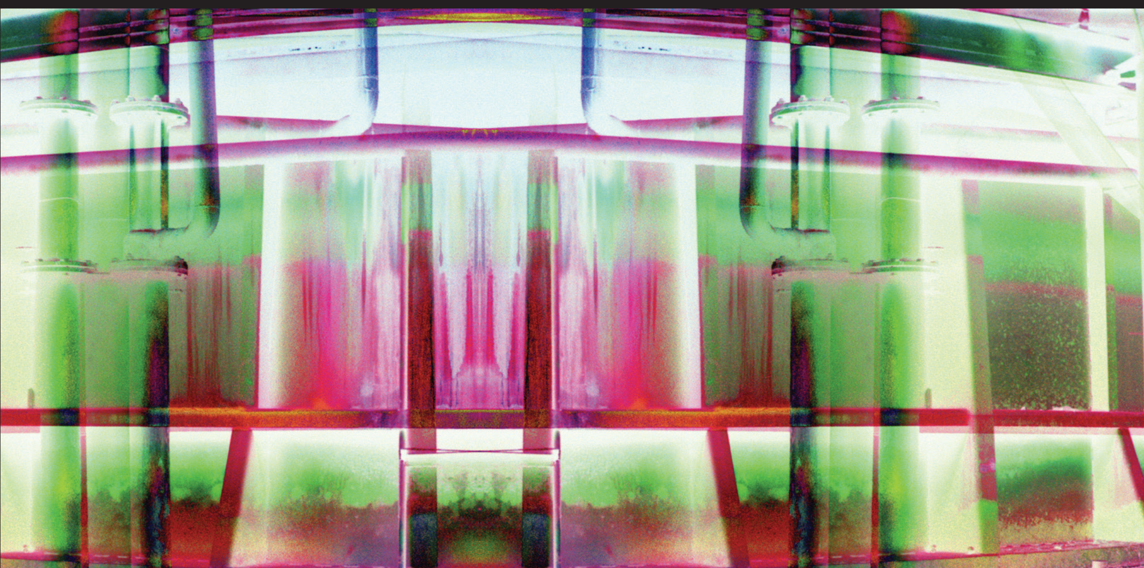
Whey Processing, Functionality and Health Benefits



EDITORS

Charles I. Onwulata • Peter J. Huth

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Preface

Milk whey proteins have come into wider use as food ingredients only in the last 40 years, taking their proper place at an emerging frontier, where nutrition and health interface. Largely regarded in the past as a waste by-product, advanced processing technology has propelled whey proteins to the top of the list of important nutrients, and still newer technologies will help keep it there permanently. This book provides an overview of the successes and challenges of the new whey processing industry. As food ingredients, whey proteins are used in a multitude of combinations and advanced well beyond the stage of simply delivering nutritional value by also providing essential functional and health benefits to complex food systems. The contributing authors to this book are outstanding scientists and health professionals in their fields of specialty, working diligently to enhance the utility of whey ingredients for the development of products that deliver demonstrated health benefits to consumers.

The knowledge presented in this book documents the wide range of potential uses for whey proteins not only as ingredients in food formulations but also as functional components providing additional metabolic and physiological benefits beyond merely supplying essential amino acids. Health and wellness, processing and functionality, are clearly areas of continuing research and offer growth opportunity for the food industry. The benefits from this continuously growing body of knowledge will be new ingredients and innovative products that will improve the overall well-being of consumers. Topics covered in this volume will provide food scientists and manufacturers with new insight into and appreciation of the health-promoting implications of whey protein science. The topics identified below and contributed by their respective subject matter experts represent the best science knowledge base in these areas. The state of the art and science are compelling, and an emerging database is confirming and solidifying the human knowledge base.

The compilation of knowledge on the functional and metabolic roles of whey proteins and their demonstrated biochemical efficacy in improving human health enhances the vision of the Institute of Food Technologists Book Communications Committee that supported the publication of *Whey Processing: Functionality and Health Benefits*. By presenting the latest information on the processing and functionality research conducted on whey proteins up to the present, this volume will accelerate new product innovation and create opportunities for the food industry.

Topics covered in volume include

- whey utilization, its history, and progress in process technology;
- fractionation and separation into biological fractions with health implications;
- whey emulsions and stability in acidic environments;
- some current applications in films, coatings, and gels;
- new process: texturization—use of texturized whey in snacks, meat analogs, candies, and as inclusions in candies;
- nanoparticles in hydrogels for delivery of bioactive components; and
- role of whey proteins in human health.

This book serves as a valuable resource for food industry professionals in research and development, academic faculty and students in food science, human nutrition and dairy science, nutrition and health professionals, and also policy makers.

Charles I. Onwulata, Ph.D.

Whey Processing, Functionality and Health Benefits

Chapter 1

Whey Protein Production and Utilization: A Brief History

Michael H. Tunick

Introduction

Whey is the liquid resulting from the coagulation of milk and is generated from cheese manufacture. Sweet whey, with a pH of at least 5.6, originates from rennet-coagulated cheese production such as Cheddar. Acid whey, with a pH no higher than 5.1, comes from the manufacture of acid-coagulated cheeses such as cottage cheese. Compositional ranges of each are shown in Table 1.1. About 9 L of whey is generated for every kilogram of cheese manufactured, and a large cheesemaking plant can generate over 1 million liters of whey daily (Jelen 2003).

Cheesemaking presumably originated in the Fertile Crescent some 8,000 years ago after it was noticed that an acid-coagulated milk gel separates into curds and whey. Experimentation would have led to the first cheeses, where the original starter cultures probably consisted of some of the whey from the previous day's cheesemaking; manufacturers of Parmigiano-Reggiano, Grana Padano, and other high-cook cheese varieties still use this method (Fox and McSweeney 2004). Reheating of the whey and recovery of the solids led to a cheese variety now known as ricotta (Italian for "recooked").

Whey not used for humans was fed to pigs or other livestock