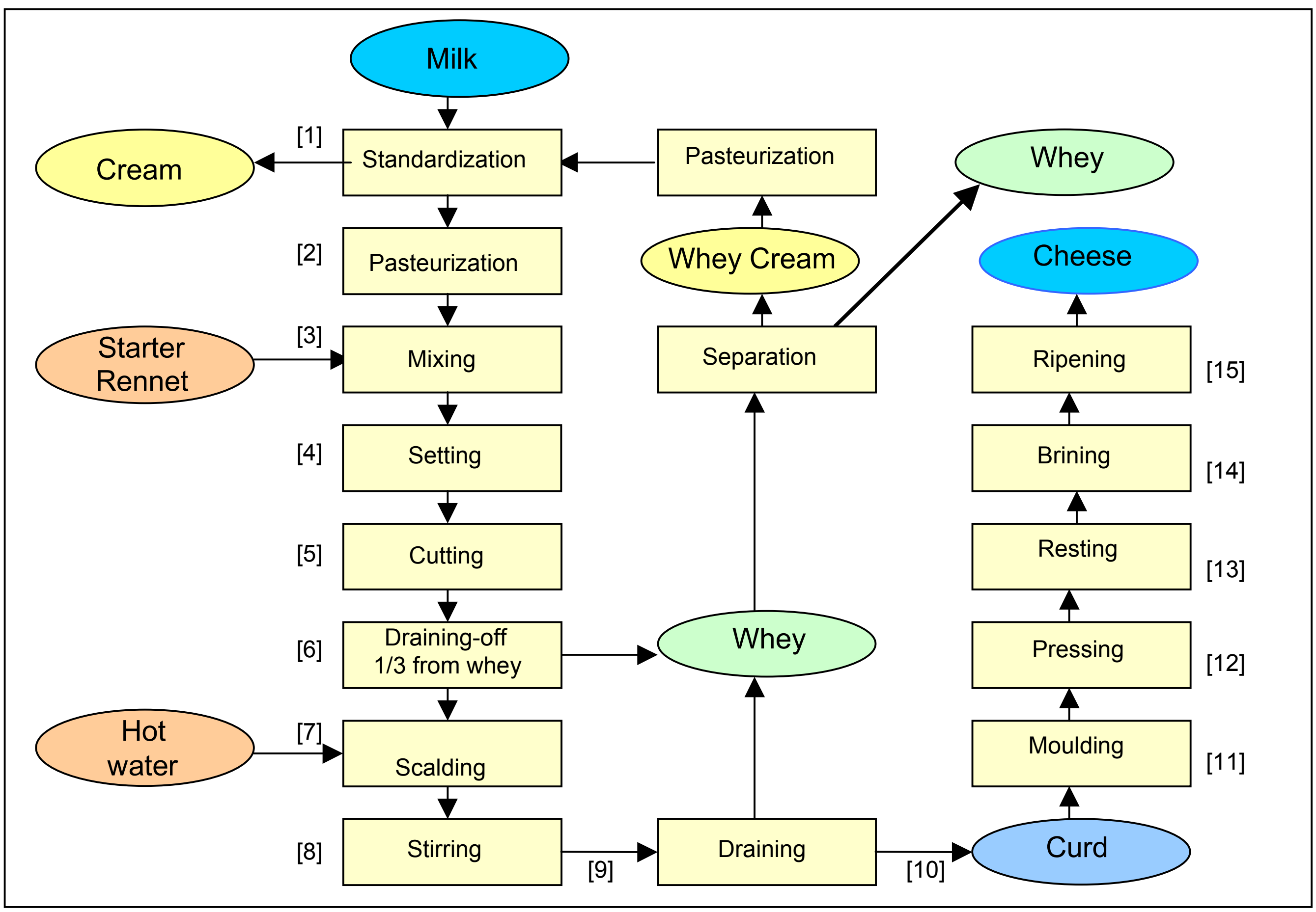

Figure 8. *Flow sheet for the manufacture of semi-hard cheese.* *Author Dr.J.N de Wit*

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cheese. Milk arriving from the farm is standardized [**1**] at a fat content of between 2.5% (40% fat on total solids in cheese) and 3.5% (full-fat cheese). Standardization and pasteurization takes place by using a separator and pasteurizer in line, as shown in figure 6. Reduction of the fat content of cow's milk from over 4% fat to the desired fat content is achieved by adjusting the cream valve, shown in figure 5. After that the standardized milk passes immediately through the pasteurizer [**2**] (e.g. 15 s 72°C) for the inactivation of contaminating bacteria. The cheese milk is subsequently cooled down to 30°C and inoculated [**3**] with a starter (a culture of lactic acid bacteria) and rennet, a mixture of the enzymes chymosin and pepsin naturally present in the stomach of young calves. The starter contributes to the characteristic cheese flavour during the ripening of the cheese. Rennet (or its replacers) induces gelation of the casein, which includes the fat globules from milk in the gel. The milk gel [**4**] is formed in a setting time of about 30 minutes at 30°C, after which the gel will be cut [**5**] into cubes by turning knives as illustrated in figure 9. The cubes will precipitate as a curd, leaving whey as the supernatant liquid. One third of this whey is subsequently drained off [**6**] and replaced by the same amount of hot water (± 40°C). This so-called scalding process [**7**] causes a shrinking of the curd particles and as a consequence the squeezing of included whey during stirring. After stirring [**8**], the curd is pressed together and separated from the remaining whey. This is achieved in large-scale industrial processes by a continuous pre-pressing system, e.g. by using the "Casomatic" as shown in figure 10.

Figure 9. *Cutting renneted milk to cheese curd*

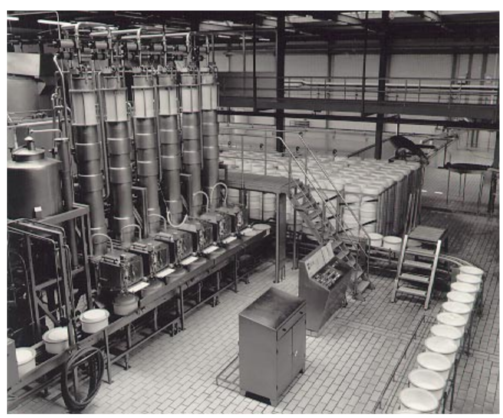

Figure 10. *Separating cheese whey from curd in a continuous pre-pressing system.*

The curd/whey mixture is pumped to the top of the cylindrical column (up to 2.5 meters high), which is closed at the bottom by a movable knife. The whey is squeezed out by the weight of the curd column and drained off [**9**] through perforated sections located at different levels of the column. The curd arrives, after a pre-set time of usually 20-30 minutes, at the bottom of the column and pieces of desired firmness are then cut-off. The curd pieces fall into moulds [**10**] located below the column and transported on a conveyor. The moulds then proceed for final pressing [**12**] to support final whey expulsion and to provide the texture and

shape to the cheese. The expelled whey from the press is collected separately, concentrated and spray-dried for use as animal feed. After pressing, the cheese is turned upside down during a resting time [**13**] at room temperature for equilibration of the moisture content in the cheese. The majority of cheeses are salted through brining [**14**] to retard starter activity and to prevent growth of bacteria in cheese. Brining takes place by submerging the cheeses for some days in a 20% NaCl-bath. Finally the cheese is ripened [**15**] in storehouses at 13°C and 75- 85% relative humidity.

Large-scale industrial production processes of cheese are obtained by linking a number of pre-pressing columns together, having a capacity of about 600 kg curd per hour each.

The whey coming from the draining processes still contains 0.2-0.5% milk fat (depending on the cheese type) and curd fines. These are mainly removed by centrifugal separation as illustrated in figure 5. The sediment, indicated in this figure, consists of curd fines, which are recovered for the production of processed cheese for example. In some countries the separated whey cream may be utilized for the standardization of cheese milk. For safety reasons a more severe heat treatment (e.g. 1 min. 110°C) is recommended. The resulting skimmed whey has a composition that is slightly dependent on the cheese type.

Table 1 summarises the contribution of major components in the composition of whey from different origins, standardized at a total solids content of 6.5%. Casein whey is obtained by precipitation of casein from skim milk by either hydrochloric acid or sulphuric acid. Lactic

Table 1. ***Typical composition of whey from different origins in g/litre***

Constituent	Casein whey	Lactic whey	Gouda whey	Camembert whey
Total solids	65.0	65.0	65.0	65.0
True proteins	6.0	6.0	6.2	6.2
NPN (N*6,38)	2.0	2.2	2.4	2.4
Lactose	47.0	40.0	47.0	45.0
Lipids	0.3	0.3	0.5	0.5
Minerals (ash)	7.9	7.9	5.3	5.6
Calcium	1.6	1.6	0.6	0.6
Phosphorous	1.0	1.0	0.7	0.7
Lactic acid	0.2	0.6	0.2	0.3
pH	4.7	4.5	6.4	6.0

Author Dr.J.N de Wit

acid whey is prepared by the incubation of skim milk using a lactic acid bacteria culture. The most significant differences are observed between both acid whey's and the cheese whey's (Gouda, Camembert). The higher Non Protein Nitrogen (NPN) content in cheese whey is due to the presence of an additional peptide (casein-macropeptide), split-off from casein micelles

during the renneting of cheese milk. The lower true whey protein content in casein whey and lactic whey is caused by a more severe heat treatment from its source (skim milk), which results in some precipitation of whey proteins at pH 4.6. The lower lactose content in lactic whey is explained by its fermentation through lactic acid bacteria, which results in a significant increase of lactic acid as shown in table 1. The higher mineral content in acid whey is due to the dissolution of calcium and phosphorous from casein micelles during acidification of milk down to pH 4.6. The total solids composition of whey is not often equivalent to the sum of its constituents, because the techniques for the determination are quite different.

Clarified whey is a colloidal dispersion of a small amount (0.5 g/l) of fatty components and bacterial cells. Removing of these particles results in a crystal clear yellowish coloured solution of whey proteins, lactose and minerals. The yellow colour of whey is caused by the presence of about 1.7 mg/l riboflavin, known as vitamin B_{2}.

Figure 11. *Appearance of whey*
Adapted from reference 2

Additional information in References 2, 3 and 4

3. NUTRIENTS IN WHEY

Whey is a nutritious liquid, containing whey proteins, lactose, vitamins and minerals, but also enzymes, hormones and growth factors. In addition to their nutritional contributions, some whey components also play physiological roles in health foods.

Figure 12 illustrates a survey of a number of nutrients present in cheese whey in concentrations varying from grams per litre (outside ring) to nanograms per litre (inner circle). The main components occurring in the gram- and milligram-ranges are summarized in table 2. The analytical composition of whey is dependent on the composition of cheese milk, which may vary somewhat depending on animal breed, feed, health, and stage of lactation. The data shown in table 2 are indicative for most of the cheese wheys.

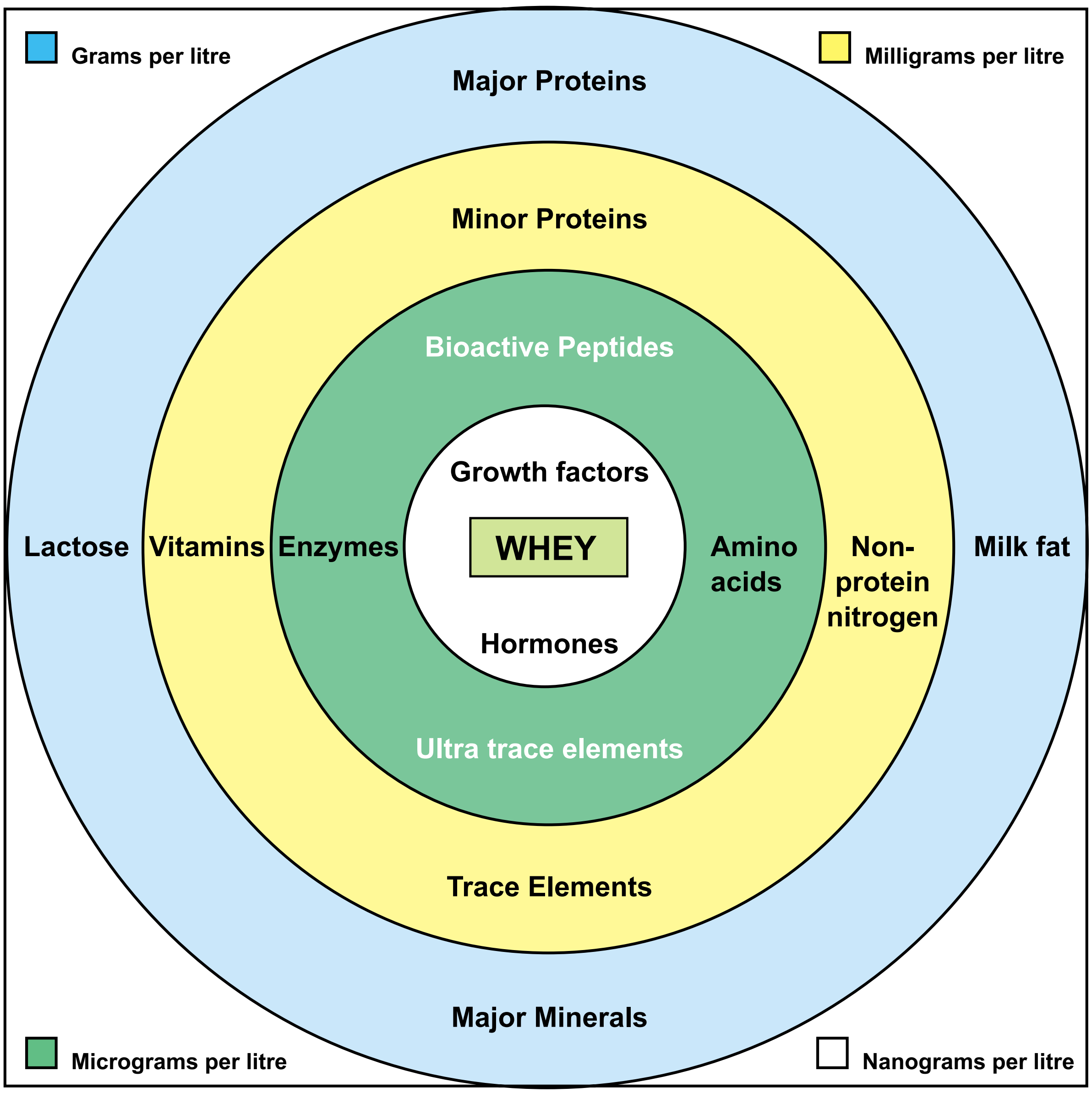

Figure 12. *Diagram of nutrients in whey, indicated in rings of different concentrations. Author Dr. J.N. de Wit*

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TABLE 2. ***Approximate composition of Gouda cheese whey***

CHEESE WHEY

WATER (935 g/l) | **TOTAL SOLIDS** (65 g/l)

Grams/litre

CARBOHYDRATES		**MILK FAT**	(g/l)	**MINERALS**	(g/l)	**PROTEINS**	(g/l)
Lactose (47 g/l)		Triglycerides	(0.25)	Calcium	(0.6)	β-lactoglobulin	(3.0)
		Diglycerides	(0.05)	Magnesium	(0.1)	α-lactalbumin	(1.2)
		Fatty acids	(0.05)	Phosphorous	(0.7)	Serum albumin	(0.4)
		Phospholipids	(0.15)	Potassium	(1.5)	Immunoglobulin-G	(0.7)
				Chloride	(1.1)	Proteose pepton	(0.6)
				Sodium	(0.5)	Other proteins	(0.3)

Milligrams/litre

NPN	(mg/l)	**VITAMINS**	(mg//l)	**TRACE ELEMENTS**	(mg/l)	**MINOR PROTEINS**	(mg/l)
Urea	(80)	Vitamin B_5	(4.0)	Zinc	(1.5)	Immunoglobulin-A	(50)
Amino acids	(25)	Vitamin B_2	(1.5)	Iron	(0.6)	Lactoferrin	(45)
Cholin	(15)	Vitamin C	(1.5)	Iodine	(0.5)	Lactoperoxidase	(25)
Orotic acid	(12)	Vitamin B_6	(0.5)	Copper	(0.2)	Lysozyme	(2)

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3.1 Major constituents

Lactose is a disaccharide composed of one glucose and one galactose molecule. Lactose is an important source of dietary energy and enhances the intestinal absorption of calcium from foods. The enzyme lactase is essential for the conversion of dietary lactose into glucose and galactose, which is necessary for uptake from the intestine. Persons of African or Asian origin and approximately 15% of Western Europeans may suffer from lactase deficiency, and are so-called lactose intolerant. Lactose intolerance means that lactose remains undigested and cannot be absorbed in the intestinal tract. It then serves as food for micro-organisms in the colon, which produce gas and lactic acid, resulting in symptoms of flatulence, bloating, abdominal cramps, and diarrhoea. The lactose challenge test for lactose maldigesters requires an instantaneous consumption of 50 gram in water or milk after an overnight fast. Fifty grams of lactose is the amount present in more than 1 litre of milk and thus represents an unphysiological dose. It has been established that most lactose intolerant people in Western countries have no problems for the consumption of 12 gram lactose (a single 250 ml serving of milk or yoghurt).

Whey minerals are involved in the regulation of the water flow by osmosis between different regions of the body. The composition of whey salts reveals a low ratio of sodium/potassium

(0.3), which is important for preventing elavated blood pressures (hypertension). Calcium and phosphate support the growth of bones and teeth, but also perform a variety of other functions in the body. Calcium from whey is readily absorbed in the intestinal tract, which is facilitated by the presence of lactose. The presence of phosphate reduces the excretion of calcium in urine.

The whey proteins are built up from 20 different amino acids, linked together as shown in figure 13A. The amino acid chain may be structured in different shapes, from which the β-sheet and α-helix are the most important ones (see 13B). These structures are folded in a compact protein structure (13C), which keeps insoluble amino acids inaccessible for water and enzymes. The unfolding of whey proteins in the stomach and intestinal tract allows digestion by acids and enzymes.

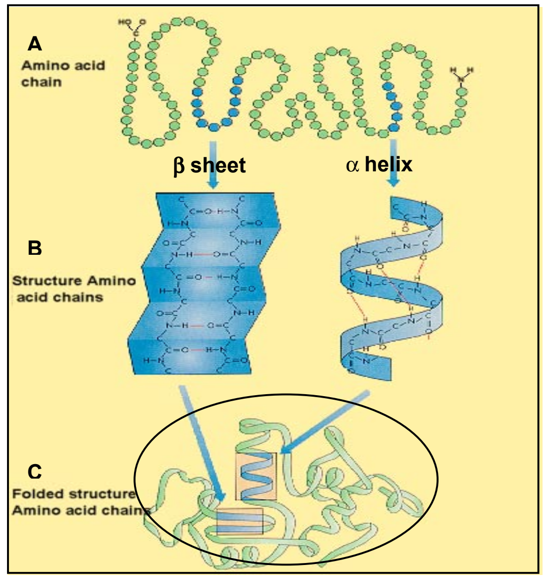


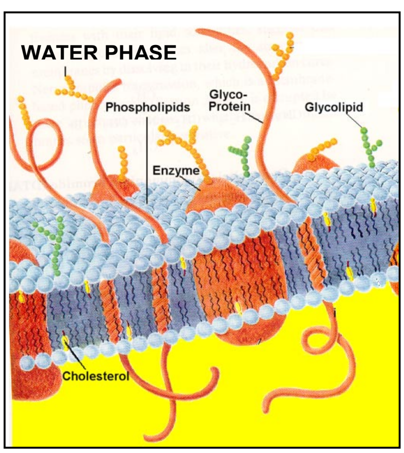
Figure 13. *Construction of the structure of globular whey proteins. Adapted from reference 6.*

The major whey protein, β-lactoglobulin is, however, remarkably stable to acids and proteolytic enzymes present in the stomach because of its very compact folding. This is probably related to the biological function of β-lactoglobulin as a resistant carrier of water-insoluble retinol (provitamin A) from cow's milk to the calf. Vitamin A is mainly required for dark and bright light adaptations of the eyes.

The biological function of α-lactalbumin is to support the biosynthesis of lactose both in human and cow's milk. α-lactalbumin is the most important protein in human milk, and plays an important nutritional role for new-borns. Bovine serum albumin (BSA) binds insoluble fatty acids, released during the digestion of food products for transportation in the blood.

Immunoglobulin-G is transferred from the blood of the mother to the milk and is a carrier of passive immunity to new-borns. Proteose peptones are mainly phosphate-containing fragments from casein. They have the ability to bind minerals and enhance gastrointestinal calcium absorption. One of the proteose peptones, known as PP-3, has been identified as a protein from the milk fat globule membrane. This protein is identical with osteopontin, involved in the synthesis of bone cells.

About 50% of milk fat in skimmed whey is present in globules smaller than 1 μm (weight average) in diameter.



LIPID PHASE

Figure 14 *Schematic diagram of a fat globule membrane. Adapted from reference 22*

The remaining amount of fat is bound to proteineous material. A thin protective layer (fat globule membrane) containing surface-active components and enzymes surrounds the fat globules, as shown in figure 14. This membrane reduces the density difference between water and the fat in small globules to a level nearly equal to that of water. This prevents centrifugal separation of the remaining fat from whey within the time specified by the flow rate in centrifuges as shown in figure 5.

3.2 Minor constituents

Figure 12 indicates constituents in the milligram range (yellow ring) such as the minor proteins lactoferrin, lactoperoxidase, lysozyme, and immunoglobulin A. These proteins are important in the defence against micro-organisms and foreign body components.
Lactoferrin is an iron containing protein for which two main biological functions have been assigned: 1) the antibacterial activity in the mammary gland, and 2) the nutritional activity by making iron more available for absorption in the gut. **Lactoperoxidase** is active against a number of enteric bacterial strains. Both lactoferrin and lactoperoxidase appear to have beneficial effects in reducing the incidence of chronic diarrhoea. **Lysozyme** causes lysis of certain bacteria by disruption of their cell walls. Well-known applications are the prevention of late gas blowing and off-flavours in cheese, caused by the growth of butyric acid-producing bacteria. So-called secretory **immunoglobulin-A** plays a major role in defending new-borns against viruses, bacteria, and other pathogens during the first days of their life.
From the trace elements**, copper** is identified as an essential component of many metalloproteins, including some vital enzymes. Copper-containing enzymes are involved in the release of energy during respiration and the synthesis of structural proteins such as collagen. **Zinc** performs many functions, like the stimulation of the insulin activity for the absorption of glucose from blood. **Iron** is part of several metalloproteins such as haemoglobin, lactoferrin, lactoperoxidase, catalase, and supports several important functions as a carrier of oxygen. Lactoferrin may withhold undesirable bacteria from binding iron so that their growth in the intestines is inhibited. **Iodine** is part of the thyroid hormone, which plays a major role in regulating growth and development of new-borns.
The vitamins in whey are water soluble, and support physiological functions in the body. **Vitamin B_5** (also known as pantothenic acid) is involved in the metabolism of carbohydrates, fats, and proteins. **Vitamin B_2** (riboflavin) is known to be essential for growth and tissue repair. **Vitamin C** (ascorbic acid) is well known as an anti-oxidant that protects the body against damaging oxidizing agents. **Vitamin B_6** functions primarily in protein metabolism. B_6 also prevents inflammations of the mouth, nose, and ears.

The non-protein nitrogen fraction contains components from the synthesis or metabolism of milk components, of which **urea** represents 40%. **Choline** is required for the synthesis of phospholipids. **Orotic acid** appears to contribute to the reduction of the cholesterol content. Constituents in the microgram range (green ring in figure 12) are bioactive peptides, which are sequences of amino acids from (whey) proteins with specific biological functions. An example is **lactoferricin**, a peptide from lactoferrin with enhanced bactericidal activity.
An important specific amino acid is **taurine**, which has recently been identified as a dietary nutritional compound for infants. Taurine is also involved in the absorption of fat in the small intestine and the regulation of the nervous system. This amino acid is sulphur-containing, which plays a role in the development of the central nervous system in infants. Human milk contains sufficient taurine, but its occurrence in cow's milk is too low for babies. Most infant formulas are therefore enriched with 40–45 mg/l of this amino acid.
A well-known ultra trace elements is **cobalt**. This element is an essential part of vitamin B_{12}, which prevents pernicious (harmful) anaemia.
More than 25 enzyme activities are present in the milk lipid globule membrane, which is partially present in whey. An example is **catalase** that may prevent infections in the intestinal tract. The main enzyme found in the fat globule membrane is **glucose oxidase,** which catalyses the oxidation of glucose to gluconic acid under the generation of hydrogen peroxide. Hydrogen peroxide has a direct bactericidal effect, but is more effectively exploited for this purpose as a component of the peroxidase system.
Constituents in the nanogram range (inner circle in figure 12) are growth factors, which are specific peptides, stimulating growth and repair of epidermal cells from skin and intestines. A well-known hormone is **insulin**, which promotes the transport of glucose from the blood into various cells of the body. The whey constituents discussed so far are only a selection of the many nutrients present.

Additional information in References 5, 8 and 12

4. CONCENTRATION AND DRYING OF WHEY

4.1 Concentration by evaporation

Whey is concentrated and dried for several reasons, e.g. to reduce costs for storage and transportation or to induce crystallization of lactose as will be discussed in section 5.5. It takes much energy to boil off water from the whey during concentration from an initial solids content of 6.5% up to a concentration of 50 - 60%. This energy is usually in the form of steam under reduced pressure. To reduce the amount of steam needed, the evaporation station is normally designed as a multiple-effect evaporator. Two or more units operate at progressively lower pressures and thus inducing successively decreasing boiling temperatures. The falling film evaporator is well known in the dairy industry, and consists of a bundle of tubes through which the whey flows as a thin film inside the tube surfaces. A steam heating jacket maintained under vacuum as shown in figure 15 surrounds the tubes. Water and condensed vapour are removed as condensate in the condenser at the bottom of the

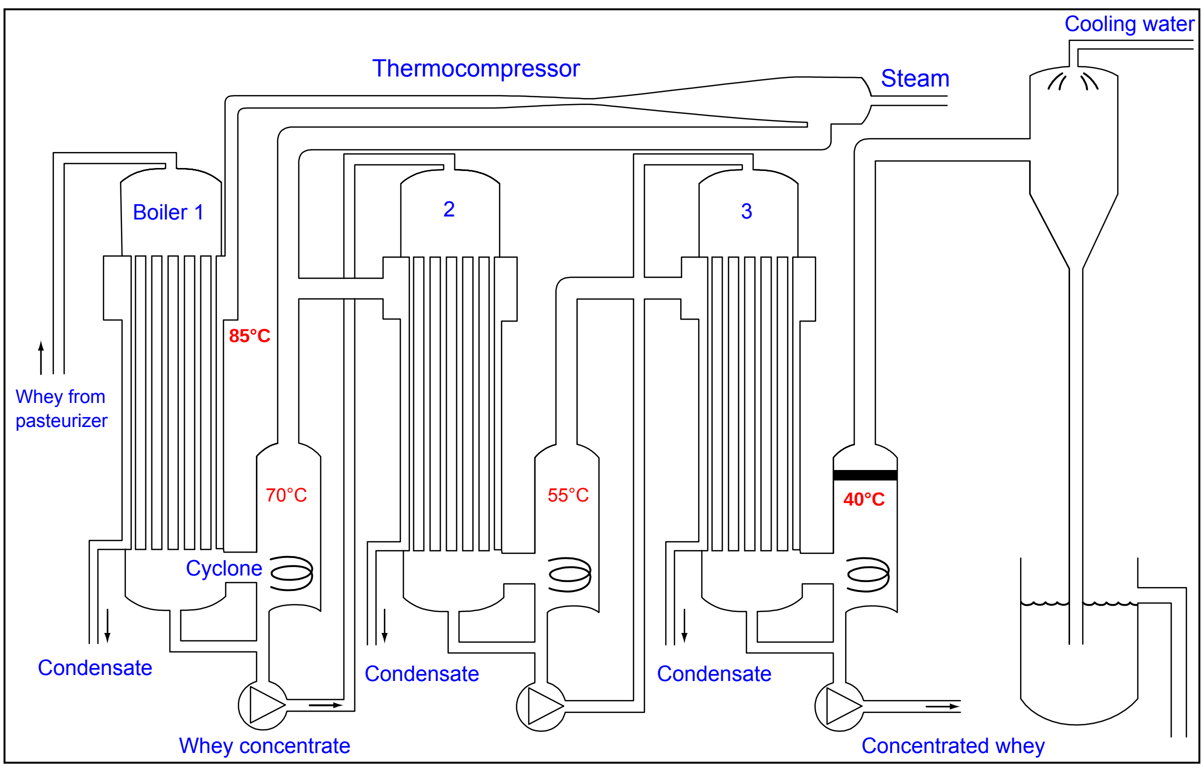


Figure 15. *Three effect evaporator with thermocompression for concentration of whey. Adapted from brochure of DMV-International.*

tube bundle. A vapour cyclone is fitted at the outlet of the evaporator and separates the vapour from the concentrated whey. The equipment shown in figure 15 is a three-effect evaporator, but it is possible to connect more evaporators in series of up to seven effects to

improve steam economy. The effects are linked with a condenser and a vacuum source. In operation, the temperature difference (15°C) between the effects is the same, and the amount of water removed in each effect is approximately equal.
Whey is pumped from a balance tank to the pasteurizer and transported continuously in-line to the first effect of the evaporator. Vapour from the first effect having a boiling temperature of 70°C is used as a heating source for the second one and so on.
The partly concentrated whey is separated from the vapour in the cyclone and pumped to the second effect. In this effect the vacuum is higher, corresponding to a lower boiling temperature for further concentration of the whey. The third effect has a boiling temperature of 40°C, resulting in the desired final concentration for further processing of the whey. A so-called thermocompressor is often used to improve the thermal efficiency of the evaporator. Figure 15 shows a steam-jet compressor, which compresses part of the vapour from the first effect. This compressor acts as a heat pump which utilizes a venturi to increase the vapour pressure and hence the temperature from 70° to 85°C. The compressed vapour is then used to heat the first effect again, which increases the thermal efficiency considerably.
Higher boiling temperatures and/or longer residence times in evaporators are utilized to produce so-called "high heat whey powders". These powders are suitable for particular application purposes, as e.g. for baking of bread.

4.2 Drying of whey concentrates

The drying process may be seen as a continuation of the concentration of whey with the intention to produce a stable low moisture product for functional and nutritional end-use attributes. Industrial dryers may be distinguished as drum dryers used for special purposes and spray dryers which are used in most drying processes.

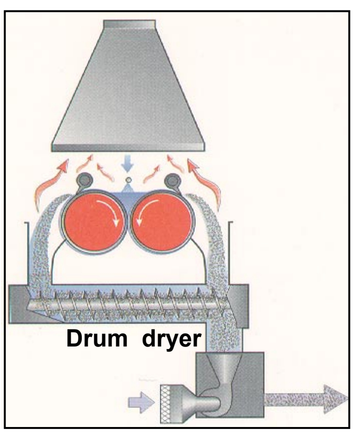


Figure 16 *Principle of drum drying. From reference 2*

Drum or roller dryers are in use for drying milk and protein products, which need intensive heat treatments for special purposes, such as high heat milk powder, caseinates, and some specific whey products. A roller dryer consist of two metal drums having a diameter of about 1 metre, internally heated by steam to a surface temperature of about 100°C. The drums are rotating in opposite directions through a trough of the concentrate, or are fed by spraying the concentrate on the drums, as shown in figure 16. Although drum drying is the cheapest drying technique, this procedure may cause undesirable heat damage for most functional applications of whey products. Spray drying is in its simplest form an atomizing process of milk

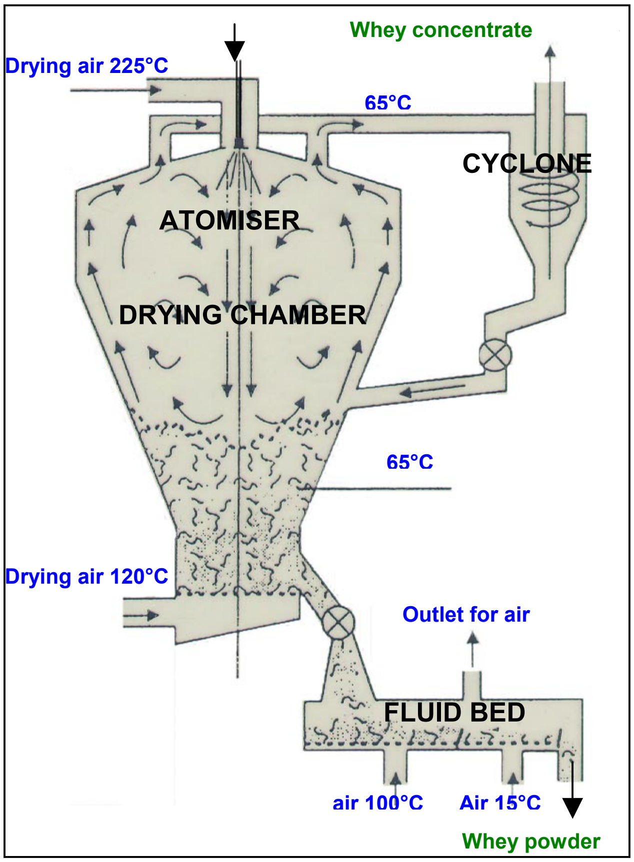


Figure 17. *Diagram of a three-stage dryer. Author Dr. J.N. de Wit*

or whey concentrates in hot air within a drying chamber, shown in figure 17. The air at inlet temperatures is between 150°C and 250°C and removes water from concentrate droplets during drying. The vaporisation temperature of water at commonly used inlet temperatures is usually between 65°C and 75°C, and the temperature of drying particles never exceeds this temperature. Spray drying may be carried out in installations of a different capacity from the simplest one-stage dryers to the complicated multistage-dryers.

The design of a three-stage dryer is illustrated in figure 17. This dryer consists of a drying chamber, an internal and an external fluid bed. Advantages of such a dryer are saving of energy and a more compact design. The concentrated whey, containing crystallized lactose, enters the top of the dryer via an atomizer. Rotary disc atomizers are often used, driven by a high-speed electric motor, which produces a range of droplet sizes in the drying chamber. Drying air is supplied to the drying chamber around the disc at temperatures of up to 225°C. Droplets are dried in the drying chamber to powder particles of different sizes down to a moisture content of about 6%. Air leaving the the drying chamber contains small particles or “fines”. The fines are separated from the air in the cyclone, and returned to the dryer where they participate in an agglomeration process. An uniform distributed powder stream is transported from the internal fluid bed dryer of the drying chamber to the external fluid bed dryer. This dryer consists of a casing with perforated bottom to allow incoming hot air to be passed through the powder layer, which reduces the moisture content of the powder down to 3-4%. Cooling and packaging in airtight sacks will ensure then the good storage quality of the powder. Previous crystallization of lactose prevents stickiness of the wheypowder during storage.

Additional information in References 2, 3 and 4

5. PROCESSING OF WHEY INGREDIENTS

5.1 Survey of recovery processes

The principles of industrial recovery processes of whey ingredients are schematically shown in figure 18. They usually occur before evaporation and/or spray drying.
Membrane processes (18A) are used for the separation of ingredients with different molecular sizes. Microfiltration is used for the removal of bacteria and fat globules, ultrafiltration for the fractionation of proteins, nanofiltration for desalting, and reverse osmosis for the separation of water. More details will be discussed in sections 5.3. Removal of lactose (18B) makes use of the poor solubility of lactose in concentrated whey, resulting in the

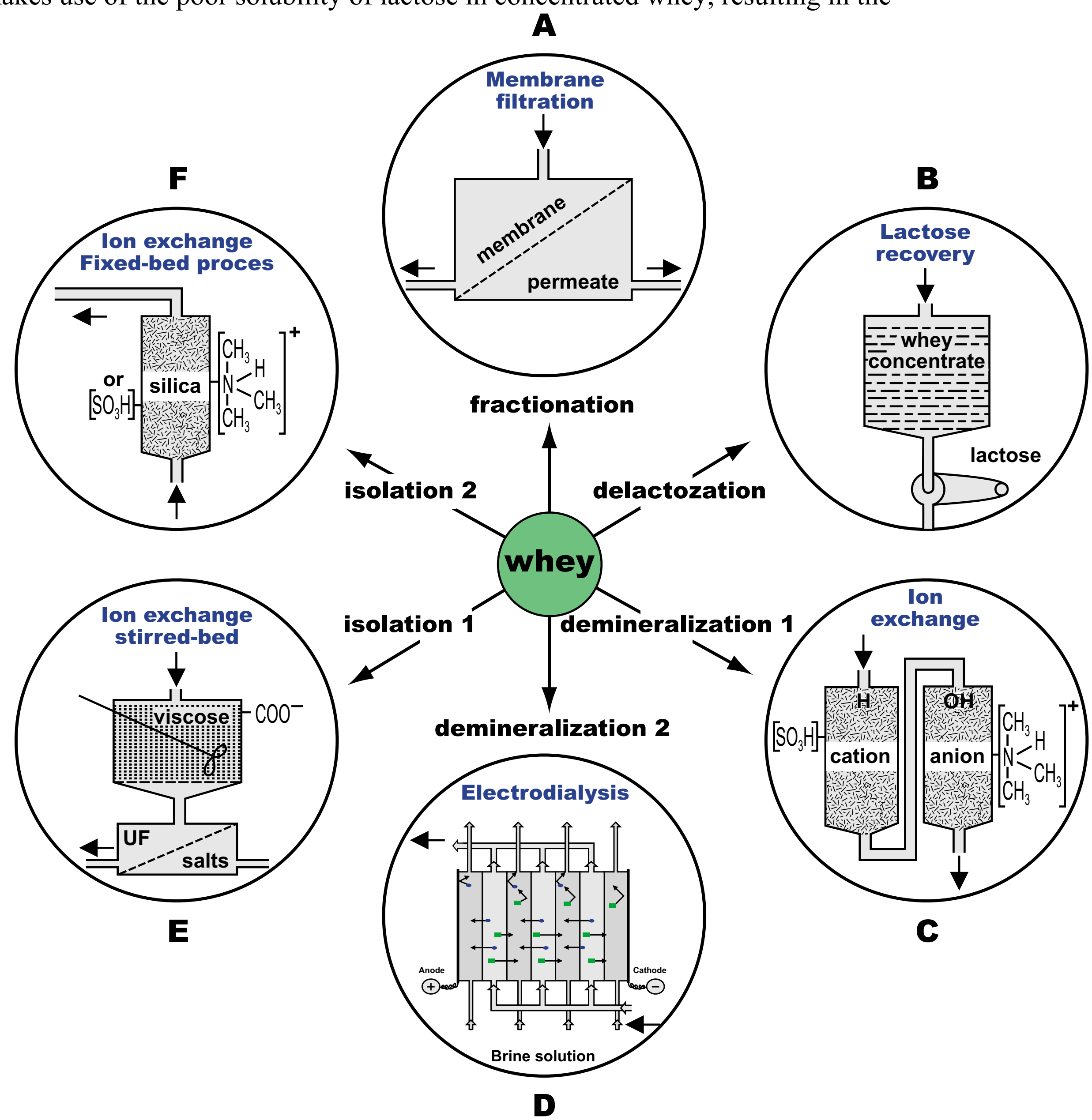


Figure 18. *Survey of processes for the recovery of whey components. Author Dr. J.N. de Wit*

crystallization and separation from concentrated whey, as discussed in section 5.5.
Demineralization involves the removal of minerals and some organic acids through nanofiltration, ion exchange or electrodialysis. The most complete demineralization is achieved by using ion exchange (18C), and is explained in the next section. Electrodialysis (18D) is a more selective demineralization method, based on the transport of preferentially mono-valent ions through semi-permeable membranes, induced by a direct current as the driving force. Direct current electrodes are located along the end compartments and whey salts are discharged through a 5% brine solution.
Specific separation of whey proteins through ion exchange may be achieved by mixing whey at pH 3.2 with porous crosslinked viscose particles, provided with cation exchange groups in a so-called stirred-bed ion exchange process (18E). The positively charged whey proteins (at pH 3.2) are bound at the negatively charged viscose particles during stirring in a big tank. When the viscose particles are saturated with whey proteins, the deproteinized whey is removed through a sieve in the bottom of the tank. After washing the particles are regenerated with NaOH at up to pH 8, which induces desorption and separation of the whey proteins through the sieve in the bottom of the tank. An additional ultrafiltration step is needed for the removal of excess salts, upon which a lactose- and salt-free whey protein isolate is achieved.
Another ion exchange method for the production of whey protein isolates is performed in columns according to a fixed-bed process (18F). Porous silica particles having positively charged Quaternary Methyl Ammonium (QMA) functional groups bind the negatively charged proteins at pH 6.5. Desorption of whey proteins takes place at pH 4.0, immediately followed by evaporation and the spray drying of the resulting protein solution.

5.2 Demineralization of whey

The salts in whey have a significant effect on its taste, and may hamper the use of whey in food products. In delactosed whey (so-called mother liquor) the lactose content has been reduced to 50% and the protein content increased from 13 to 28%, but the mineral content has also been increased to about 20% on total solids. This makes the taste of mother liquor still more unfavourable for applications in human food, a problem that may be solved by desalting. Demineralization of whey or mother liquor may be realized by using ionic exchange, as shown in figure 18C. The whey or mother liquor first enters a strong cation exchanger, loaded with a resin in the H^+-form. An exchange of cations from whey with the H^+-ions from the column causes a pH reduction in whey down to pH 1.5. This acid whey continues to the basic anion exchanger where the anions are exchanged with OH^--ions, causing an increase of the pH. The columns are regenerated with HCl (for cation exchanger) and NaOH (for anion exchanger), when the pH of the whey (leaving the anion exchanger)

increases above pH 8. Ionic exchange processes have the capability to demineralize the whey by up to 90%. Whey is, however, a liquid with a high mineral load and the chemicals required for regeneration after ionic exchange even doubles that load in the waste. It is expensive to get rid of the mineral waste, which limits the use of ion exchange. Electrodialysis is a cheaper and more current demineralization process for whey. Figure 19 shows a schematic picture of an electrodialysis unit, consisting of a number of compartments separated by alternate cation and anion membranes at mutual distances of about 1 mm. Negative ions can pass through a (positively charged) anion membrane, but are stopped by a (negatively charged) cation membrane, as indicated by the red arrows. Conversely positive ions can pass through a cation membrane but not through an anion membrane. Direct current electrodes are placed in the end compartments, indicated in figure 19 as anode and cathode.

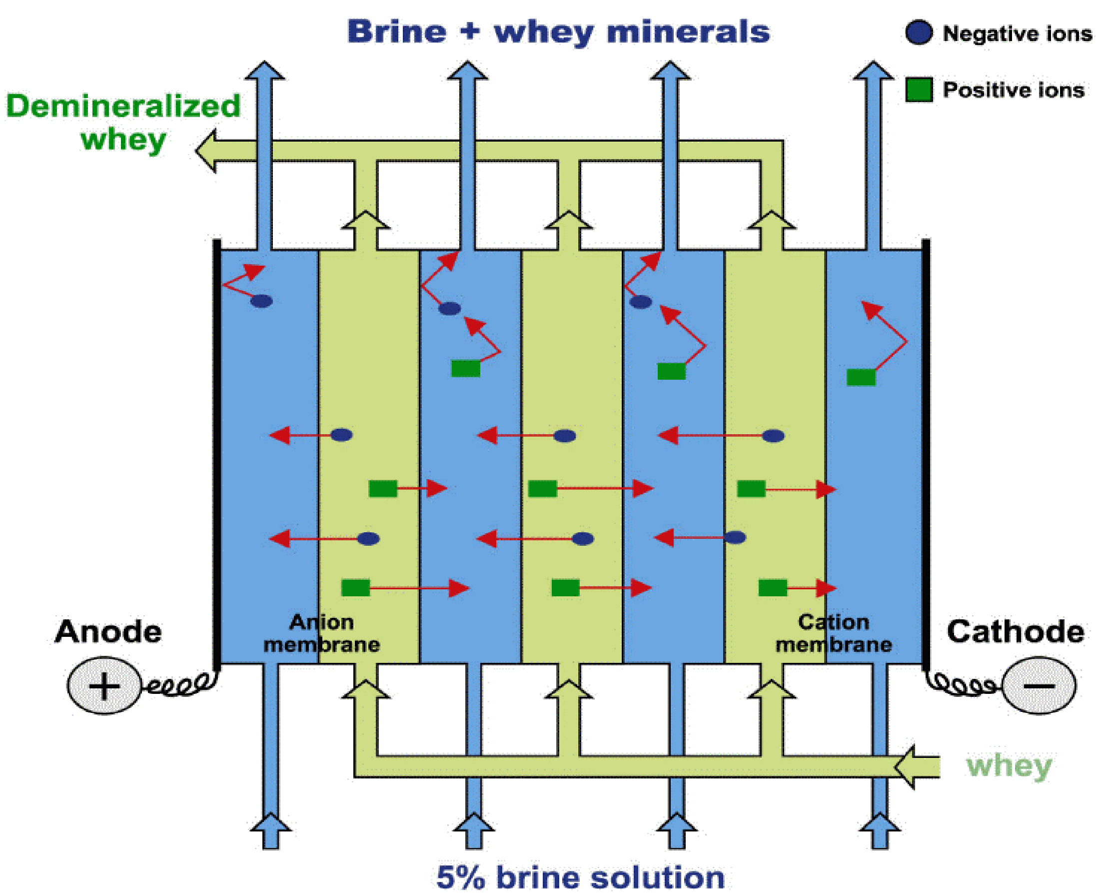


Figure 19. *Principle of demineralization through electrodialysis. Author Dr. J.N. de Wit*

Whey is circulated through the dilution cells (indicated in green), and whey salts are carried off through a 5% brine solution in the concentration cells (indicated in blue). When a direct current is applied across the cells, cations attempt to migrate to the cathode and anions to the anode. However, completely free migration is not possible because the membranes act as barriers to ions of like charge. The net result is a depletion of free ions in the (green) whey cells.

Double charged cations such as Ca^{++}- and Mg^{++}-ions are mainly bound to the negatively charged whey proteins and phosphate ions and are only partially removed. So, the whey demineralized by electrodialysis (ED) contains more calcium, magnesium and phosphorus than whey demineralized by ion exchange (IE), as shown in table 3. The composition of ED-demineralized dried mother liquor resembles that of skimmed milk powder (SMP) in its main components.

Table 3. ***Composition of various types of cheese whey powders (WP) and skim milk powder (SMP) for comparison***

Constituents (weight %)	**WP**	**Demineralized WP**		**Demin. Delactozed WP**		**SMP**
		(ED)	**(IE)**	**(ED)**	**(IE)**	
Lactose	73	77	80	47	47	49
Total Proteins	13	14.5	13	38	45	37
Lipids	1	1	1	1.5	2	1
Minerals (ash)	8	4.5	1	8.5	2.5	8
Moisture	3	3	3	4	3	4
Calcium	0.6	0.5	0.05	0.5	0.2	1.2
Magnesium	0.2	0.1	0.02	0.1	0.05	0.1
Phosphorus	0.6	0.5	0.15	0.5	0.4	0.9

Author Dr.J.N de Wit

5.3 Membrane filtration of whey

Well-known fractionation processes for the production of whey protein concentrates (WPC's) are based on membrane separation, which include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Separation takes place through semipermeable membranes, using a hydrostatic pressure gradient as the driving force. The separation mechanism is generally based on a sieving effect through thin filters of controlled pore size, as indicated in figure 20.

The dimensions of the solids in whey are categorized on different particle sizes according to their molecular weight, as indicated in figure 20. Membranes may possess additional separation characteristics when they are charged, which is important for the separation of ions of a particular charge.

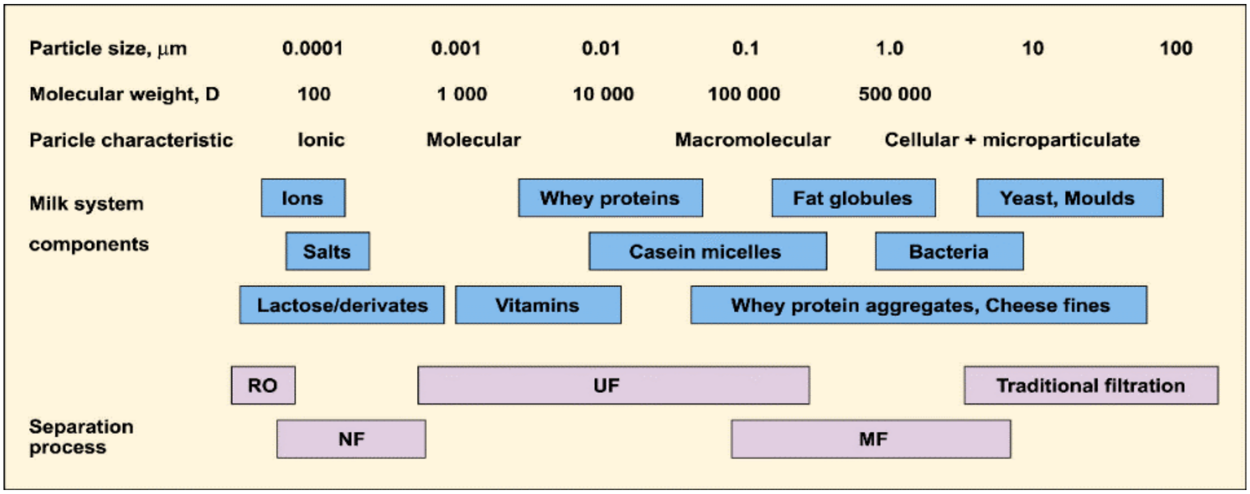


Figure 20. *Membrane processes applied for the separation of whey particles from different sizes. Adapted from reference 2.*

Microfiltration is used for the removal of bacteria and fat (globules) from whey, by using membranes with fairly wide pores (> 0.1 µm). Ultrafiltration is used for the separation of whey proteins, and these membranes are usually characterized by separation capabilities on molecular weight (usually indicated as “cut-off”).

Nanofiltration is used to fractionate mixtures of smaller molecules, e.g. partial demineralization of whey products. Nanofiltration can be applied as an alternative desalting process for electrodialysis. Reverse osmosis is applied to remove water against an osmotic pressure, and requires much higher pressures than the other membrane techniques. Reverse osmosis is not a filtration process, but a phenomenon that opposes osmosis. Reverse osmosis membranes act more as a layer of material in which only water can dissolve and pass by diffusion, while the other whey components cannot.

Membrane filters are sealed on a porous support in filtration modules of different configurations, such as plate and frame, tubular, spiral wound, and hollow fibre.

The plate and frame design consist of membranes sandwiched between membrane support plates which are arranged in stacks, identical to the heat exchanger shown in figure 4.

The tubular design, illustrated in figure 21, can be assembled to modules of many tubes in series. A tubular module can readily be converted from ultrafiltration to reverse osmosis by replaceable membrane insert tubes, fitted inside perforated stainless steel pressure supports. Ultrafiltration membranes used for the fractionation of whey proteins normally have a molecular weight cut-off in the range from 10,000 – 50,000 Dalton. Low molecular weight

solids such as lactose, minerals and water readily pass the membrane as permeate, and proteins and residual fat are rejected and stay inside as retentate. The practical limit for whey protein concentration is about 20 times, usually indicated as volume reduction of 95% of the whey.
Higher degrees of whey fractionation result in a too high viscosity of the retentate. Adding water during ultrafiltration to remove more salts and lactose in a process called “diafiltration” can solve this problem. The composition of a whey protein concentrate (WPC) depends on the properties of the membrane, the duration of the filtration process, and the use of water (diafiltration). With ultrafiltration it is possible to produce all types of WPC, with protein contents ranging from 25 to 80% on total solids.

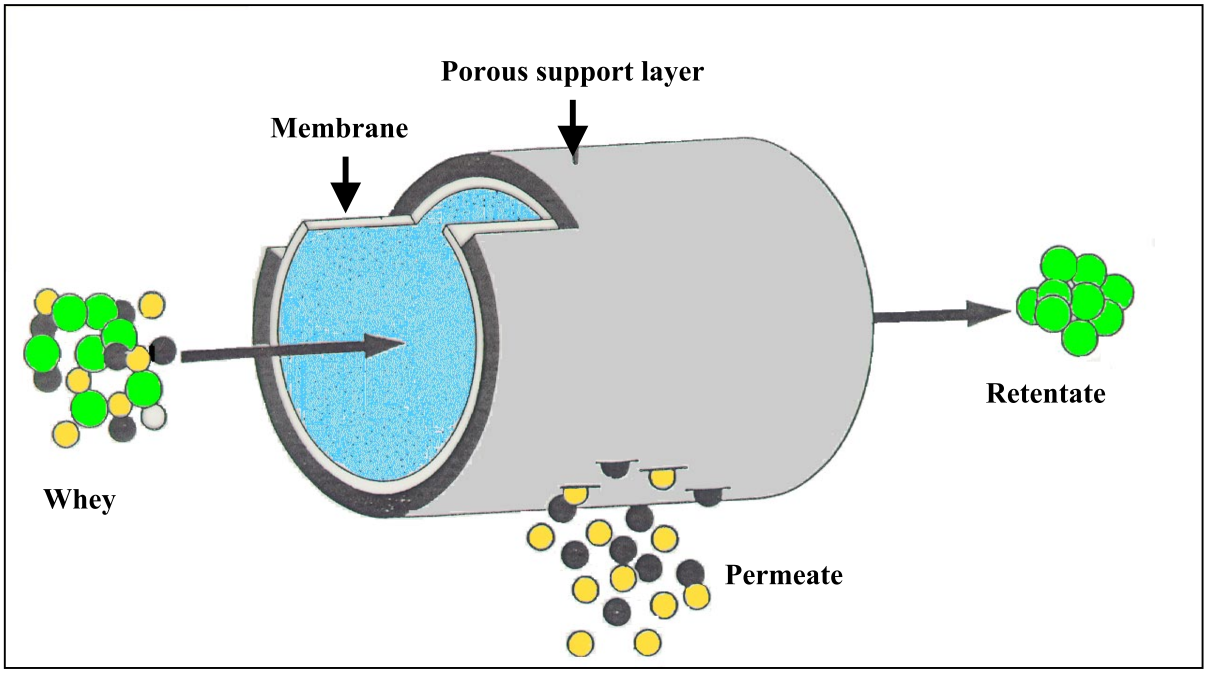


Figure 21. *Principle of a membrane filtration process from whey in a tubular module. Author Dr. J.N. de Wit*

Industrially produced WPC may be distinguished as: low protein WPC (typically between 25% and 45%), medium protein WPC (typically between 45% and 60%) and high protein WPC (typically between 60% and 80%). Whey protein isolates (WPI) are a separate catagory with a protein content of about 90%; they are prepared from defatted whey obtained by microfiltration (MF).. Table 4 shows the composition of some industrially produced WPC. Striking compositional differences are that the fat content increases markedly with the protein content and the contents of lactose and minerals are significantly decreased compared with whey powder.

Table 4. ***Composition of powders from permeate and UF-WPC's***

Component%	Permeate	WPC-35	WPC-60	WPC-80
Total Protein	3.3	36.2	63.0	81.0
True Protein	0	29.7	59.4	75.0
NPN	3.3	6.5	3.6	6.0
Lactose	81.3	46.5	21.1	3.5
Minerals (ash)	8.2	7.8	3.9	3.1
Lipids	0	2.1	5.6	7.2
Lactic acid	3.2	2.8	2.2	1.2
Moisture	4.0	4.6	4.2	4.0

Author Dr.J.N de Wit

The composition of WPC-35 corresponds to that of skim milk powder, just as demineralized delactosed whey. WPC-60 represents the ultimate product that can be obtained by ultrafiltration and WPC-80 represents about the limit of what can be produced by a combination of ultrafiltration and diafiltration of whey.

WPC-35 products are mainly used as replacers for skim milk. WPC-60 products may replace egg white in a number of bakery and confectionery applications, whereas WPC-80 products are well known for their specific properties in meat and fish products.

5.4 Chromatographic separation of whey proteins

The various whey proteins, mentioned in table 2, are often classified according to their charge, relative hydrophobicity (fear of water), and molecular weight (or size). In the 1970's column chromatography was introduced as a separation technique for proteins on an industrial scale. There are several useful methods in this category for the isolation of proteins from whey according to specific protein properties. Well-known are gel filtration chromatography based on differences in molecular sizes, ionic exchange chromatography on the basis of charge differences, and affinity chromatography as a technique using specificities in molecule-molecule interactions. **Gel filtration** is usually applied for the separation of whey proteins from other components in whey.

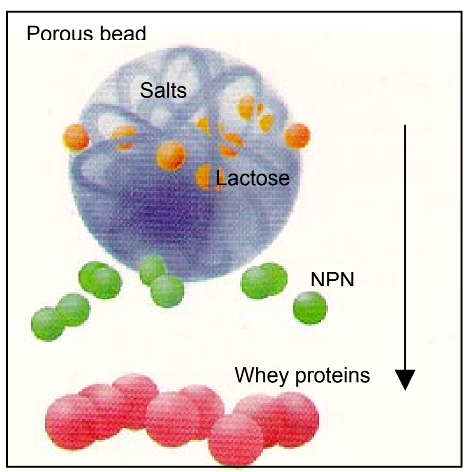


Figure 22 *Gel filtration of whey. Elution in order of decreasing molecular weight*

The principle is based on differences in the diffusion rate of molecules of different sizes through a column filled with porous resin beads. As whey passes through the column, the porous resin beads only allow small molecules such as salts, lactose and part of the NPN to enter their pores. The passage of these small constituents through the column is therefore delayed. The larger whey proteins cannot enter these beads and pass through the column at a higher rate, as illustrated in figure 22. Gel filtration is mainly used as a last purification step of defatted WPC.

In **ion exchange chromatography** (IEC), the whey protein molecules of interest carry a charge opposite to the resin particles from the ion exchanger, as described in chapter 5.1. IEC is an extremely useful technique for isolating specific whey proteins. Important parameters for controlling the binding of proteins and the beads of the IEC column are the pH of the whey, the protein's net charge and the binding capacity of the beads. Variation of these parameters enables the selective elution of proteins. Elution of bound proteins from the beads is achieved by using a salt solution of increasing concentration.

An example is the isolation of lactoferrin (LF) and lactoperoxidase (LP) from whey (or milk) after a microfiltration step to remove fat and other particles. Both LF and LP are positively charged proteins at the normal pH (6.5) of sweet whey, while the rest of the whey proteins are negatively charged at this pH. The LF and LP molecules thus bind to negatively charged beads of the IE column. Salt solutions of different concentration are used for elution of LF and LP from the beads. Both proteins may be recovered separately in different eluates, and further processing by ultrafiltration and diafiltration yields products of about 95% purity. Finally, the products are sterilized by microfiltration (0.1 – 0.2 µm pores) and spray dried.

Affinity chromatography is a separation technique based on specific reversible interactions between two biologically active substances such as antigen affinity for an antibody. One of the active substances is coupled to the matrix with minimal modification of its structure, which is essential for binding. Almost all affinity chromatography systems involve a covalent (chemical) bond between ligand and matrix (usually sepharose beads). The ligand binds specifically the protein to be isolated from a crude mixture loaded on the column, as shown in figure 23.

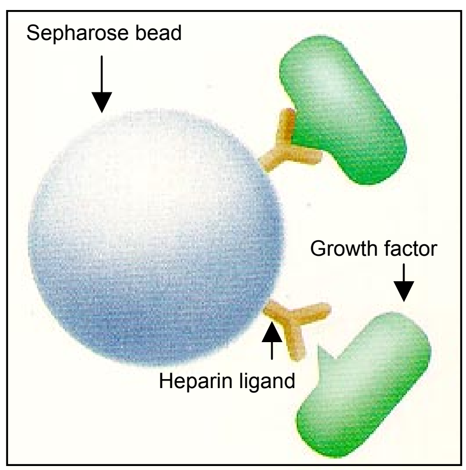


Figure 23. *Affinity chromatography for isolation of growth factors from whey*

The retained molecules can be desorbed with buffer, which modifies the recognition site. Affinity chromatography is used for the isolation of growth factors from whey, indicated in figure 12).
The following procedure has been developed to isolate the cell growth promoting factor from cheese whey. As the first step pasteurized whey is passed through a 0.8-µm microfilter to remove fat and small particles. Subsequently the whey has to be loaded on a cation-IEX chromatography column to remove major whey proteins at pH 6.5. The eluated protein solution from this column was loaded on the heparin-affinity column and after that the column was eluted with a solution of 1–2 molar solution of ammonium bicarbonate. The final yield was 0.1-mg growth factor from 1,000 kg of cheese whey, equivalent to 100-nanograms/kg whey.

5.5 Recovery of lactose from whey

Lactose is the main component of whey and is recovered by crystallization from sweet and/or acid whey. There are two basic methods for the recovery of lactose, depending on the composition of the source: 1) Crystallization in concentrated whey, and 2) crystallization in concentrated deproteinated whey (e.g. ultrafiltation permeate from whey).
Figure 25 shows a flow sheet for the production of lactose from sweet cheese whey. The whey is pasteurized and concentrated by evaporation to 60 – 65% total solids, after removal of whey cream and casein fines as described in section 2.2.2. The concentrated whey is then transferred to crystallization tanks at a temperature of about 50°C. The concentrate is, during gentle stirring, subjected to a predetermined time/temperature programme for cooling down to 10°C. The concentration of lactose in the concentrated whey amounts to 40-45%, while its solubility decreases from 17.5% at 50°C to about 6% at 10°C. Because of supersaturating the lactose will crystallize mainly to so-called α-monohydrate lactose crystals, containing one molecule of crystallization water. Adding lactose seed crystals accelerates this crystallization process. After crystallization, the slurry proceeds to a decanter centrifuge for separation of the crystals, indicated (1) in figure 24. The horizontal conical cylinder with a central rotating screw conveyor   separates and unloades the delactozed liquid at (2) and the crystal mass at (3). The delactozed whey is protein-enriched and may be applied as animal feed, or after demineralization, as a skim milk replacer in food products, which will be discussed in chapter 7.

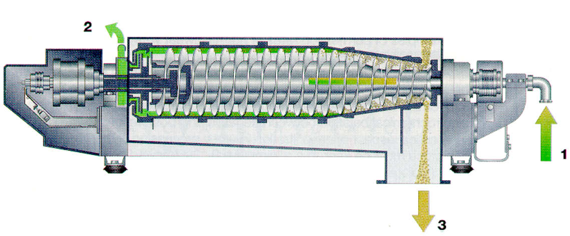


Figure 24. *Decanter centrifuge. From reference 2*

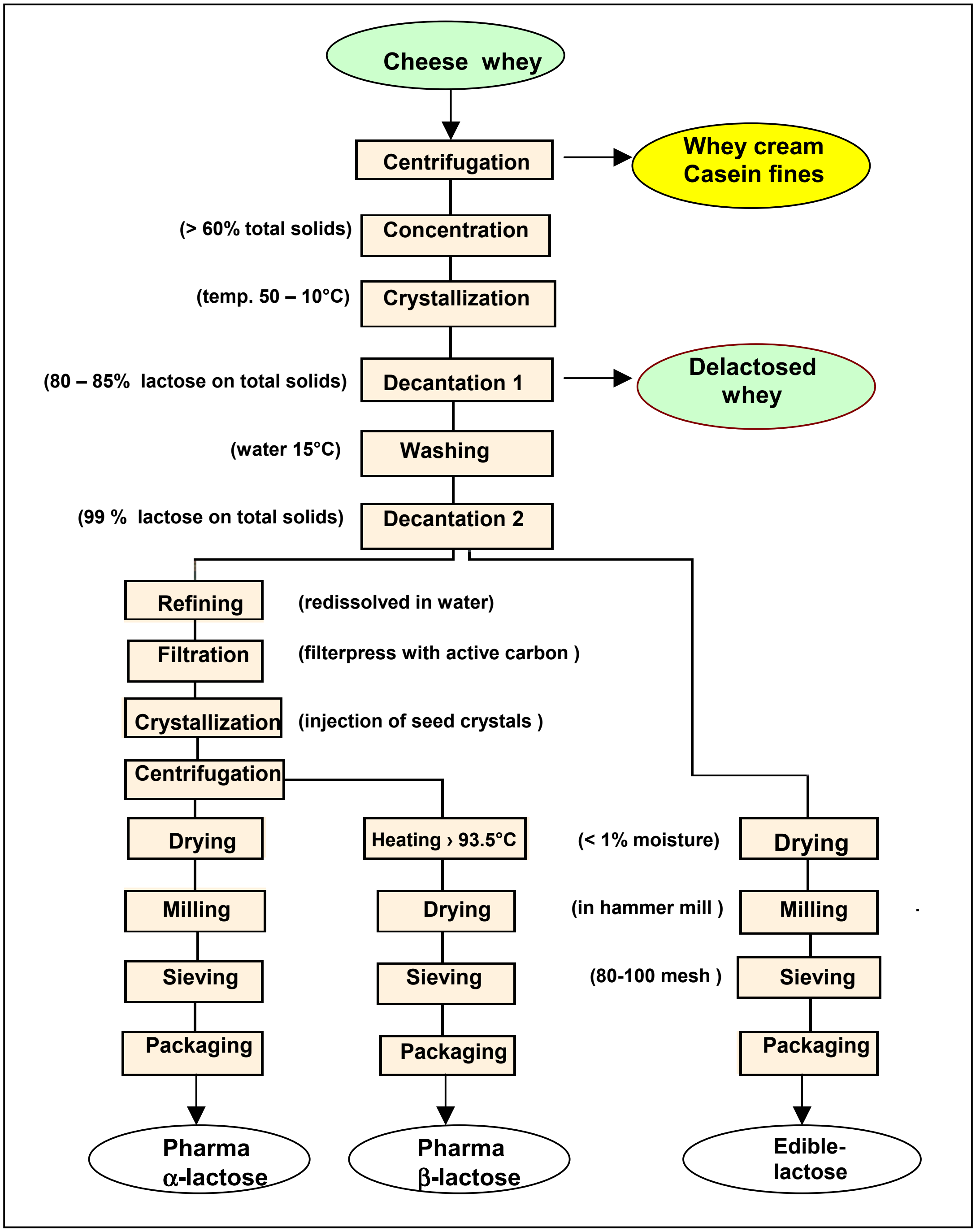


Figure 25. *Flow sheet for the recovery of lactose from sweet cheese whey. Author Dr. J.N. de Wit*

The lactose crystals are subsequently reprocessed by washing in a second more efficient (decanter) separation, which increases the lactose content from 80 to 99% on total solids; a product known as edible lactose. The moisture content after the second decantation stage is already less than 9%, and will be reduced to less than 0.5% moisture after spray-drying. The temperature of the product in the dryer should not exceed 93.5°C, because at higher temperatures anhydrous β-lactose crystals are formed. Drying takes place in a fluid bed dryer, as shown in figure 17. After drying, the lactose is usually ground and sieved to the desired particle dimensions before packing. Edible lactose is used in the food industry, e.g. as ingredients in substitutes for human milk.
A higher degree of purity is required for pharmaceutical applications, which requires an additional refining process. For this purpose the edible quality lactose mass is redissolved in hot water to a concentration of 50%. Active carbon, phosphate, and filtration agents are added, and the solution is pumped through a filter press. A second crystallization process is then induced in crystallization tanks. The refined lactose is subsequently separated by a decanter centrifuge and dried as described for edible lactose. The purity of pharma-lactose is at least 99.8% and may be modified for specific applications related to crystal size and crystal structure. A heat treatment of lactose above 93.5°C before drying results in water-free β-lactose crystals with specific binding properties. The α-lactose monohydrate crystals are observed in a variety of shapes, depending on the conditions of crystallization. If the crystallization proceeds rapidly, only prisms are formed. At lower crystallization rates, the dominant form changes to pyramids and tomahawk shaped crystals with beautiful colours in polarized light. Very hygroscopic lactose, called amorphous lactose, is obtained when e.g. concentrated whey is dried without prior crystallization. Another important functional property of pharma-lactose is determined by the particle size, which may be adjusted by grinding and sieving the dried product.

5.6 Recovery of milk salts from whey

Table salt (NaCl) is one of the most used additives in food products either as preservative or as an enhancer of taste. Although Na^+- and Cl^--ions are essential constituents of all forms of human life; the average salt intake is estimated to be about 20 times the required daily need. One of the risk factors of a high sodium intake is hypertension (too high blood pressure). In response to current health concerns about the overconsumption of sodium, food processors are looking for salts with a reduced sodium content to replace table salt. One of the options is to fractionate milk salts from whey in their natural (physiological) composition, which reveal a high (soluble) calcium concentration as an additional nutritional benefit. Moreover it appeares that fractionated whey salts provide the same salt-sensation as table salt does.

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One of the sources for milk salt production is delactozed whey; a by-product from the production of lactose as described in section 5.5. The delactozed whey is fractionated by ultrafiltration resulting in WPC and delactosed permeate. The permeate is concentrated by evaporation of up to 65% upon which the lactose after crystallization is removed as described in section 5.5. The supernatant thus obtained has, after drying, a composition as shown in table 5. This milk salt preparaton has a salty taste, in spite of the presence of 50% lactose. The salty taste appears to be caused by the presence of sodium and potassium salts. The ratio of sodium to potassium is about 1:3, which is the ratio in milk. The ratio in extra- and intracellular fluids of the body is estimated at 2:3, which allows some more sodium in the diet. The calcium salts are soluble and in mainly bio-available complexes, e.g. associated with some non-protein nitrogen (NPN) compounds. Maillard reactions between lactose and NPN fractions during the concentration and drying of this milk salt provides additional flavour notes.
The use of these salts supports the desired browning effect in bakery products.

Table 5. ***Composition of a milk salt preparation (%)***

Lactose	50.6
Non protein nitrogen	13.6
Potassium	2.0
Sodium	3.7
Calcium	0.5
Magnesium	0.3
Chloride	9.0
Phosphate	2.2
Nitrate	0.3
Zinc	0.3
Copper	0.03
Remaining salts	1.0
Riboflavin (Vit. B_2)	3.0
Water	3.5

Author Dr.J.N de Wit

Recently milk calcium powders containing 17 to 25% calcium have been introduced into the market. These nutrients, prepared according to proprietary technologies, are applied in food products requiring an increase of the natural calcium content for nutritional purposes.

Additional information in References 1 and 2

6. STRUCTURE AND FUNCTIONALITY OF WHEY PROTEINS

Before starting the discussion on applications of the various whey ingredients, some background information on structure and functionality of whey proteins may be helpful. Structure and physical properties of the major whey proteins have been studied more extensively than any other food protein, and much attention has been paid to relate this information to functional properties of whey protein products. The notion functional properties is often used in relation to physico-chemical properties of proteins in aqueous solutions or in simple model systems. The functional behaviour of whey proteins in food products, however, is much more complicated, as schematically shown in figure 26.
The native whey proteins, as designed by the cow (indicated at the top of figure 26), reflect a number of functional properties in aqueous solutions (mentioned in the middle), which are modified during during food processing to the desired protein functionality (indicated at the bottom). In this sequence the functional properties are the result of intrinsic properties of native whey proteins, and a number of extrinsic factors.

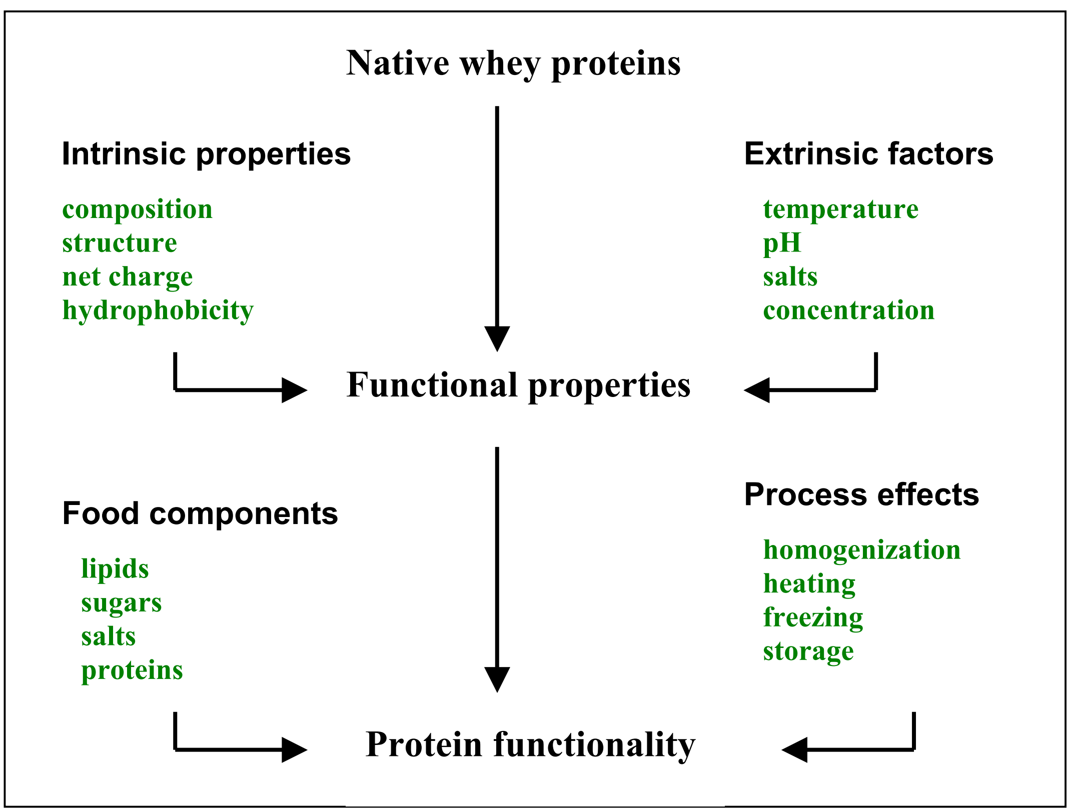

Figure 26. *Factors and driving forces involved in achieving functional properties and functionality of whey proteins. Author Dr. J.N. de Wit.*

6.1 Intrinsic and extrinsic properties of whey proteins

Intrinsic properties such as amino acid composition, amino acid sequence, conformation, molecular size, flexibility, net charge and hydrophobicity of protein molecules determine the folding structure of whey proteins. Two levels of the folding structure are distinguished, known as secondary and tertiary structure.
Figure 27 shows schematically the three dimensional structure of β-lactoglobulin; the most dominant whey protein.

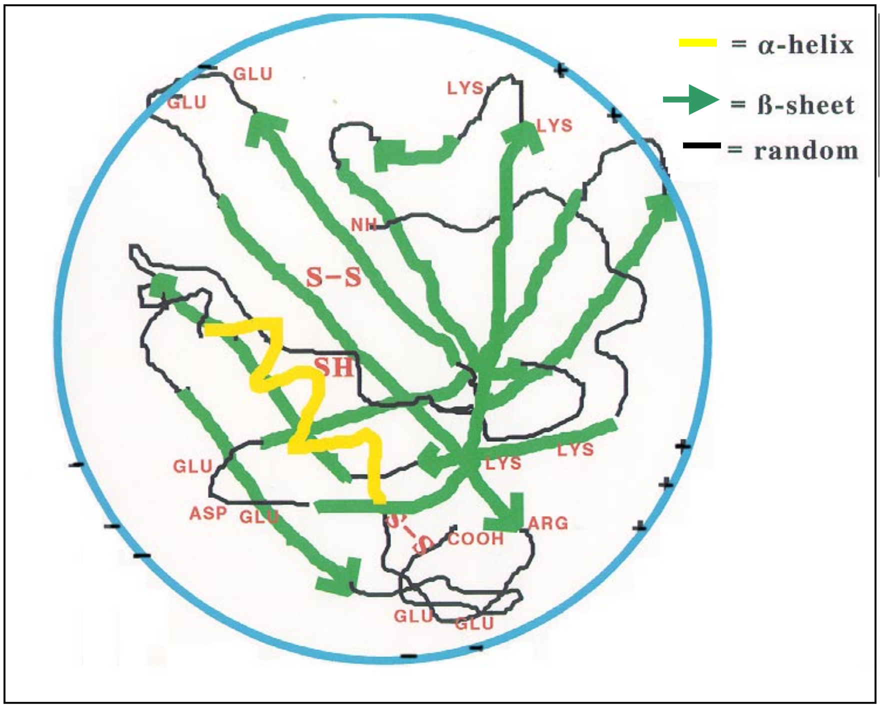

Figure 27. *3-Dimensional structure of β-lactoglobulin at 0.28 nm resolution*
Author Dr. J.N. de Wit

The secondary structures involve a spiral wound (helix) chain indicated in yellow and so-called β-sheets shown as green arrows, structured as revealed in figure 13. The black line indicates unordered (random) structures within a tertiairy folded (globular) molecule. Both the secondary and tertiary structures keep most of the hydrophobic amino acids inside, and the polair (and charged) residues mainly at the surface of the molecule.
Two covalent disulphide bridges within the amino acid chain stabilize the thus obtained globular structure of the β-lactoglobulin molecule. The molecular structure of the other whey proteins may differ somewhat, depending on their amino acid composition and sequence. The presence of polar and charged groups at the surface,

and the shielding of apolar amino acids from water inside the molecule explains the good solubility of native whey proteins in aqueous solutions.
The solubility and related functional properties of whey proteins are largely determined by a number of extrinsic factors during their recovery and processing. Knowledge of the relationship between intrinsic protein properties and extrinsic factors such as temperature, pH, salts and protein concentration is critically important for elucidating and controlling the functional properties.
Most whey proteins unfold at temperatures above 70°C and then start to aggregate depending on pH, salt and protein concentration. During heat treatment the disulphide bridges may be rearranged by the thiol (SH) group present in ß-lactoglobulin. This so-called denaturation process significantly impairs the solubility and related functional properties of whey proteins. Heat denaturation and aggregation of whey proteins is facilitated by the presence of calcium ions in the neutral pH range, leading to insoluble less functional whey protein products.

6.2 Whey protein functionality in food products

Functional properties as solublity, foaming, emulsifying, and gelation properties of whey proteins inform us primarily on the process history and composition of the whey protein product involved. These properties, often determined in aqueous solutions, are not directly related to those in food systems. The desired performance of whey proteins in food products is another characteristic, which may be defined as as protein functionality. This characteristic reflects the manner in which proteins interact with the components of a food product such as lipids, sugars, salts and also other proteins, as indicated in figure 26. These interactions are governed by effects of processing, such as homogenization, heating, freezing and conditions during storage. Thus nearly each application requires specific functional attributes to obtain the desired performance, and this is usually achieved by trial and error. Studies are on going to improve the predicting value of functional properties, which should result in solid relations between the various factors and effects shown in figure 26. Typical functional properties related to their mode of action, relevant for some food systems, are summarized in table 6. Various characteristics may be relevant for the different food products. In a beverage, for example, solubility under appropiate conditions is a primary requisite. Native whey proteins are highly soluble in a pH range from 3 to 8, which is an important property for beverage. In meat products , a number of functional properties are required of which water and fat holding and the ability to gel during heating are the most important attributes. In soups and gravies, whey proteins should have heat-induced thickening and stabilizing properties. Liquid infant formula require thermostable emulsifying

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properties and sufficient emulsion stability during storage. Formulated foods often require support in binding and release of desired flavours under appropriate conditions. Whey proteins may support the binding of bioavailable minerals such as calcium, zinc and iron which is important for nutritional purposes.

Table 6. Typical functional properties in food systems

Functional property	Mode of action	Food System
Solubility	Dissolvable	Beverages
Water absorption	Water-binding	Meat/Bakery
Viscosity	Thickening	Soups/Gravy
Gelation	Structure-forming	Meat/Fish
Emulsion properties	Emulsifying	Infant formula
Fat absorption	Binding free fat	Sausages
Foaming properties	Aeration	Whipped topping
Flavour binding	Binding/Release	Formulated foods
Mineral binding	Specific adsorption	Nutritional foods

Author Dr.J.N de Wit

The background information given in this chapter provides some guidance in product development. However, still trial and error work in laboratory and pilot plant has to be carried out to obtain the desired end product.

Additional information in Reference 20

7. Applications of whey products

In the past whey has been regarded as a cure for many illnesses, and was used in thermal baths or as a medicine in cure centres. The unbalanced composition of whey solids limited the application of whey and whey powder in human food products. In particular the dominant presence of lactose (72%) and minerals (8%) were difficulties which had to be overcome for application of whey in food products. The increasing production of whey and whey powder stimulated, their use as nutritional supplements for animal feed, particularly as a cheap replacer for skim milk powder. The introduction of fractionation and isolation techniques for whey components further increased the application possibilities in food products, as shown in the specifications in chapter 10.3.

Nowadays, potential uses for whey components either as functional or as nutritional supplements in food products are numerous, an arbitrary selection of them are summarized in figure 28.

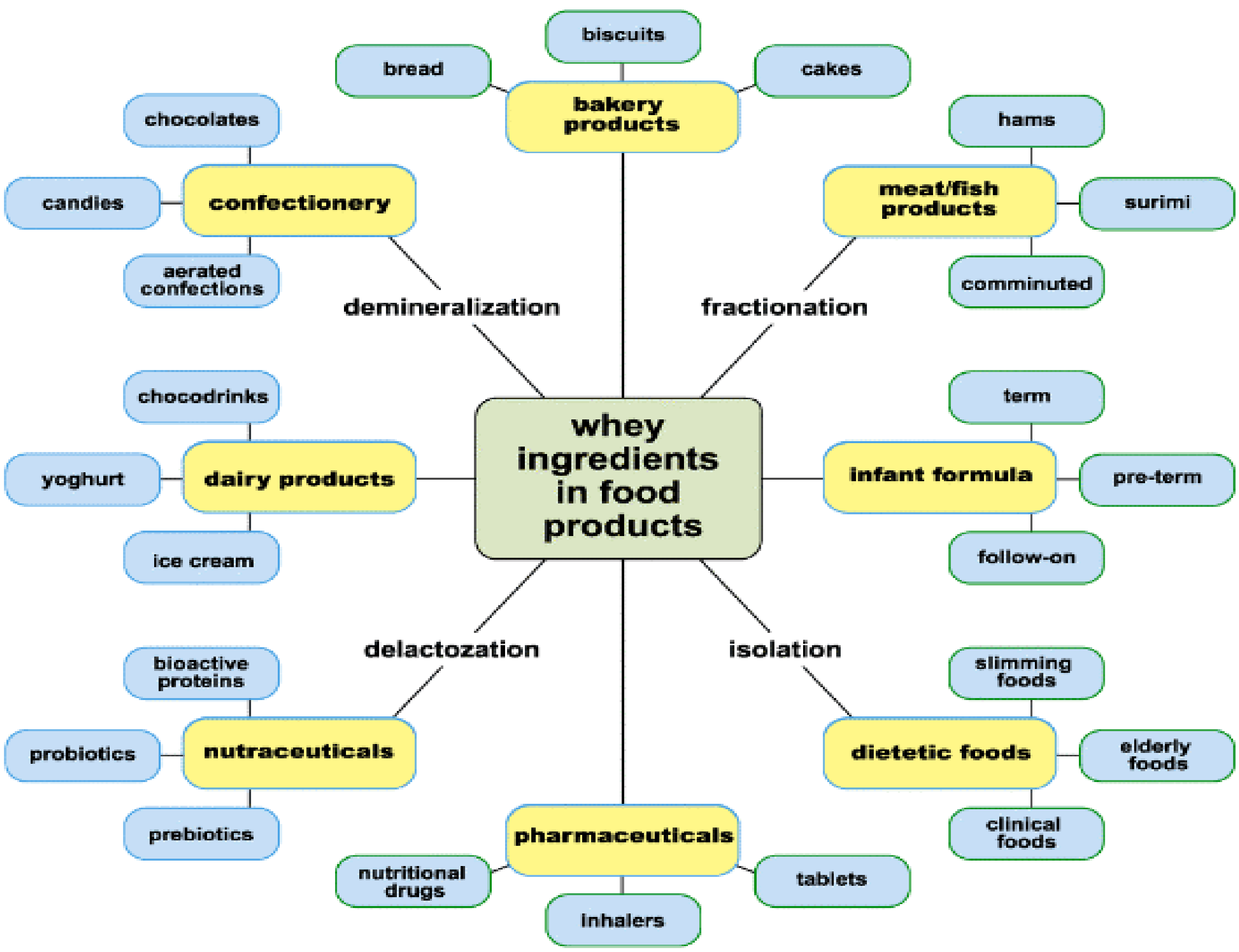


Figure 28. *Recovery procedures and utilization of whey ingredients in food products. Author Dr. J.N. de Wit*

Applications in confectionery and bakery products are important outlets for whey and whey products in human foods. Lactose, the major component of whey, contributes to colour and flavour in these products. Whey and whey-based products have been found to improve the flavour, aroma, colour, texture and (in some cases) also the shelf life of bakery products. The use of demineralized whey is preferred, because of its blander taste, which is required for most applications in dairy and food products. Fractionation of whey by using membrane processes, as discussed in section 5.3, results in whey protein-enriched concentrates, which are well-known functional ingredients in bakery, meat and fish products. Particularly, the heat sensitivity of whey proteins is an important functional attribute, which contributes to the structure of many food products during heat treatments.
Demineralized delactosed whey is often called "skim milk equivalent", because its composition shows much resemblance with that of skimmed milk, as shown in table 3. Demineralized delactosed whey is an important ingredient in infant formula. The lactose recovered from whey is also an important ingredient in the composition of infant formula, and this sugar is also used in pharmaceutical products.
The high nutritional quality of whey proteins and the presence of specific growth factors make whey an important source for infant formula and elderly foods. Highly nutritional minor components may be isolated from whey by using column chromatography, as discussed in section 5.4. These isolates are used as bioactive proteins and nutrients (usually indicated as prebiotics) for probiotic bacteria cultures. Probiotic bacteria are used in health foods such as some yoghurt products. The application possibilities mentioned in figure 28 will be discussed successively in the next sections.

7.1 Dairy products

WPC can be applied in a comprehensive range of dairy products. In this section three are of them are discussed, which does not mean that others like cheese products are of less interest.

7.1.1 Ice cream

The creation of ice cream probably originates from China, where mixing snow with fruits and fruit juices is still an ancient culinary practice. Iced desserts were probably introduced in Europe by Marco Polo, when he returned to Italy in 1295 after a 17 year stay in China. The name ice cream comprises a number of related products, which primarily differ in the relative quantities of ingredients rather than in manufacturing technology. Ice cream can be divided into four main categories according to the ingredients used:

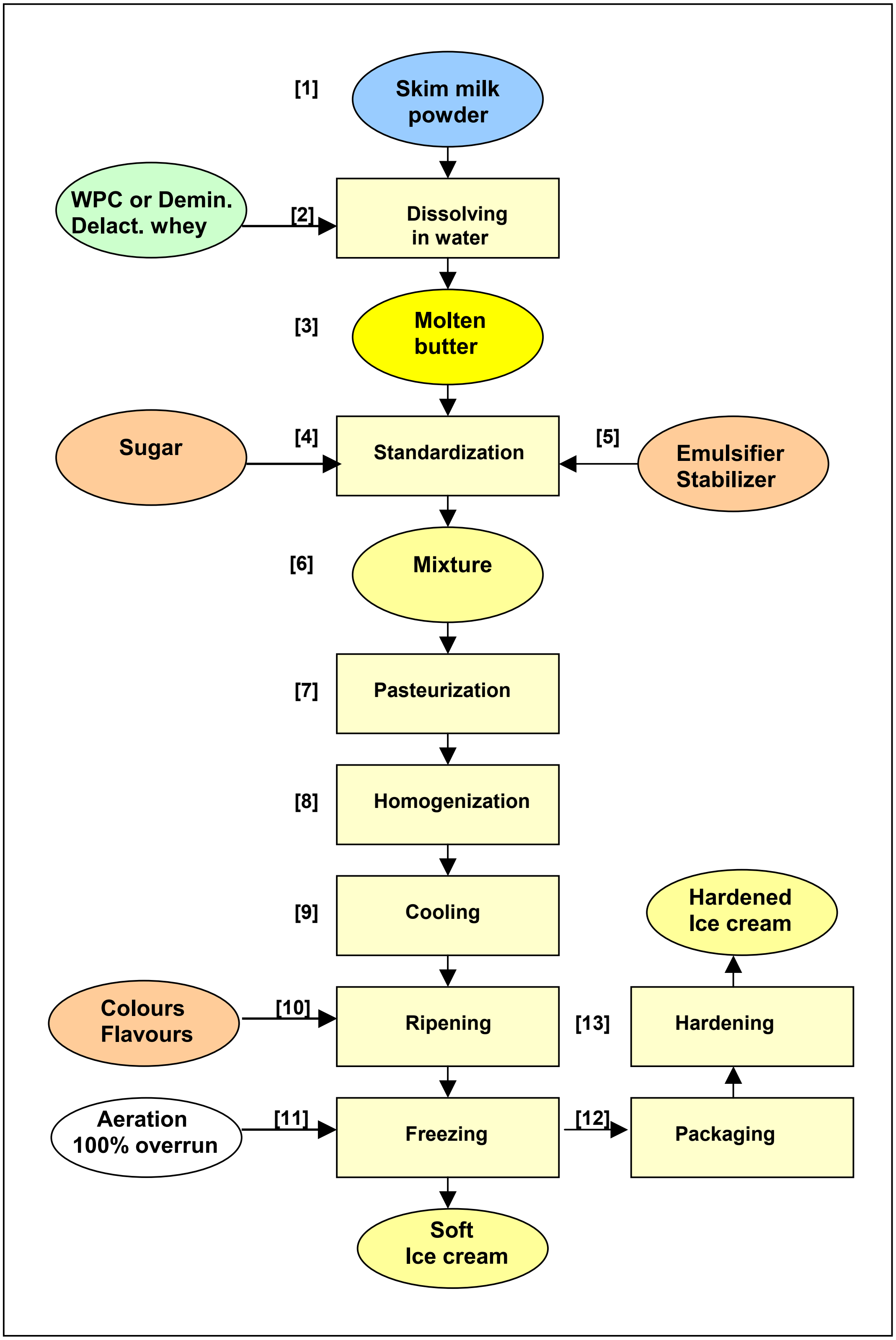


Figure 29. *Flow sheet for the manufacture of ice cream*
Author Dr. J.N. de Wit

1) dairy ice cream made exclusively from milk products, 2) ice cream containing vegetable fat, 3) sherbet ice cream made from fruit juice with added milk fat and milk solids-non-fat, and 4) sorbet or water ice made of water, sugar and fruit concentrate. The first two types of ice cream account for 80 – 90% of the total world production.

A typical manufacturing procedure is shown in figure 29. Medium heat milk powder [**1**], obtained from high temperature pasteurized (e.g. 1 min at 85°C) skim milk, concentrated and dried (as described earlier) forms the basis. A recipe for dairy ice cream may contain per 100 kg ice cream mix, 11 kg skim milk powder, of which 25 to 50% is replaced by WPC or demineralized delactosed whey powder [**2**]. Demineralized whey powder may also be replaced by demineralized delactosed whey powder or WPC-35. After some hydration time the dispersion is heated up to 40°C and mixed with 12.5 kg butter [**3**], which provides body and mouthfeel of the ice cream. The mix is completed by adding 13.6 kg sugar [**4**] for sweetness and 0.5 kg emulsifier and stabilizer [**5**] for improving the emulsifying and whipping qualities of the ice cream. The mixture [**6**] is subsequently heated up to 82°C in the pasteurizer [**7**] and homogenized [**8**] in two steps: first 15 Mega Pascal (MPa) to disperse the butterfat into small globules and next at 3 MPa to reduce the viscosity. Then the dispersion is returned to the pasteurizer in a similar route as illustrated in figure 6, and cooled down to 2-4 °C in the cooler [**9**]. At this temperature colouring and flavouring agents are added to give the ice cream its attractive appearance and flavour. Subsequently the mix is ripened or aged ideally for 12 hours [**10**] for crystallization of fat within the small fat globules. After ripening the mix is frozen [**11**] while air is beaten in to a volume increase of about 100%. During this stage the water is frozen to very small ice crystals. The ice cream leaves the freezer at a temperature of -5°C for consumption as soft ice cream. When the ice cream is stored or shaped in cups, cones or containers, packing [**12**] is required. For hardening [**13**], the packed ice cream can be passed through a tunnel in which air of -40°C is blown along the product for about 20 minutes. After that the ice cream is usually stored at -20°C.

7.1.2 Yoghurt

The word "yoghurt" is derived from the Turkish word "jugurt", which was a traditional food and beverage in the Balkan countries. Yoghurt is an acidified milk product obtained by fermentation of milk through 2 types of lactic acid bacteria, which generate a pleasant taste and flavour. Originally yoghurt was produced as in Bulgaria by inoculation of concentrated milk, obtained by evaporation through boiling the milk to 2/3 of its volume. Yoghurt from the previous day was usually taken for inoculation of the new milk concentrate. Subsequent incubation overnight at room temperature resulted in a firm gelled product that played an

important role in the diets of East European communities. This product from concentrated milk has become well known in Western Europe under the name: “Bulgarian yoghurt”. Nowadays yoghurt is produced with selected cultures of lactic acid bacteria strains, indicated as *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus* growing “in concert”. The percentage of inoculation depends on the use of a ready set (concentrated) culture or a bulk culture. In bulk cultures the inocculation percentage is higher e.g. up to 2.5%.

The industrial manufacture of yoghurt has resulted in different product types according to composition, type of cultures, method of production, and flavours or additives. The main types produced are set yoghurt, stirred yoghurt and drinking yoghurt. Set yoghurt is a continuous semi-solid mass obtained by fermentation and coagulation of milk in retail containers. Stirred yoghurt is a viscous milk product obtained when the solid mass is produced in bulk and the gel structure is broken before cooling and packaging. Drinking yoghurt may be considered as a stirred yoghurt of low viscosity. Within the drinking yoghurts one may distinguish fresh and long life products. In long life drinking yoghurts, the bacteria are inactivated by pasteurization for storage at room temperature. Addition of hydrocolloids is then required for maintaining sufficient stability of this low viscosity product.

A flow sheet of the industrial production of various types of yoghurt is shown in figure 30. Yoghurt may be made from the milk of any species, mostly cow’s milk, but milks from sheep and goats are also well known sources. High demands are put on the microbial and hygienic quality of the fresh milk used, as well as the absence of antibiotics and other growth inhibiting substances. The fat content of the milk is standardized between 0.5% (skimmed yoghurt) and 3% (full cream yoghurt). An increase in the milk solids non-fat content will result in a firmer yoghurt structure. This is usually achieved by adding skim milk powder, but also when stabilizers such as gelatine, sodium caseinate or whey protein products are used. A higher proportion of whey proteins in milk results in yoghurt having a smooth and more pleasant texture and a higher nutritional quality. In some European countries it is allowed to replace up to 20% of the yoghurt milk by WPC-35; a whey protein product having a composition similar to skim milk powder, as discussed in section 5.3. The main difference between these products is that the protein part in WPC-35 comprises whey proteins, while the protein part in skim milk powder contains 80% casein micelles.

Drawbacks of the use of whey proteins are the reduced prevention of serum separation during the storage of yoghurt compared to gelatine and caseinate. Moreover whey proteins may mask the typical yoghurt flavour, a phenomenon which is not observed in

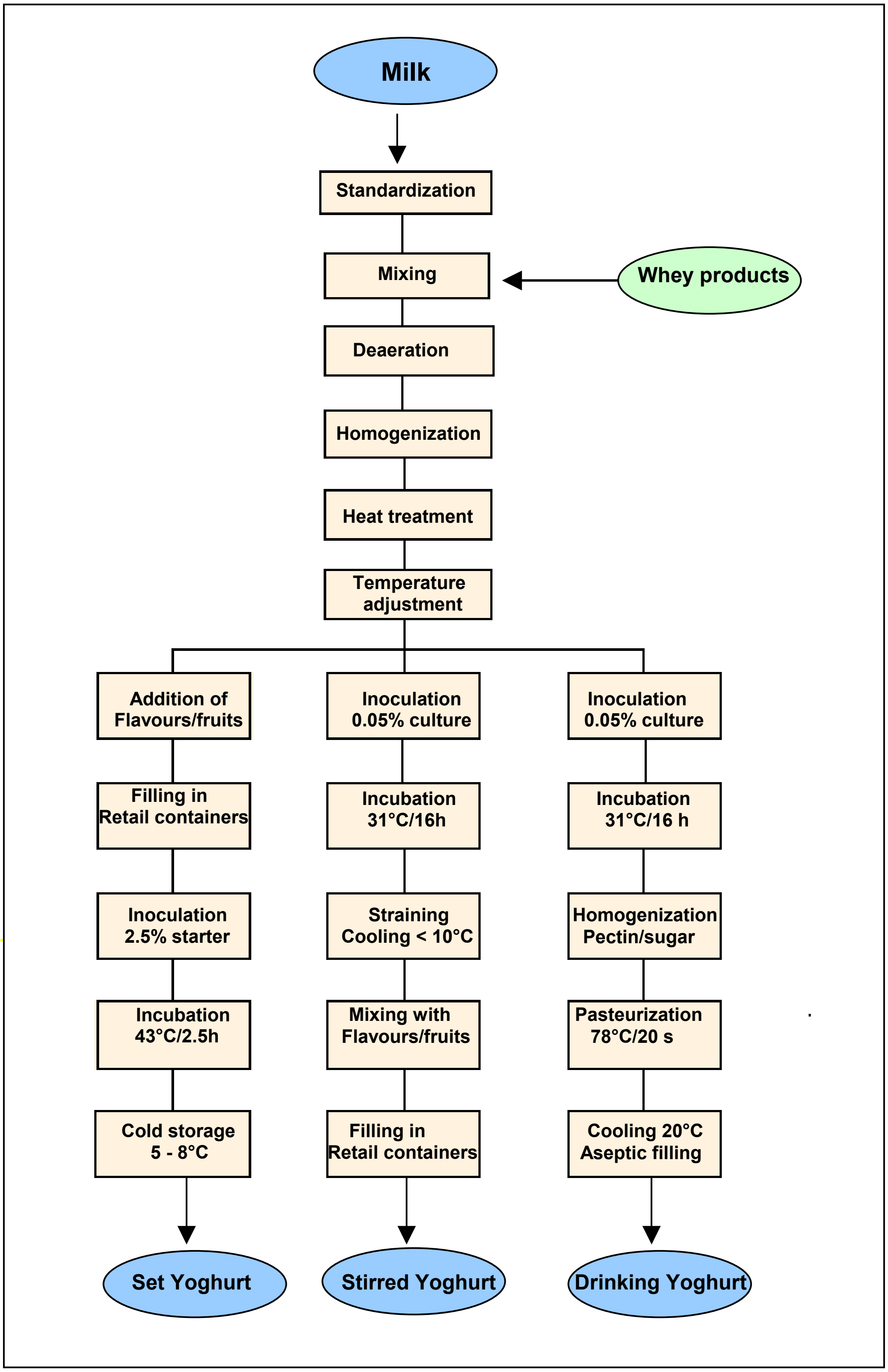


Figure 30. *Flow sheet for the production of different types of yoghurt. Author Dr. J.N. de Wit*

flavoured and fruit yoghurts. The water binding properties of WPC-35 (to prevent serum separation) may be significantly improved by the use of thermally modified whey proteins. This is achieved by the heat treatment of whey under slightly alkaline conditions resulting in denatured whey proteins that keep their solubility.
After the addition of WPC (or one of the other stabilizers), the yoghurt milk is deaerated to reduce its air content. This is important for the growth and symbiosis of the two mentioned lactic acid bacteria strains of the yoghurt culture. Homogenisation is an integral part of the yoghurt manufacturing process, which splits the fat globules into smaller ones, coated with a new membrane largely composed of casein and whey proteins. The best results are achieved at homogenization pressures around 20 MPa and temperatures between 60° and 70°C. The milk is subsequently heat treated during 5 minutes at 90 – 95 °C both to improve the properties of milk for the yoghurt starter, and to ensure a firm structure of the finished product with less risk of serum separation.
At this stage the manufacture of set yoghurt, stirred yoghurt and drinking yoghurt diverge as shown in figure 30. The culture used for the yoghurt does not differ and usually comprises a 1:1 ratio of *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus*. From these organisms, growing "in concert", the Streptococcus produces acid and the Lactobacillus forms aroma components.
The final stage of incubation is achieved when the pH is reduced to 4.4-4.6. This is reached within 2–4 hours in set yoghurt, owing to both the higher inoculation percentage (1-2.5%) and the higher incubation temperature (41°-43°C). The industrial manufacture of stirred and drinking yoghurts requires usually incubation times longer than set yoghurt. In figure 30 a process of stirred and drinking yoghurt is given in a Dutch setting, in which very low incubation percentages (0.05%) and low temperatures (31°C) are given. In France the inoculation percentages are higher (1-1.5%) as well as the incubation temperature (41°-42°C), which results in an incubation time of 4-6 hours. Due to the more firm coagulant the straining of this stirred yoghurt is carried out at a higher temperature of about 18°C. Cooling is performed directly after the yoghurt has reached the desired acidity, in order to reduce metabolic activity of the culture and to control acidity. In the case of drinking yoghurt homogenization is needed to improve the stability and drinking properties.
Long life drinking yoghurt needs a pasteurization process to ensure a shelf-life of 5 to 6 months. A mixture of pectin and sugar is added before pasteurization to prevent phase separation of the milk proteins. Specific pectin preparations from fruits can stabilize milk proteins in drinking yoghurt at pH values around 4. Most drinking yoghurts are enriched with strawberry flavour..
Therapeutic yoghurts are prepared by using starter cultures that contain specific micro-organisms in various combinations. Well-known bacteria in these cultures are *Lactobacillus*

a*cidophilus*, *Bifidobacterium bifidum* and *Bifidobacterium longum*, which are typical residents of the human intestinal tract. Bifidobacteria comprise one quarter of the flora in the intestine of normal healthy adults and they are expected to stimulate health benefits. Bifidobacteria require selective growth media at pH values above 4.5, containing so-called bifido factors e.g. lactulose and galacto-oligosaccharides, as will be discussed in section 7.7.3.

7.1.3 Chocolate drinks

Chocolate milk is a palatable milk beverage, which is traditionally prepared from standardized (3% fat) or skim milk by the addition of cocoa, sugar and a stabilizer. The stability and taste of chocolate milk put high demands on the quality of the cocoa powder used. The first patent on the manufacture of chocolate milk of sufficient palatability and stability was granted in 1828 to Van Houten, a Dutch manufacturer. He partly removed cocoa butter from roasted and ground cocoa beans, and crushed the remaining cocoa mass after

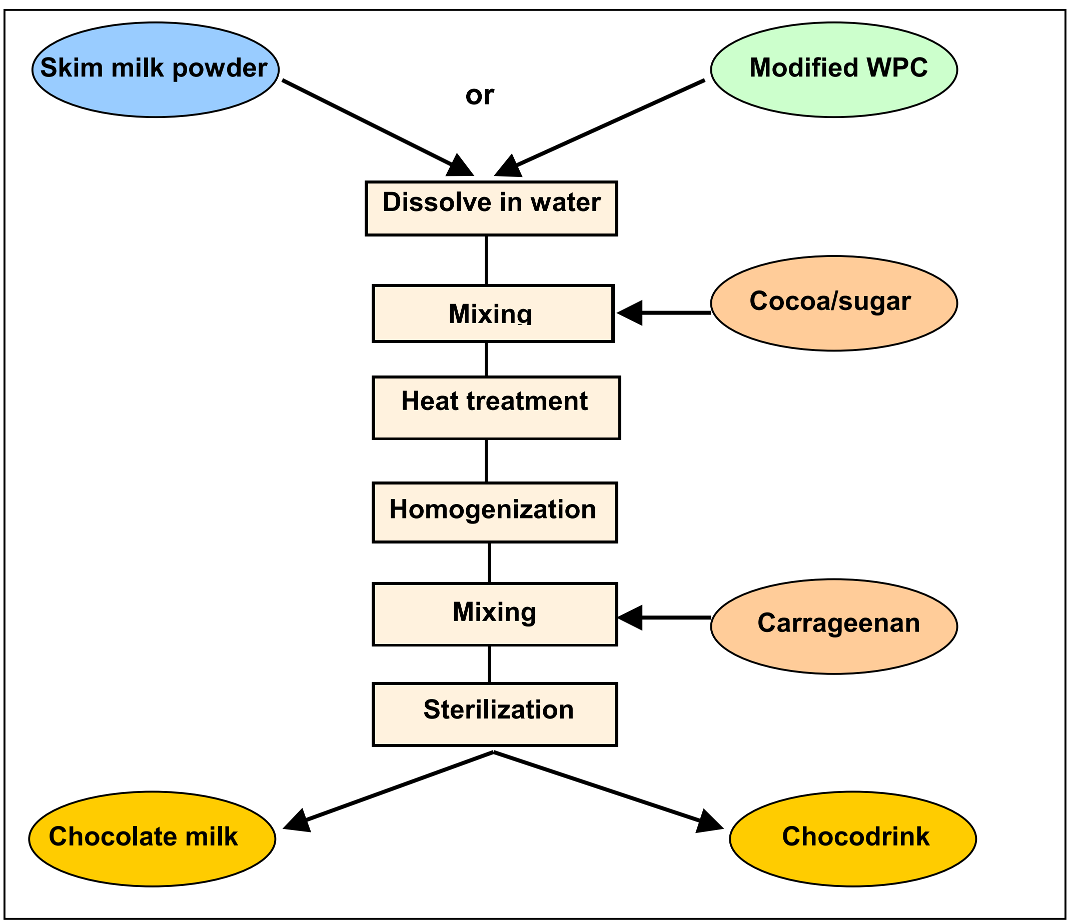


Figure 31. *Flow sheet of the production of chocolate drinks. Author Dr. J.N. de Wit*

drying to very fine particles.
A flow sheet of a model production process for chocolate beverages is shown in figure 31. Starting with skim milk powder indicated on the left side in this figure, the next procedure is followed. The powder is dissolved in water up to a concentration of 8.7%, and a mixture of 1.6 kg cocoa powder with 6.5 kg sugar subsequently added per 100 kg reconstituted skim milk. The mix is preheated for 15 minutes at 90°C immediately followed by homogenization at 20MPa at 70°C. These processes are important for the reduction of both cocoa particles and fat globules to a sufficiently fine dispersion. This dispersion is stabilized by 0.02% kappa carrageenan before the chocolate milk is bottled. Autoclave sterilization takes place during 30 minutes at 120°C. A network formed between milk proteins and carrageenan diminishes the sedimentation of cocoa particles during storage, and significantly contributes to the viscosity of chocolate milk.
Casein micelles are the main contributors to the characteristic mouthfeel of low fat chocolate milk; a phenomenon that cannot be achieved by using whey proteins because of their too small size. It is, however, possible to modify whey proteins to particle sizes in the order of casein micelles (100 times their molecular size). This is achieved by thermal denaturation of WPC under accurately controlled protein concentration, pH and salt concentration, followed by a homogenization process.
The manufacture of chocolate drinks is less strictly regulated than chocolate milk. Replacing skim milk by modified WPC-35 follows the procedure shown in figure 31 under slightly changed conditions. Starting at the same total solids concentration, milder homogenization (10 Mpa at 60°C) and sterilization (30 min at110°C) conditions are allowed now. This may be explained by the increased sensitivity of denatured whey proteins compared to casein micelles dissolved in water (up to a concentration of 8.7%). After adding a mixture of cocoa and sugar, the mixture is preheated, homogenized, stabilized by 0.03% kappa carrageenan and sterilized. The resulting whey chocolate drink shows an identical viscosity, palatability and storage stability as the non-fat chocolate milk.
The chocolate milk or drinks are usually sterilized in bottles, but also paper or plastic packagings are used. Paper and plastic packagings do not allow sterilization treatments. In those cases the milk or drink is previously UHT (ultra high temperature) sterilized and after that aseptically filled into paper or plastic packs.

7.2 Confectionery products

7.2.1 Aerated confections

Most aerated confectionery products are protein-type foams, which are highly sensitive to fatty components. Examples are meringue and frappé. Meringue is a whipped (egg white)

protein/sugar preparation which is dried at 110-125°C. In particular the drying process puts high demands on foam stability, and requires the absence of fat. WPC may replace egg white in meringue, only when the residual fat in WPC has been removed. In a successful preparation procedure a 14% defatted WPC solution was used to replace the egg white; 200 grams of the WPC solution was whipped for 15 minutes in a Hobart whipping machine at medium speed. Subsequently 400 grams of sucrose was gradually added during whipping, and 250 grams of sucrose was folded in the aerated mix after whipping. The final batter was squeezed on a baking sheet and dried for 30 minutes at 125 °C.
The WPC-60 meringues appeared to be of the same quality as those obtained from egg white. Meringues prepared according to the same procedure from regular WPC-60's reduced to flat cookies during drying, as shown in figure 32.

Figure 32. *Meringues prepared from: sugar and egg white (left), regular UF WPC-60 (middle), and defatted WPC-60 (right). Author Dr. J.N. de Wit*

The same holds for the preparation of frappés, which only allows defatted WPC's for the complete replacement of the egg white. Frappé is an aerated sugar-glucose-protein dispersion, containing 20-25% moisture and less than 0.5% whipping protein (egg albumin or defatted whey proteins). This aerated mixture should keep their stability during storage for at least one week and after that also during mixing in candy-type products such as nougats. These candy products are too viscous for whipping and need their aeration from frappé.
The advantage for using defatted WPC instead of egg white in these applications is that whey proteins cannot be overwhipped, which is a problem by using egg white.

7.2.2 Candy products

During the past few decades there has been a proliferation of products known as candy-type products, aerated sweets and desserts. Both economical considerations and opportunities for obtaining products with improved physical characteristics have stimulated growing interest in these products. Candy-type products such as toffees, caramels and fudges are cooked syrups,

originally textured and flavoured by using sweetened condensed milk. The palatability of confectionery products is often improved by the incorporation of air supported by whipping proteins, which do not allow the presence of fat. Exceptions are aerated desserts from cream-type foams such as ice creams, which may contain some fat.
The utilization of whey ingredients in confectionery products is well established. Typical ingredients for whey candies are sweetened condensed whey, sugar, corn syrup, butter and chocolate. Lactose (the major component in whey) contributes to the colour and flavour of confectionery products by reactions known as "Maillard" reactions. During cooking, lactose interacts with (whey) proteins, peptides and amino acids (building blocks of proteins) through Maillard reactions. These reactions generate both flavour compounds and complexes that develop brown colours within the product, as indicated in figure 33. The remaining lactose acts as a carrier of flavour and slightly affects the sweetness of confectionery products. Whey proteins enhance the miscibility of formula ingredients because of their emulsifying properties, and contribute to lightness during whipping and the structure of the products during cooking.
Both condensed (concentrated) whey and sweetened condensed whey is used in the confectionery industry. Sweetened condensed whey is concentrated sweet whey that contains 60% sucrose. Spray-dried whey powders are less frequently used because they are difficult to work with unless they are properly hydrated in water prior to processing. Sweetened condensed whey can be whipped up to a 3 to 4-fold volume increase within 4 minutes.
The foam remains stable for 10 hours and is used to incorporate air in special types of candy

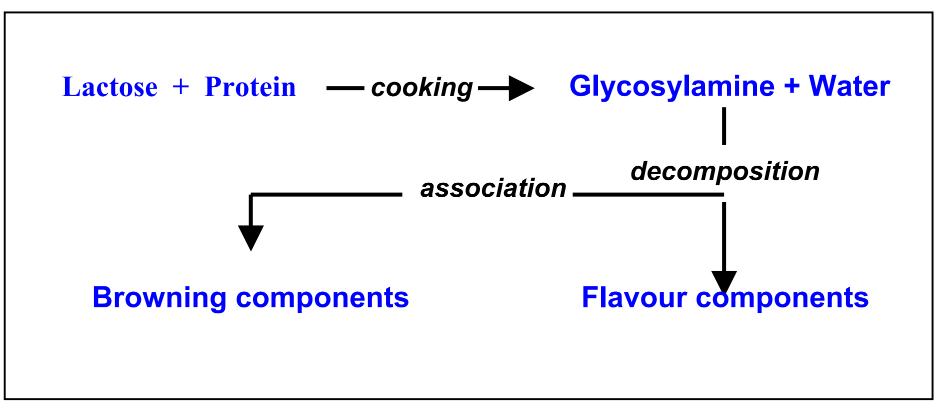


Figure 33. *Diagram for the formation of browning and flavour components during cooking*
Author Dr. J.N. de Wit

such as (fruit) fillings for bonbons, caramels, and toffees. These foams are called frappé as discussed in section 7.2.1. This stability is accomplished by first whipping the whey product and then carefully folding the whipped product into the cooked and partially cooled confectionery product (e.g. nougat). Equipment for whipping is distinguished in apparatus

used for batch operation at atmospheric pressure, and those for batch or continuous operations using compressed air.

7.2.3 Chocolates

Milk ingredients are valuable components in chocolate, especially in milk chocolate, owing to their flavour, sweetness, and protein profile. According to regulations in the European Community, milk chocolate should contain at least 14% dry milk solids and not less than 3.5% milk fat. In addition to the original flavour of milk components, new flavours are generated by heat treatments through Maillard reactions during the manufacture of chocolate. A basic step in the chocolate manufacture is "conching", indicating a heating process with aeration for some hours, which creates typical chocolate flavours.
In order to maintain the chocolate flavour during extended storage periods, milk crumb has been introduced as an ingredient. Milk crumb is prepared from sweetened condensed milk, sugar, chocolate liquor and a cocoa mass. This mixture was originally drum dried and subsequently crushed into grains, which may be stored for several months without loss of flavour when packed into sealed sacks. The milk crumb is converted into milk chocolate by grinding in the presence of cocoa butter and any other ingredients needed in the recipe.

Not all products that have the appearance of chocolate meet the official standards, and by regulation these products may not be labelled as chocolate. They are generally referred to as confectionery coatings or compound coatings and are developed for specific uses where real chocolate is inappropriate. Examples are "chocolate" compositions used as coatings on centres of ice cream bars, enrobed candy bars and baked goods. In these recipes sweetened condensed whey, various sugars and optimal additions of fats and emulsifiers may replace part or all of reconstituted milk powder . A well-known whey-based compound coating contains 6.6% cocoa, 18% whey powder, 44% sucrose, 31% fat, 0.03% vanillin and 0.4% lecithin.

7.3 Bakery products

7.3.1 Bread

Sweet whey is a well-known ingredient in the bakery industry for a long time, because of its flavour enhancing and tenderizing qualities. Volume, texture, crust, and retention of freshness in wheat bread are optimized by the incorporation of a combination of emulsifiers with whey

powder in the flour. Usually 1 to 2 % whey solids (on the basis of flour) are added, depending on the type and structure of the bread. Direct use of whey in breadmaking has historically resulted in a depression of loaf volume. However studies using WPC as a nutritious supplement in bread have given good results due to the removal of loaf volume depressants during ultrafiltration. Interactions between whey proteins and wheat proteins (gluten) during baking appear to improve colour and tenderness of bread. Whey proteins aid emulsifiers such as sodium stearoryl-lactylate to lower the rate of staling during the storage of bread. Lactose induces a uniform golden brown crust and improves the flavour of bread through interactions with proteins during baking. The nutritional quality of bread is improved by the introduction of proteins, calcium and B-vitamins from whey.

7.3.2 Biscuits

In the 1970's there was an increasing interest in the production of milk protein-enriched biscuits as nutritional food for children in developing countries. A mixture of delactosed whey (mother liquor) and buttermilk added to wheat flour resulted in tasty biscuits containing 20% milk proteins, that met the nutritional needs of school children in developing countries. The World Health Organization (WHO) and Food and Agriculture Organization (FAO) of the United Nations (UN) have devised these needs as standards. Figure 34 shows the biscuits produced that met the FAO requirements.

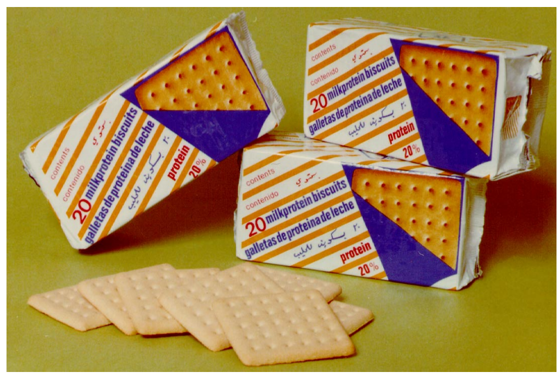


Figure 34. *Milk protein biscuits, containing 20% proteins*

The mix of milk proteins was composed of 60% whey proteins and 40% casein, which provided the required nutritional contribution to the biscuits prepared from the commonly used flours. The milk protein product was prepared by heating a mixture of delactosed whey and buttermilk during 15 minutes at 90°C. The milk proteins thus precipitated were washed to remove lactose and milk salts and then spray dried.

The composition of the biscuit was 57% wheat flour, 20% milk protein product, 16% sugar, 2% fat, 2% minerals, and 3% moisture. The nutritional quality of the biscuits was justified by the presence of sufficient essential amino acids; the building stones for the synthesis of human proteins. There are nine essential amino acids for children. Table 7 shows these amino acids and the requirements compared with their presence in both usual wheat flour biscuits and milk protein-enriched biscuits. An amino acid score method may be used to assess the nutritional quality of the food product, and that method is based on the ratio of the limiting

amino acid in the food over its level required. The dietary absence of even one essential amino acid inhibits the synthesis of body proteins. Table 7 shows that lysine is the limiting amino acid in the wheat flour biscuit, and causes a score of 2.9/4.6= 0.63 in this product. Whey protein biscuits meet scores of all essential amino acids, which indicate their high protein quality for school children.

Table 7. ***Essential amino acids needs for school children, compared with amino acid patterns in normal and whey protein-enriched biscuits***

Amino acid	**WHO/FAO ref.** (g/16 g N)	**Normal biscuit** (g/16g N)	**Whey protein biscuit** g/16g N
Histidine	1.8	2.2	2.5
Isoleucine	2.9	3.8	3.8
Leucine	4.6	6.8	11.4
Lysine	4.6	2.9	8.6
Methionine/Cysteine	2.3	2.7	3.6
Phenylalanine/Tyrosine	2.3	4.2	6.7
Threonine	2.9	3.1	3.5
Tryptophan	0.9	1.1	2.4

Author Dr.J.N de Wit

7.3.3 Cakes

Hen's eggs are particularly used in the baking industry because of their unique properties. Whey proteins have a number of properties in common with egg (white) proteins, and many attempts have been made to substitute WPC for egg white proteins in bakery products. Well-known bakery products in which **egg white** is used are angel food cakes in the USA and split cookies in the Netherlands. The three basic ingredients of angel food cakes are egg white, sugar and flour. The usual proportions are about 40 parts flour, 100 parts liquid egg whites, and 80-100 parts sugar. Egg whites and sugars are whipped to an aerated mix into which the flour is folded. The egg whites and flour contribute to the strength of the aerated structure of the cake during baking at 190 °C, and sugar acts as tenderizer to improve eating quality. The beating of egg white is a critical step in this recipe because egg white may be overwhipped. For this and economical reasons there is much interest to replace egg white by WPC. Bakery products require an optimal interaction between whey proteins and flour proteins, and this interaction is improved by the presence of fatty components present in WPC's. Important requirements for WPC are both a reduced lactose content (to prevent too

much browning during baking), and an increased whey fat content. It appeared that WPC-60, having a composition as shown in table 4 meets these requirements.
The same holds for Dutch split cookies, in which complete replacement of egg whites by WPC-60 can be achieved. The following recipe has been used successfully: 12% protein solution of WPC (13.5%), flours (7.5%), sugar (21%) and whipping agent (1.5%). After whipping at 45°C, this batter was mixed with almond paste (56.5%) and baked at 175°C for 17 minutes. Immediately after baking, a cream is spread between two cookies, and the resulting twins are dipped in a “chocolate”compound.
Another bakery product is the sponge cake, an aerated cake, made of equal amounts of **whole eggs**, sugar, and flour, which requires specific functions from egg yolk. These functions are absent in WPC’s, and hamper the replacement of whole eggs in this type of cake. However, it appears that the functions of egg yolk might be imitated by using WPC–60 in combination with additional emulsifiers. Selected emulsifiers support the interaction between whey proteins and flour proteins.

Because of the presence of cholesterol in egg yolk, there is much marketing interest in replacing this component for nutritional reasons.
Numerous experiments have been carried out to replace **whole eggs** by whey proteins in Madeira type cakes, made from a mixture of equal amounts of sugar, fat, flour and whole eggs. The main function of eggs in this cake is the binding of the fat (by egg yolk) during mixing and stabilization of the aerated structure during the baking stage through coagulation of the (egg white) proteins. In addition to that eggs contribute to the typical taste and colour of the crumb. It has been shown that whole eggs cannot simply be replaced by WPC because of insufficient foam stabilization, fat binding, and heat setting properties of the whey proteins. However, special procedures for mixing and baking have solved these problems. The complete substitution of whole eggs by WPC-80 is possible as shown in figure 35, indicating the characteristic domed top of Madeira type cakes. Preparing a pre-emulsion of fat and whey proteins before mixing the sugar has solved the lack of fat binding. After that the mix is whipped to the required aerated structure in which the flour is folded, and immediately baked to stabilize the foam structure. A pre-determined temperature/time programme between 120° and 160°C resulted in a cake as shown in figure 35 (2). The general appearance of the WPC cake is similar to that of the reference whole-egg cake,

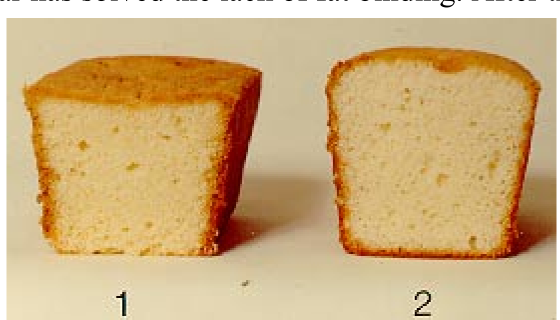


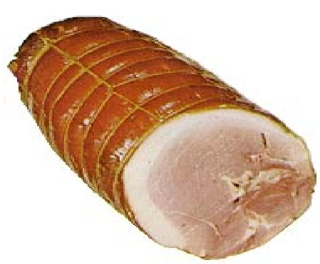
Figure 35. *Cakes prepared by using a normal recipe (1) and a WPC containing recipe (2). Author Dr. J.N. de Wit*

shown in figure 35 (1). The volume of the WPC cake is even higher than that of the reference cake, but the taste appears to be somewhat poorer than that from whole egg cakes. The mouthfeel of the WPC cake is dry (like bread) because the fat is encapsulated in an emulsion, while the whole egg cake has more tenderness.
Fruit and choco cakes prepared from WPC according to this procedure reveal a structure and mouthfeel which resemble that of whole egg cakes. However, the market for these special WPC cakes appears to be too small for industrial production. Most of the WPC applications in cakes are therefore based on partial substitutions according to the usual preparation procedures. WPC helps then to control moisture loss during baking, to support tenderness and to improve the development of colour and structure of cakes.

7.4 Meat/Fish products

7.4.1 Hams

Cost control of meat products and the large variations in the quality of meat proteins are important stimuli for using non-meat proteins in both whole and comminuted meat products. Two properties of meat proteins are of particular importance, i.e. their water-holding capacity and their fat-binding abilities.
Lean meat contains about 75% water, 20% proteins, and 5% fat. More than 70% of the water is “free water”, which is both immobilized within the microstructure of the tissues and bound by meat proteins. The amount of water present and the extent to which it is bound by muscle components are thought to influence the tenderness, texture and juiciness of whole meat products. After slaughtering, part of the “free water” is expelled during the “rigor mortis” stage. Part of this loss can be restored with the help of salts and milk proteins such as WPC’s. Other important functions of whey proteins in whole meat products (such as hams) are the



prevention of both shrinkage during cooking, and syneresis during storage. The ham should retain juiciness through an adequate water-holding capacity and should keep its meat-like (not too firm) texture.
Protein fortification of whole meat products is achieved by injecting a whey protein solution into the meat, using a multi-needle system. After injection, the meat is massaged or alternatively tumbled (rolled over and over) in a solution of whey proteins or in brine. The hams are stuffed into casings and cooked up to a core temperature between 70° and 75°C. Most suitable WPC’s for this purpose are low temperature gelling WPC-80, which should be

highly soluble in a 2% salt solutions with up to 10% protein. Additional demands are low viscosity to avoid clogging of the injection needles and pocketing of the solution in the meat. Moreover, WPC should not have adverse effects on flavour, colour, appearance and texture. A whey protein fortified cured (preserved) ham comprises about 70% intact meat muscle tissue, and 30% curing composition containing 5 to 10 % WPC solids.

7.4.2 Comminuted meat products

Luncheon meat is a comminuted (fine-particle) meat product enriched with pork fat and flavouring additives. Fine-particle meat products are prepared by comminution of the muscle tissue in a grinder/ mincer, as shown in figure 36-2. Pork fat is usually dispersed as pre-emulsion stabilized by milk proteins in a bowl chopper (figure 36-1), and then mixed with the minced meat slurry. The pre-emulsion usually contains also finely comminuted and cooked pork skin to ensure easy distribution of the emulsion in the meat slurry. Other ingredients such as sugar, salts and remaining water are added after a rigid emulsion has been formed during chopping, and this process is continued until all the ingredients are dispersed. The luncheon meat is subsequently cooked and filled into cans for setting during cooling. Compositions of luncheon meats may differ, depending on the quality of the meat products used. Table 8 shows an example of one of the compositions. Caseinates are well-known milk proteins used for fat binding in luncheon meat emulsion, but WPC's may also be used. This is in particular important for pâtés, which contain a greater amount of fatty tissues than luncheon meat as shown in table 8. Liver pâté formulations should be chopped at higher temperatures to make the fat connective tissue more pliable. The use of WPC significantly improves the tenderness and water holding capacity in these formulations. Liver pâtés are usually made from pre-cooked pork back fat, trimmings and water to be chopped at 50°C in a bowl chopper together with sufficient WPC as emulsifier. When (after 3 to 5 minutes) the pre-emulsification has been completed, uncooked liver is added and chopping is continued until bubble formation starts. Cooking will damage the liver proteins, which contribute significantly to the stability and the smoothness of pâtés. At that point the other additives such as salt, seasonings and onions are added.

Figure 36. *Bowl chopper (1) and grinder/mincer (2)*

Table 8. ***Formulations of luncheon meat and liver pâté***

Component (%)	Luncheon meat	Base for liver pâté
Cow's meat	28.0	-
Pork meat	7.0	-
Trimming (pork fat tissue)	33.0	-
Cooked pork fat	-	38.0
Cooked pork skin	7.5	7.5
Fresh liver	-	23.0
Sugar (saccharose)	8.0	-
Water	12.7	25.7
Milk proteins	2.0	1.8
Curing salts	1.5	1.4
Spices and herbs	0.25	0.6
Fried onions	-	2.0

Author Dr.J.N de Wit

The base for the pâté emulsion, which acts as a carrier for the liver pâté, is now ready. The secret of manufacturing the finished pâtés is actually the formulation itself.
Varying the coarseness of additional included pre-cooked meats such as cured ham, poultry breast, and seasoning can create a variety of flavours. Pre-cooking these ingredients is important in developing flavour and smooth texture. The pâté is then baked in ceramic or aluminium terrines for 2 to 3 hours at 71°C.

7.4.3 Surimi

Originally the term "surimi" referred to minced and water-washed fish muscle tissues, mostly derived from Alaska Pollock, a gadoid food fish, indigenous in northern seas. Surimi can be described as a myofibrilar protein concentrate, which is primarily used in the manufacture of various types of Japanese heat-gelled products, such as Kamaboko.
The gel-forming characteristics of Pollock deteriorate rapidly after the fish is caught in the sea, which is caused by enzymatic degradation of its myofibrillar proteins. Even when frozen immediately after being caught, there is a significant decrease in gel strength. Therefore, after catching, the fish is immediately processed on shipboard to prevent undesirable changes in frozen muscle tissues during the storage period. Figure 37 shows a flow diagram for the processing of surimi. Starting with washing in refrigerated seawater; the head, internal organs and main part of the

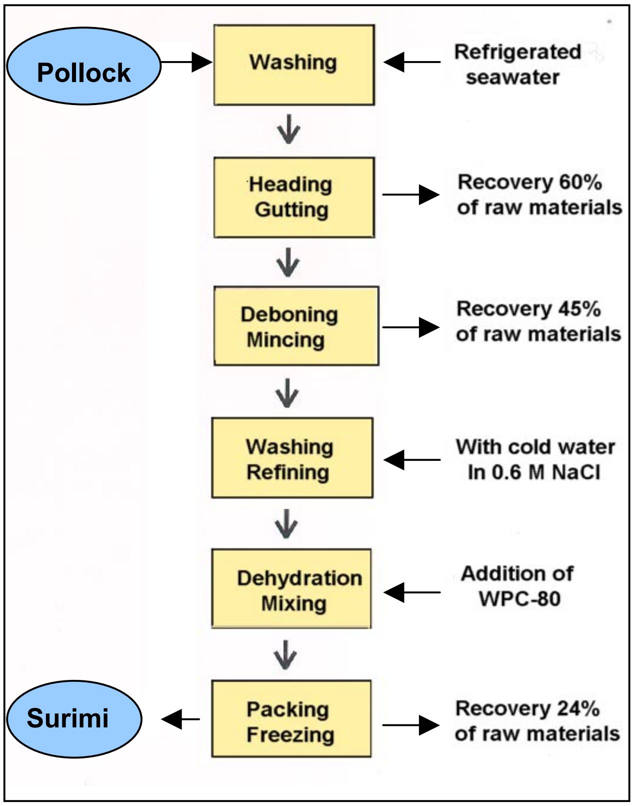


Figure 37 *Flow diagram for the processing of preserved surimi*

backbone are removed. The resulting fillets are separated from the skin tissues of the fish with a mechanical deboner. The crude muscle tissues obtained are then extruded to obtain minced meat. The minced meat thus obtained is thoroughly washed to remove digestive enzymes (such as proteases and lipases) and inorganic salts. The protein recovery is then about 45% of the raw materials, consisting mainly of actin, myosin and tropomyosin. These proteins are insoluble in water, but are easily extracted using a 0.6M NaCl solution. Insoluble material, such as small bones and skin tissues, is then removed by a high speed rotary refiner and dehydrated by a screw press. The solids recovery of the well-dehydrated minced and washed meat is about 24% of the raw materials. - Table 9 shows the compositions of the fresh filleted fish and the preserved surimi product. Minced flesh contains approximately two-thirds myofibrilar protein, which possesses the desired gelation properties. The remaining one third consists of sarcoplasma proteins and enzymes, which impede gel formation of the final surimi product. Adding cryoprotectants to surimi products before freezing retards the loss of gelling ability during storage. The cryoprotectants used are sucrose and sorbitol that protect actomyosin from freeze denaturation. Salt is added to dissolve actomyosin, the main component forming gels. Polyphosphate inhibits denaturation of actomyosin mainly by sequestering calcium and zinc ions.

Protein additives have been widely used to improve the gel strength of surimi. Some of the most functional proteins are egg white, WPC-80, either as a functional binder or as a functional filler. However, the functional contribution of WPC-80 is not merely based on its gelling behaviour, because the gelation temperature of WPC (75°C) is much higher than that of actomyosin (40°C). During the heat setting of fish gels there are three temperatures where major textural transitions take place. At about 40°C the setting phenomena are attributed to the gelation of actomyosin. In the temperature range from 50-60°C, a weakening of the gel structure is observed that is generally attributed to the activity of endogenous enzymes (proteases). Rapid cooking of surimi to 80° or 90°C inactivates these enzymes. In particular

proteases endogenous to Pacific-whiting are known to catalyze the hydrolysis of myosin and, hence, the degradation of the surimi structure. The addition of 3% WPC-80 has shown to be very effective for the inhibition of this autolytic enzyme activity.

Table 9. ***Composition of Pollock fillet and preserved surimi***

Component (%)	Pollock fillet	Surimi product
Proteins	90.0	78.0
Fat	4.0	3.5
Carbohydrates	1.5	1.3
Sucrose	-	4.0
Sorbitol	-	4.0
Salts	1.5	3.0
Tripolyphosphate	0.3	2.5
WPC-80	-	2.0
Curing salts	1.5	1.4
Spices and herbs	0.25	-.-

Author Dr.J.N de Wit

7.4.4 Comminuted fish products

Finely comminuted fish products are usually prepared in a bowl choppers and sometimes in a grinder (see figure 36). Examples of comminuted fish products are fish sticks, fish nuggets, and Japanese-style fish pastes such as Kamaboko and Tempura. The word nugget means "little piece or chunk" and that is how it began. Nuggets are in principle prepared from white meat such as chicken meat, pork, veal and fish as raw material. Fish nuggets are prepared in a bowl chopper on the basis of different species of fish, usually as a paste of thawed surimi. If a nugget of a more coarse structure is desired, only a quarter of the fish is chopped into a binding mass with salt and phosphate. Water and 2.5% whey proteins (as water binder) are subsequently added, and chopping is continued until a homogeneous mass is obtained. Finally the remaining part of the fish is added and thoroughly mixed at slow speed to prevent comminution. The total chopping time is 2 to 4 minutes. The mass is then cooled with dry ice to -5°C to allow good shaping and is

directly transferred to the shaping machine, and after that breaded, frozen and packed. The nuggets are fried again before consumption by the consumer or in restaurants.
Water binding and associated juiciness induced by whey proteins and starch is much better when finely comminuted nuggets are produced This product is obtained by the comminution of all fish ingredients in the chopper. The method for preparation of finely comminuted nuggets is as follows: Surimi at -5°C and salt are chopped or ground at 15°C. Subsequently other ingredients including egg white or whey proteins are added. Finally the dispersion of starch/water/ice is added very slowly and the mass is chopped or ground at 18°C. After preparation the fish paste is filled into casings and pasteurized (Kamoboko) or packed in open moulds, cooled, cut into thick slices and fried (Tempura). Important criteria for the quality of fish paste products are: elasticity, water binding, flavour and taste, colour and nutritional value.

7.4.5 Soups and sauces

A variety of milk protein products are used in soups and sauces, mainly for their emulsifying properties. Skim milk powders are extensively used in neutral sauces and cream-type soups. WPC's are advantageously used in acid sauces and acid soups because of their good acid solubility and their high water binding properties during heat treatments. The emulsifying properties of WPC's can be utilized optimally when the emulsions are prepared before the acid ingredients are added. Combinations of whey proteins and caseinates improve the thickening of (acid) soups. The actual balance between these proteins is determined by the choice of other emulsifiers and starches.

Additional information in References 3 and 19 (dairy products), 1 (confectionery, bakery products), 10 and 11 (meat and fish product)

7.5 Infant formula

Infant formulae are mainly designed from cow's milk as a substitute for human milk. A striking difference between these milks is that cow's milk contains nearly three times more protein and minerals than human milk. This is explained by the much faster growth of young

calves compared to new-born infants. Dilution was therefore the earliest attempt to adapt cow's milk for consumption by human infants, followed by the addition of sugars for restoration of the total solids balance. When in the early 1970's the usefulness of whey-predominant infant formula became apparent to simulate human milk, attention was turned to the development of formulae supplemented with whey. More insight in the nutritional roles of casein and whey proteins pleaded in favour of changing the ratio of whey proteins/casein from 20/80 in cow's milk to 60/40 as present in human milk. This was the start for so-called whey-predominant formula prepared by mixing equal amounts of skim milk and demineralized whey. More recently attention is paid to adaptation of the whey protein composition itself to that of human milk.
Several procedures are utilized in the manufacture of infant formulas, which can be distinguished as "dry procedures", and "wet procedures", or a mixture of both. In all cases pasteurized skim milk forms the base, either as a concentrate or after reconstitution of skim milk powder. The total solids concentration is adjusted in such a way as to amount to 45% after blending with other ingredients. Demineralized whey powder, vegetable oils and fat soluble vitamins are added prior to homogenization at a pressure of 15-20 MPa and a temperature of 75°C. The mix is subsequently pasteurized at an intensity sufficient to prevent bacterial growth and subsequently spray dried. The quality requirements for infant formulas are much stricter than those for milk powders.

7.5.1 Term formula

Standard formula for infants weighing more than 2.5 kg after a normal gestation period, are often indicated as term formula. Whey-predominant formula contains both the desired whey protein/casein (60/40) balance and a reduced mineral content. Milk fat present in cow's milk is replaced by vegetable oils, and adapted to the desired fat composition in human milk. Increasing attention is paid to the addition of lactoferrin, which is quantitatively the second important protein in human milk but a minor protein in cow's milk (see section 3.2). A comparison of the average composition of the main components present in human milk, cow's milk and a whey-

Table 10. ***Average composition of macronutrients in human milk, cow's milk, and a whey-predominant infant formula***

Component (%)	Human milk	Cow's milk	Whey-predominant formula
Water	87.0	87.0	87.0
Fat	4.2	4.1	4.2
Total proteins	1.5	3.5	1.5
Whey proteins/Casein	60/40	20/80	60/40
Lactose	7.0	4.6	7.0
Minerals	0.2	0.7	0.3

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predominant formula is shown in table 10. Vitamins and minerals are added to this formula, to complete the 60/40 mixture of skim milk and demineralized whey.
All of the nutrients required in the first 4 to 6 months of an infant's life may be provided by whey-predominant formula supplemented with iron (ferrous sulphate), fluoride (for teeth), and vitamin D. The addition of iron partially interferes with the function of (added) lactoferrin as an iron-binding protein. The bacteriostatic properties of lactoferrin disappear when it becomes saturated with iron. In addition to the standard formulas for normal healthy term infants there are two other types of cow's milk based formulas. These are "pre-term" formula for prematures and "follow-on" formula for infants older than 6 months.

7.5.2 Pre-term formula

Premature infants (weighing less than 2.5 kg) have particular needs in terms of energy, protein, minerals and vitamins. Specific whey-predominant formulas have been developed for pre-term low-weight infants, to support a more appropriate balance of amino acids for growth and metabolism. The amino acid profile in blood (plasma) is very important particularly for premature infants. The concentrations of some essential amino acids, such as lysine (lys), methionine (meth), and threonine (thr) are higher in whey pre-dominant infant formula than in human milk as shown in figure 38. This amino acid profile hampers the possibility to achieve an optimal balanced amino acid composition in blood plasma of infants. The blood plasma concentration of breast-fed infants is considered as the "golden standard", and many studies are performed to adapt the protein quality in formula to achieve this goal. The increased plasma threonine content appears to be caused by the presence of the casein-macropeptide (see section 2.2.2) in cheese whey. This peptide is absent in acid casein whey. Whey-predominant formulae contain a lower proportion of phenylalanine (phe) than human

milk, which may be important for infants with phenylketonuria (PKU). PKU is a genetic defect of phenylalanine metabolism in which a deficiency of an enzyme (phenylalanine hydrolase) prevents the conversion of phenylalanine to tyrosine (tyr), which is also an essential amino acid. Moreover, a too high phenylalanine concentration in blood plasma may cause brain damage. The casein-macropeptide contains no phenylalanine, which makes it suitable for use as a nutritional supplement for patients suffering from PKU. The shortage of tryptophan (trp) in infant formula is subject to increasing attention. Tryptophan is a precursor for the neurotransmitter serototin, which induces sleep. Attempts are being made to correct this amino acid in formula by supplementing α-lactalbumin (a milk protein having the highest tryptophan content). Human milk contains taurine, a free sulphur amino acid, in much greater quantities than cow's milk. Taurine is thought to be important for rapidly growing preterm infants, but discussions on its relevance are still ongoing. Taurine is an important component of bile acids, and appears to support the efficient absorption of fat.

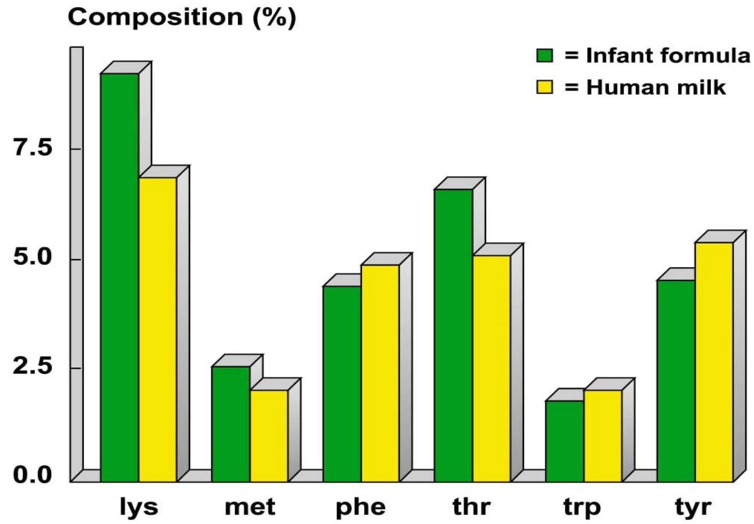

Figure 38. *Concentration of some essential amino acids (as % of total amino acids) in a 60/40 whey- predominant infant formula and human milk. Author Dr. J.N. de Wit.*

7.5.3 Follow-on formula

"Follow-on" formula has been developed to meet the needs of infants older than 6 months. These are milk-based formulas with higher electrolyte, iron and protein concentrations supplemented with solid foods (cereals and fruits). Egg, meat and cheese are considered to be suitable (additional) protein sources in the solid diet of these infants.

Additional information in References 7 and 18

7.6 Dietetic foods

7.6.1 Slimming foods

Slimming foods have been introduced to prevent or control obesity, the most prevalent nutritional disorder in prosperous communities. Obesity and overweight may have serious health consequences and nutritionists are trying to understand their causes and to advise people with these problems. Obesity arises as a consequence of taking in more energy in food than is expended in the activities of daily life, leading to a positive energy balance which is mainly stored as fat. There is currently a debate on the role played by macronutrients in the development of a positive energy balance and obesity. Some scientists have argued that, in considering the reasons underlying a positive energy balance, low levels of physical activity are more important than a high energy intake. High fat foods have been identified as a major single dietary factor involved in the development of weight gain and obesity. Recent studies have shown that *ad libitum* consumption of diets low in fat and high in protein and complex carbohydrates (such as starch) contributes to the prevention of weight gain in normal weight persons. The addition of daily physical activity to this diet contributes to the weight loss in overweight persons. A diet leading to weight loss at a reasonable rate should be adequate in all nutrients, but deficient in total energy. Contrary to claims made by advertisements, there have been no breakthroughs in weight control and there are no easy solutions. Diets having a high satiety value (end of meal signal) with some fats and high levels of proteins appeared to delay the feeling of hunger longer than isocaloric diets containing more fat. Whey protein products fit well in slimming foods, owing to their excellent amino acid composition.

7.6.2 Diets for elderly

Whey protein enriched dairy products with additional food coming from fruits, vegetables or

cereal products may meet the requirements of elderly foods. As age advances, physical activity tends to decline and so less dietary energy is required. Food intakes also decline with age, but information on the specific nutrient needs of elderly people is scarce. It is generally assumed that foods of a high nutrient density are needed to provide the recommended amount of nutrients in an elderly diet. Whey protein products meet these requirements, and much work is being done to develop tasty food products enriched with whey protein products. Most activities are focused on the supply of calcium and zinc in combination with vitamins in the diets of women in particular. The efficiency of calcium absorption declines with age and is accompanied by increased

excretion of calcium and loss of bone mass. The possible relationship between loss of bone mass and calcium deficiency has been vigorously discussed. Important factors to consider are the form of calcium, the efficiency of its absorption and the recommended requirements. Whey is a valuable source of both high quality proteins and bioavailable calcium for (elderly) people. Some currently recommended nutrient intakes for women over 51 are shown in table 11, and compared as an example to the amount of these nutrients present in 100 g of whey solids.

Table 11. ***Recommended nutrient intakes for females over 51 years compared with the composition of whey solids.***

		Recommended intake	Present in 100 g whey solids
Protein	(g)	47	10
Calcium	(mg)	800	878
Phosphorus	(mg)	1000	1096
Magnesium	(mg)	210	178
Iron	(mg)	8	1
Zinc	(mg)	9	2
Iodine	(mg)	0.16	0.68
Vitamin A	(µg))	800	10
Vitamin D	(µg)	5	0.5
Vitamin E	(µg)	6000	100
Ascorbic acid	(µg)	30000	1000
Thiamin	(µg)	800	500
Riboflavin	(µg)	1000	2000
Vitamin B_6	(µg)	1600	600
Niacin	(µg)	1400	1000
Folic acid	(µg)	190	12
Vitamin B_{12}	(µg)	2	2

Author Dr.J.N de Wit

Dieticians report that the following nutrients need to be present in adequate amounts in the diets of elderly persons: calcium, zinc, vitamin D, vitamin E, thiamine, riboflavin and folic acid. These nutrients occur in whey and in particular calcium and zinc salts are present in a bioavailable form.

7.6.3 Clinical Foods

Clinical or medical foods are designed to provide complete or supplemented nutritional support to persons who are unable to digest adequate amounts of food in a conventional form. These foods are also used to provide specialized nutritional support to patients who have special physiological and nutritional needs. Whey proteins are normally present in a diet as intact proteins, and have nutritional advances for use in medical diets, because they are (nutritionally) complete proteins. Normally a complex process of protein digestion and absorption begins in the stomach under the influence of HCl and pepsin. After leaving the stomach, dietary protein is further digested (hydrolyzed) by pancreatic enzymes such as trypsin and chymotrypsin. The net result is the production of a combination of free amino acids and small peptides, which may enter the blood stream through the small intestine. Some unique peptides from whey proteins have important physiological functions, which involve e.g. the stimulation of growth factors, blood flow regulation.

Some patients having defects in their (enzymatic) digestion system or other diseases require a diet that contains previously (in vitro) hydrolysed proteins. In those cases, food proteins have been broken down into small fragments (peptides). The degree of hydrolysis can vary from almost completely (65% of the peptide bonds broken) to partial (35% of the peptide bonds broken). The required degree of hydrolysis may vary according to the required use of the formula. A more rigorous hydrolysis is required for so-called parenteral diets, containing small peptides and amino acids, which are injected directly into the blood stream. They meet high demands on purity and allergenicity and are defined as “hypoallergenic foods”. Another category comprises so-called enteral diets, which are orally consumed and contain larger peptides, capable of further digestion in the gastro-intestinal tract. Enteral diets should also be hypoallergenic for patients who are known to be allergic to specific proteins.

Hypoallergenic whey protein formulas are for example applied to patients having an allergy to cow’s milk. Extensively hydrolysed hypoallergenic formulas may have an unsatisfactory (bitter) taste caused by the presence of some peptides and amino acids. This problem is lessened in partially hydrolysed (enteral) whey protein diets.

Examples of diseases, which require enteral diets, are pancreatitis (no pancreatic enzyme secretions) and Crohn’s disease (malabsorption of proteins in the gastrointestinal tract).

Additional information in References 6, 7, 9 and 16

7.7 Pharmaceuticals

Lactose, the main component of whey, is quantitatively also the most significant excipient (non-active substance) in pharmaceutical applications. Thousands of tons of lactose are used every year in medicines. Tablets, capsules and inhalers are the most widespread and convenient forms for administering drugs to patients.

7.7.1 Tablets

The weight of tablets is usually more than 50 milligrams, while the active drug weights only a few milligrams or even micrograms. Refined lactose is well-known as an inert carrier of drugs because if its purity and consistent chemical and physical stability. One of the most important physical properties of lactose in the manufacture of tablets is its capability for direct compression. The source of the tablet is a powder comprising 85% crystalline pharma α-lactose embedded in a matrix of amorphous lactose (see figure 39) obtained by a specific spray drying technique. Particle size and globular shape of these α-lactose particles determine the required flow properties and the (hygroscopic) amorphous component act as a good binder due to its plasticity. Coherent tablets, produced by compression, have a porous surface structure suitable for a uniform adsorption of the drugs. Even better binding properties are obtained by using roller-dried powder containing mainly β-lactose owing to its high fragmentation propensity under compression. The moisture stability of this β-lactose powder is better, but the particle size distribution (and related flow properties) is more irregular than the powder composed of α-lactose (see figure 39).

A lubricant is an essential part of the ingredient list for almost all tablet formulations. A well-known lubricant is magnesium stearate forming a thin film around the particles necessary for the disintegration of the tablets when used.

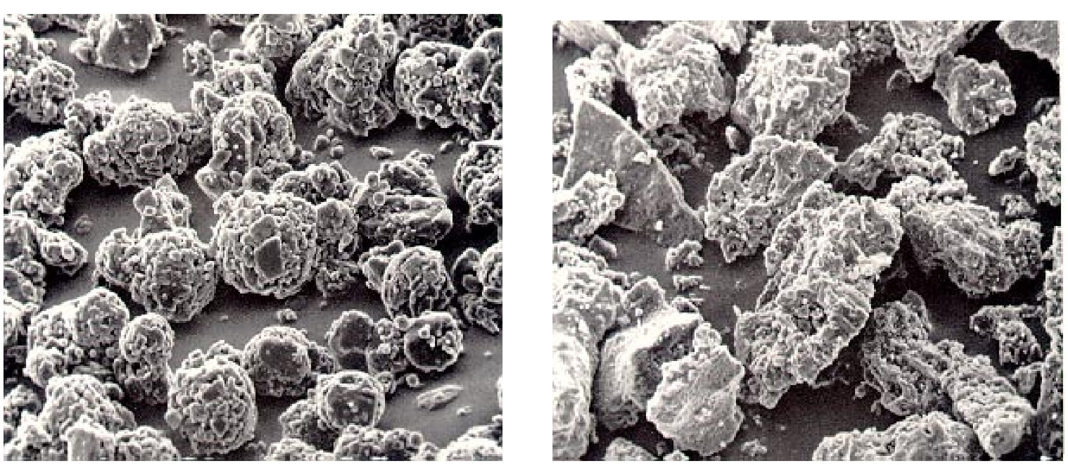

Figure 39 *Scanning electron micrographs showing uniform sized powder particles from coated α-lactose (left), and more irregular sized particles from mainly β-lactose (right).*
From DMV International

7.7.2 Inhalers

Another category of administration of medicines is formed by the inhalers, The majority of inhalers contains the active drug bound to small homogeneous sized lactose particles. The drug particles must range in size from 0.5 to 5 µm for optimal delivery to the deepest parts of the lung. Particles larger than this are trapped in the respiratory tract, and moved upwards by action of cilia and then swallowed. The small particles of the active drug are coated on the somewhat larger lactose particles that act as a carrier for the drug and deposited in the throat. It is essential that the inter-particulate attractive forces between drug and carrier particles are not so great that the drug is deposited in the throat and swallowed as well.

7.7.3 Nutritional drugs

The versatility of lactose is demonstrated by the range of derivatives that can be obtained through chemical and biochemical reactions, as schematically shown in figure 40.
The major derivatives of lactose are lactobionic acid (produced by oxidation), lactulose (formed by isomerization) and lactitol (produced by hydrogenation). Oligosaccharides are formed during (enzymatic) hydrolysis of lactose under specific conditions. Enzymatic hydrolysis of lactose performed under normal conditions results in glucose and galactose.

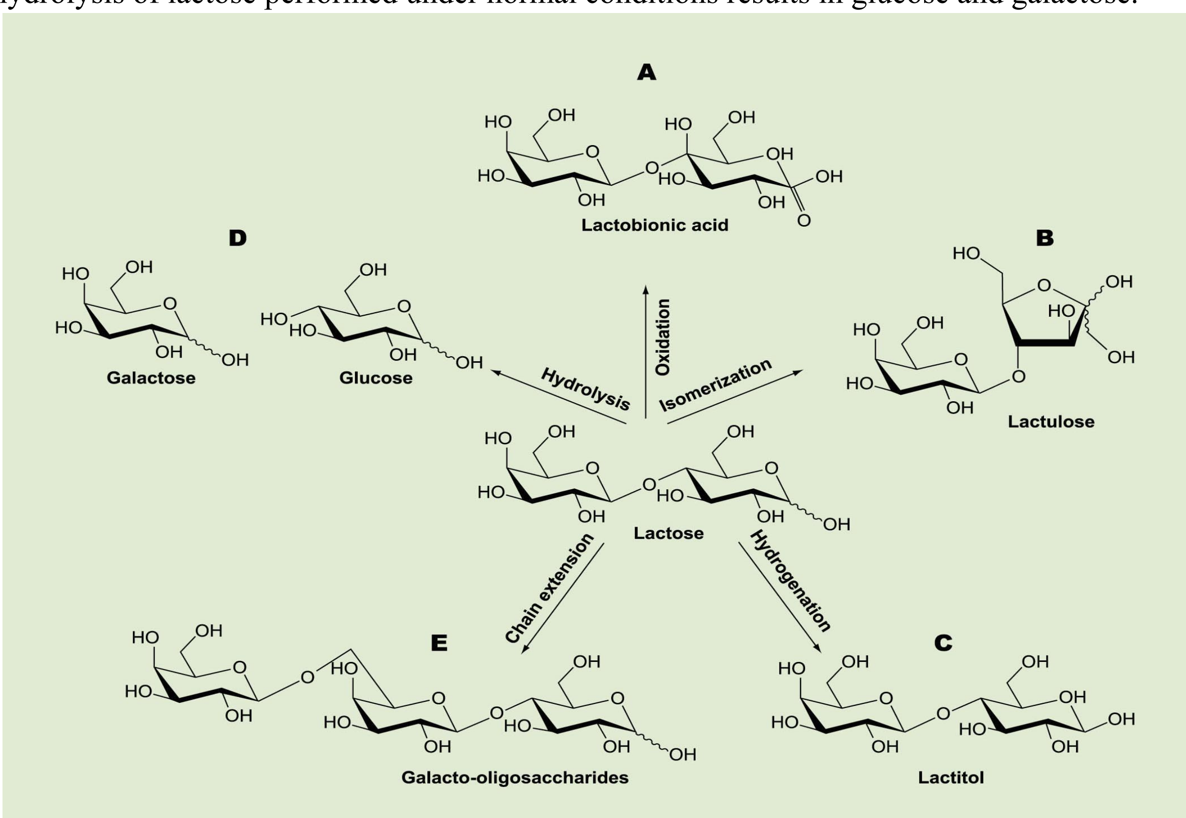

Figure 40. *Lactose derivatives, obtained by chemical and biochemical modifications. Adapted from reference 23*

Lactobionic acid (figure 40A) is produced by oxidation of the free aldehyde group of lactose. High yields of lactobionic acid may be obtained by catalytic oxidation with platinum, using bismuth as a promoter. Lactobionic acid may also be obtained enzymatically. Calcium salts of lactobionic acid are used as a carrier for antibiotics in pharmaceutical preparations. The Food and Drugs Administration (FDA) in the USA. has also defined calcium lactobionate as a food additive for use as a firming agent in dry pudding mixes.
Lactulose (figure 40B) is obtained from lactose by a rearrangement of the molecular structure (isomerization) of the glucose part to fructose. This isomerization process is obtained under alkaline conditions using borate as a catalyst in a continuous reactor system. Separation of lactulose from salts and other sugars (lactose, galactose, and glucose) is achieved by ion exchange chromatography, followed by crystallization in an aqueous solution. Lactulose has been identified as a bifidus factor as indicated in section 7.8.3, which encourages the development of Bifidobacteria in the intestinal tract. These bacteria suppress harmful intestinal bacteria, which is important in infant nutrition.
Lactitol (figure 40C) is a disaccharide sugar alcohol prepared from lactose by catalytic hydrogenation of the glucose part of the molecule to an alcohol (sorbitol). This reduction occurs in a 30% aqueous lactose solution at about 100°C under hydrogen pressure of 0.4 MPa in the presence of Raney nickel as a catalyst. Lactitol can be used as a substitute for saccharose in many food applications. Its relative sweetness is about 35% of that of saccharose and this sugar is tolerated by diabetic patients. Clinical trials have shown that its consumption neither increase blood glucose nor insulin levels. Apparently, lactitol is not absorbed or hydrolysed in the small intestine; instead, it is fermented by bacteria in the large intestine to biomass and short-chain fatty acids.
Galacto-oligosaccharides (figure 40E) are formed during the enzymatic hydrolysis of lactose under specific reaction conditions. Depending on the type of enzyme and the reaction condition, oligomers up to eight monomers can be formed. In the production process, the most important condition for the formation of oligosaccharides is the use of bacterial β-galactosidase at high lactose concentrations. Galacto-oligosaccharides (GOS) cannot be digested by human intestinal enzymes and consequently arrive in the human colon where they are fermented preferably by the Bifidobacteria in the colon (see section 7.8.2). Japanese claims of specific beneficial health effects of GOS are often related to protection against the development of colon cancer.
The **hydrolysis of lactose** to glucose and galactose (figure 40D) is catalyzed by the enzyme lactase, which is present in the intestines of mammals. Commercial lactases are mainly derived from yeasts, but enzymes from other sources are also marketed. The enzyme costs play a significant role in the price of hydrolyzed lactose products, and therefore techniques to immobilize the enzyme were introduced to allow its repeated use. Hydrolyzed lactose product properties, when compared with lactose, are characterized by the increased solubility,

increased sweetness, increased flavour enhancement, and easier digestibility. Both galactose and glucose are absorbed from the small intestine and are used as an energy source in the body. To this end galactose must be isomerized to glucose, a process that is predominantly and efficiently carried out in the liver. Previous hydrolysis of lactose in milk products is important for lactose intolerant people.

Additional information in References 13, 14, 15 and 17

7.8 Nutraceuticals

Nutraceuticals or functional foods are food products or ingredients that provide medical or health benefits, including the prevention and treatment of diseases. Examples of functional foods are bioactive proteins, probiotics and prebiotics. Both the food and pharmaceutical industries are interested in developing new products in this category, using whey as a valuable source.

7.8.1 Bioactive proteins

A group of specific bioactive whey proteins include lactoferrin, lactoperoxidase, lysozyme and a number of growth factors. Most of these proteins are now commercially isolated, as described in section 5.4. Lactoferrin is credited with several beneficial health promoting effects during and after digestion in the intestinal tract, including antibacterial activity, carrier for iron, and regulation of the immune system. Lactoferrin binds iron, thus inhibiting the growth of bacteria which need iron. Lactoperoxidase and lysozyme are natural antimicrobial whey proteins, which have been described as prospective additives to protect milk and milk products against microbial deterioration. The lactoperoxidase system is also used in the cosmetic sector (shampoo), toothpaste and animal feed.
Another category of bioactive proteins with specific antibodies are immunoglobulins, which may be harvested from whey. These antibodies are secreted into the milk of cows immunized with bacteria or viruses causing intestinal infections. These specific antibodies can be used to protect humans e.g. against rotavirus causing traveller’s diarrhoea.
A third group of bioactive whey proteins includes several growth factors. Growth factors are highly potent hormone-like proteins with specific biological actions in the regulation and stimulation of cell growth and repair. Well-known is the insulin growth factor that stimulates

wound healing of the skin and intestinal tract. Perhaps this explains the beneficial effects of whey baths on wound healing in some health centres.
A growth factor, called osteopontin, has been identified as a factor from the proteose peptone fraction (PP-3) in whey (see table 2). This is a glycoprotein that is involved in the nucleation of calcium phosphate in bones and the growth of bone cells.
Casein-macropeptide is another bioactive peptide occurring in cheese whey (see section 2.2.2). It is a glycopeptide that inhibits the adhesion of harmful coli-bacteria to intestinal walls and prevents tartar adhesion to teeth. Another bioactive whey peptide is the proteose peptone factor 5 (PP-5), split off from β-casein by plasmin, an indigenous milk enzyme. PP-5 is a phosphopeptide that has the ability to sequester calcium at a high concentration in soluble complexes along the oral and gastrointestinal tract. It may also form organophosphate salts with trace elements such as iron, magnesia, manganese, copper and selenium. Hence they function effectively as biocarriers for a variety of minerals.

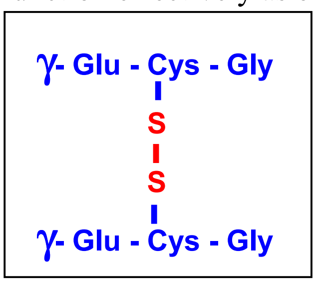

Figure 41.
Oxidized glutathion

Consumption of undenatured whey proteins in the diet has been associated with the retardation of chemically induced cancers in several animal models through stimulation of the immune system. Whey proteins processed at low temperatures (in particular β-lactoglobulin) contain a high concentration of a specific amino acid sequence (glutamyl cysteine) which may promote the synthesis of glutathione, an important antioxidant involved in cellular protection and repair. Glutathione plays a key role in detoxification by reacting with harmful by-products in the human body. In this reaction two tripeptides are linked by a disulphide (S-S) bridge, and restored in its activity by an enzyme (figure 41).

7.8.2 Probiotics

Probiotics may be defined as deliberately digested, health promoting live bacteria that beneficially affect the microbial intestinal balance of the host. It is widely accepted that probiotics are active in the prevention of intestinal infections. Increasing interest is focussed on finding alternatives to classic antibiotic treatments for gastrointestinal infections, in view of the rapid development of widespread antibiotic resistance.
Very few probiotic micro-organisms are actually able to survive in high numbers passaging through the stomach. The stomach is an organ that, in physiological conditions, has a very low pH (± 2). Probiotic micro-organisms that survive this gastric acidity are *Lactobacillus acidophilus, Lactobacillus casei, Lactobacillus plantarum*, and *Bifidobacterium spp*.
Bifidobacterium is predominant in the intestinal microflora of infants and is considered to play an important role in maintaining their health. Bifidobacteria ensure protection from enteric infection. The protective effect is enhanced by a small decrease in the intestinal pH

and high lysozyme activity. The optimum pH for growth of bifidobacteria is 6.5 to 7.0, and they stop growing below pH 4.5. Lysozyme has bacteriolytic activity and is considered to play a role in the protection of infants from enteric infection. The number of Bifidobacteria decreases with age while the number of harmful bacteria (coliforms and clostridia) increases. The bacteria currently being examined as potential probiotics are predominantly from the genera Lactobacillus and Bifidobacterium used in the production of (therapeutic) yoghurts. Therapeutic yoghurts differ from the conventional type in the micro-organisms used for fermentation. Specific health-promoting bacteria are Lactobacillus casei, Lactobacillus acidophilus, and Bifidobacteria, which attach themselves to the surface of the epithelial cells in the large intestine (colon). In doing this, they prevent infectious bacteria to attach to the colon wall and to increase in population. Infectious bacteria may cause disorders like diarrhoea but they may also damage the mucus and disturb barrier functions for antigens. Cocktails of antimicrobial enzymes such as lysozyme, glucose oxidase and lactoperoxidase proved to be effective for the biopreservaton of the probiotic bacteria in the colon.

7.8.3 Prebiotics

Prebiotics may be defined as non-digestible food ingredients of the diet that reach the colon intact and beneficially affect the host by selectively stimulating the growth and/or activity of probiotic bacteria in the colon. The colon contains 10^{11} bacteria per gram, and resident microflora cannot be easily outnumbered under the influence of ingested probiotic micro-organisms. Modulation of the microflora in the colon can be affected by ingesting prebiotics. By stimulating the growth of probiotic bacteria, intestinal disorders can be reduced and serious health problems, such as diarrhoea, irritable bowl syndrome and flatulence may be prevented. Specific growth factors (bifidogenic factors) for probiotic bacteria may be derived from whey such as lactulose and galacto-oligosaccharides (GOS) or from other sources such as fructo-oligosaccharides (FOS). These are non-digestible food ingredients in the small intestine, which are metabolised by probiotic bacteria in the colon. Non-digestible oligosaccharides have also been shown to inhibit development of pathogens in the intestines by inhibiting the attachment of pathogens to mucous surfaces.
Lactulose (and oligosaccharides) are not absorbed in the stomach and small intestine, but migrate to the large intestine. In the large intestine, they appear to be utilized predominantly by all species of Bifidobacteria residing in the human intestinal tract. Moreover, the metabolism of these compounds stimulates the growth of a healthy intestinal flora.
Additional information in References 6 and 8

8. SUMMARY AND CONCLUSIONS

This handbook provides a comprehensive overview on the origin, manufacture and properties of whey and whey products and their use in a wide variety of food products and pharmaceutical applications. Both functional and nutritional applications of whey ingredients are covered in an integrated and up to date review. The various subjects are discussed in six chapters.

The origin of whey and its processing history are described in the chapters 1 and 2, emphasizing the natural source and strictly controlled manufacturing processes. The composition of whey is discussed in chapter 3, with reference to the many components, which play an important role in human nutrition and pharmaceutical applications.

Industrial concentration and drying processes for preservation and storage of whey and whey products are discussed in chapter 4. Remote controlled operations ensure a constant keeping quality of the whey products produced. Up-to-date information on the techniques for the fractionation and isolation of desired ingredients from whey is provided in chapter 5. Attention is paid to membrane processes for the recovery of whey protein concentrates and specific techniques for the isolation of bioactive proteins and pharmaceutical quality lactose of high purity.

More than 20 applications of whey and whey products in various human foods are discussed in chapter 6. Functional properties of whey protein concentrates (WPC) like foaming to support the aeration in confectionery and bakery products are well known in these industries. Moreover the colour and taste of these food products are improved by the interaction between lactose and proteins during heat treatment. The emulsion (fat binding), gelation and water binding properties of WPC are important attributes for improving the quality of meat and fish products. WPC-80 appears to be the most functional whey product in these applications.

Specific attention is paid to the nutritional benefits of whey ingredients in infant formula, dietetic foods and pharmaceutical products. Whey is a well-known source for adapting infant formula to that of human milk. Specific bioactive proteins such as lactoferrin, lactoperoxidase and a number of growth factors reveal several beneficial health promoting effects. Whey salts, particularly calcium and zinc, are present in whey in a bioavailable form which is important in for example elderly foods. Lactose, the main component of whey, is quantitatively the most significant excipient in pharmaceutical applications.

The interest in the functional and nutritional efficacy of whey ingredients is still growing, and interesting results may be expected in the near future. Worldwide, an annual source of more than 100 billion kilograms of whey is potentially available for use as valuable ingredients in food and feed products.

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10. ADDENDA

10.1 Acknowledgement

EWPA thanks Dr. de Wit for his considerable efforts to write this handbook. Many years of experience in research and industry are released in this book for the future generation.
Dr. de Wit received for his work on whey and whey products the International Dairy Science Award from the American Dairy Science Association in 1996. He was awarded by the International Food System Functionality Association in 1997 for his contributions to the applications of whey components in food products.
Furthermore EWPA thanks the following lecturers for their very valuable comments and suggestions: Mr.Linders, Mr.Peschek, Ms Pernot-Barry, Prof.Herrmann, Dr. Brack, Ms Barden Jensen, Mr.Buch Kristensen, Mr.Tupasela, Mr.Mietton, Mr.Brulé, Mr. Mafart, Dr.Girardet, Dr.Fitzgerald, Dr.Kelly, Prof.Morrissey, Mr.Koenemans, Mr.Rouweler, Mr.Oosterloo, Mr Hall, Dr.Burling, Dr.Barclay, Ms Merrick, Mr. Ludvigsen, and Mr.Wilby.
Also the substantial input of the translators, Ms Lewis and Mr. Dodinval is appreciated by EWPA. The book highlights the upgrading of whey as valuable source of versatile ingredients for applications in food and pharmaceutical products.
EWPA hopes that this handbook will stimulate lecturers and students in all kind of professional schools for the benefit of both producers and consumers.

10.2 Information on European Whey Products Association

The European Whey Products Association (EWPA) was created in 1994 to represent the interests of the whey processing industry in Europe.
The EWPA has the objective to promote the industry and its products. For this reason common projects are undertaken. This can be projects of a scientific and technical nature. In particular applications for whey products are studied.
The results of these studies are made available to its members and its customers and are used for the promotion of whey products. Economic and marketing projects are jointly organised, such as market and statistical data research. In terms of joint marketing efforts, not only sales and marketing material is developed, but congresses and seminars are also jointly organised.
EWPA represents the interests of the whey processing industry in the European Union (EU) towards the EU authorities, in particular the EU Commission.
The lecturer's handbook is a result of the efforts of the members of EWPA to promote whey products by increasing the knowledge about the processing of whey and whey products in general.

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Contents

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F- 86361 CHASSENEUIL-DU-POITOU
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http://www.bonilait-proteins.com

BORCULO DOMO INGREDIENTS
Hanzeplein 25,
NL- 8017 JD ZWOLLE
P. 0. Box 449,
8000 AK ZWOLLE
http://www.borculodomo.com

CARBERY FOOD INGREDIENTS
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Ireland
http://www.carbery.com

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http://www.dcingredients.co.uk

DMV INTERNATIONAL
NCB laan 80
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NL- 5460 BA VEGHEL
http://www.dmv-international.com

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http://www.euroserum.com

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http://www.kerry.ie

GROUPE LACTALIS
"Les Placis"
F-35230 BOURGBARRE
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LACTOSERUM FRANCE
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P. 0. Box 2400
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http://www.arlafoods.com

MEGGLE GmbH
Postfach 40
D-83513 REITMEHRING
http://www.meggle.de

MILEI GmbH
Rosensteinstrasse 22
D-70191 Stuttgart
http://www.milei.de

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P.O. Box 10
FIN-00039 VALIO
Meijeritie 6, HELSINKI
http://www.valio.fi/english

10.3 Specifications of some whey products

(*For education purposes only)*

SWEET WHEY POWDER

GENERAL QUALITY CHARACTERISTICS

Appearance:	Slightly yellow
Origin:	Separated from production of cheese curds
Production:	Spray-dried after concentration of whey
Properties:	Mostly crystallized non-hygroscopic powder.

CHEMICAL COMPOSITION

Moisture	3.5 - 5.0 %
Protein (N x 6.38)	11 - 14 %
Lactose	70 - 75 %
Ash	8 - 9 %
Fat	1 - 2 %
pH (6% solution)	6.0 - 6.5

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 50.000/g
Yeasts	< 50/g
Molds	< 50/g
Coliform	< 10/g
Salmonella (25 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS
Baked goods, beverages and cheese products.

ACID WHEY POWDER

GENERAL QUALITY CHARACTERISTICS

Appearance:	Slightly yellow
Origin:	Separated from the production of fresh cheese and casein curds
Production:	Spray-dried after concentration of acid whey
Properties:	Powder with distinctive acid flavour and salty taste

CHEMICAL COMPOSITION

Moisture	3.5 - 5.0 %
Protein (N x 6.38)	9 - 12 %
Lactose	61 - 75 %
Ash	10 - 13 %
Fat	0.5 - 1.5 %
pH (6% solution)	4.5 - 5.0

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 50.000/g
Yeasts	< 50/g
Molds	< 50/g
Coliform	< 10/g
Salmonella (25 g)	Negative
Staphylococcus aureus (1g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS

Spreads, seasonings and cultured dairy products.

DEMINERALIZED WHEY POWDER

GENERAL QUALITY CHARACTERISTICS

Appearance:	Slightly yellow
Origin:	Fresh sweet whey
Production:	Demineralization by ion exchange or electrodialysis
Properties:	Clean, slightly sweet, dairy taste and good solubility after reconstituition.

CHEMICAL COMPOSITION

Moisture	3.0 - 4.0 %
Protein (N x 6.38)	13 - 15 %
Lactose	75 - 80 %
Ash	1 - 5 %
Fat	1 - 1.5 %
pH (10% solution)	6.5

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 10.000/g
Yeasts	< 10/g
Molds	< 10/g
Coliform	< 10/g
Salmonella (50 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 24 months at less than 25°C.

APPLICATIONS

Frozen desserts, dietetic products and baby food.

DELACTOSED WHEY POWDER

GENERAL QUALITY CHARACTERISTICS

Appearance:	Slightly yellow to cream
Origin:	Concentrated cheese whey or casein whey
Production:	Partial separation of lactose by crystallization
Properties:	A savory, salty taste.

CHEMICAL COMPOSITION

Moisture	3.5 -5.0 %
Protein (N x 6.38)	20 - 25 %
Lactose	48 - 54 %
Ash	15 - 22 %
Fat	1.5 - 2.5 %
pH (10% solution)	5.5 - 6.5

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 50.000/g
Yeasts	< 50/g
Molds	< 50/g
Coliform	< 10/g
Salmonella (25 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS

Snack foods, cheese products and seasonings

LACTOSE EDIBLE

GENERAL QUALITY CHARACTERISTICS

Appearance:	Fine to coarse, white to slightly yellow
Origin:	Concentrated whey or concentrated permeate
Production:	Crystals are separated, washed, dried and milled
Properties:	Flavour-enhancing and inducing golden brown colour.

CHEMICAL COMPOSITION

Moisture	0.2 - 0.5 %
Protein (N x 6.38)	0.1 - 0.3 %
Lactose	99.0 - 99.5 %
Ash	0.1 - 0.3 %
Fat	–
pH (10% solution)	6.0

MICROBIOLOGICAL ANALYSIS

Standard plate count	<	500/g
Yeasts	<	10/g
Molds	<	10/g
Coliform	-	
Salmonella (50 g)	Negative	
Staphylococcus aureus (1 g)	Negative	

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 36 months at less than 25°C.

APPLICATIONS
Infant formula, confectionery, and soups/sauces.

LACTOSE PHARMACEUTICAL GRADE

GENERAL QUALITY CHARACTERISTICS

Appearance:	Crystalline white powder of different particle sizes
Origin:	Concentrated whey or concentrated permeate
Production:	Crystals are separated, washed, refined, dried, milled and sieved
Properties:	Carrier of pharmaceutical drugs in tablets, powders and inhalers

CHEMICAL COMPOSITION

Moisture	< 0.2 %
Protein (N x 6.38)	< 0.1 %
Lactose	> 99.9 %
Ash	< 0.1 %
Fat	-
pH	-

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 100/g
Yeasts	< 10/g
Molds	< 10/g
Coliform	< 1/g
Salmonella (100 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS

All kind of pharmaceutical applications and source for lactulose production.

DELACTOSED DEMINERALIZED WHEY POWDER

GENERAL QUALITY CHARACTERISTICS

Appearance:	Off-white, light cream coloured powder
Origin:	Concentrated cheese whey or casein whey
Production:	Combination of delactosation and demineralization
Properties:	Skim milk replacer based on its major chemical composition

CHEMICAL COMPOSITION

Moisture	3.0 – 4.0 %
Protein (N x 6.38)	30 - 45 %
Lactose	45 - 55 %
Ash	3 - 9 %
Fat	1 - 3 %
pH (10% solution)	6.0- 6.5

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 10.000/g
Yeasts	< 10/g
Molds	< 10/g
Coliform	< 10/g
Salmonella(50 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS

Ice cream, frozen desserts and infant formula.

WHEY PROTEIN CONCENTRATE (WPC)

GENERAL QUALITY CHARACTERISTICS

Appearance:	Off-white to light cream coulored powder
Origin:	Fresh cheese whey or casein whey
Production:	Fractionation by ultrafiltration and/or diafiltration
Properties:	Excellent amino acid profile; skim milk and egg white replacer.

CHEMICAL COMPOSITION

Moisture	3.0 – 4.0 %
Protein (N x 6.38)	34 - 80 %
Lactose	10 - 55 %
Ash	4 - 8 %
Fat	3 - 8 %
pH (10% solution)	4 - 6.5

MICROBIOLOGICAL ANALYSIS

Standard plate count	< 50.000/g
Yeasts	< 10/g
Molds	< 10/g
Coliform	< 10/g
Salmonella (50 g)	Negative
Staphylococcus aureus (1 g)	Negative

PACKAGING

25 kg multiply paperbags with a polyethylene liner
Shelf life up to 12 months at less than 25°C.

APPLICATIONS

Functional ingredient in bakery and meat products; nutritional ingredient in health and clinical foods.

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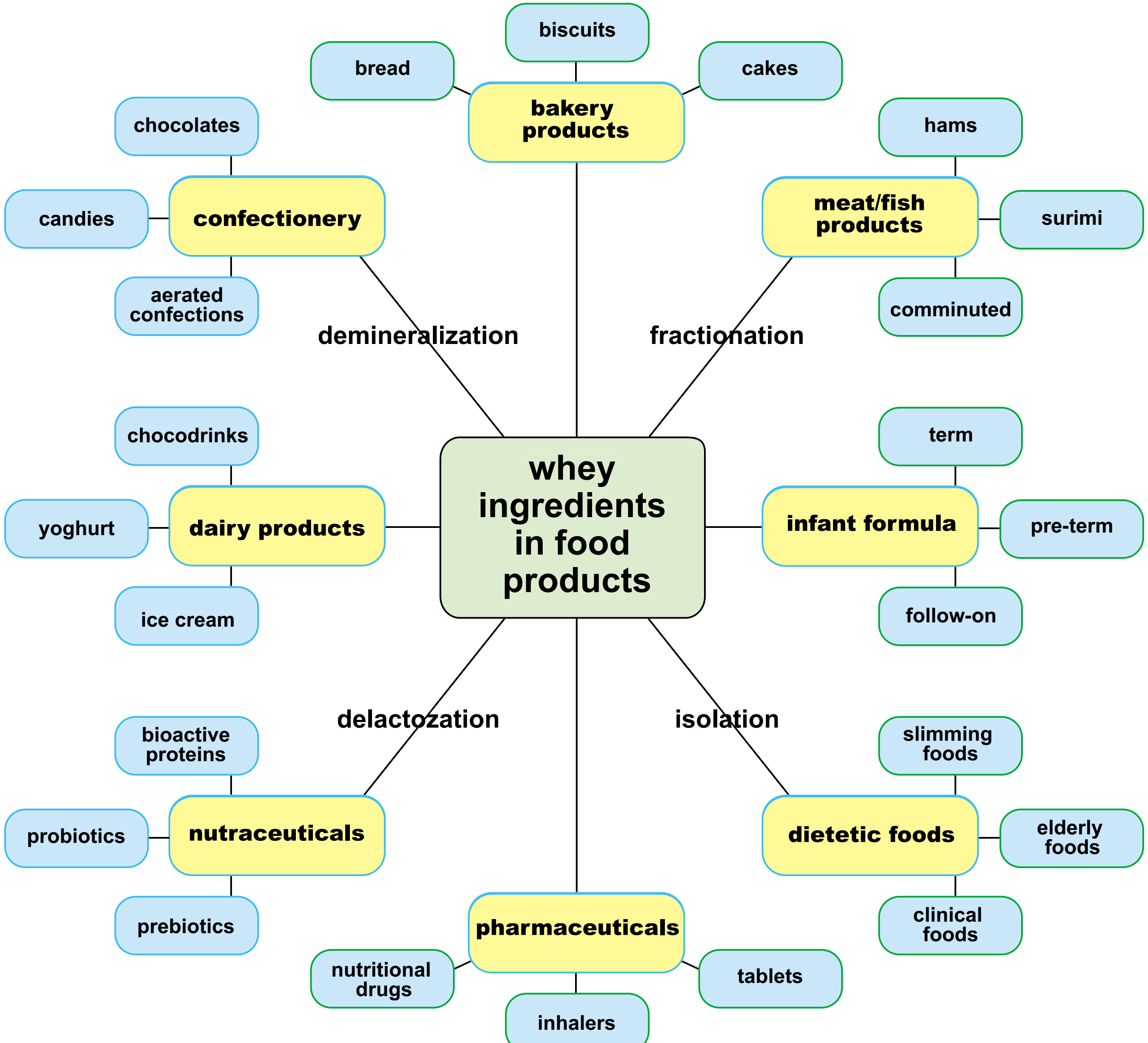

Figure 28. Recovery procedures and utilization of whey ingredients in food products.

(Author Dr J.N. de Wit)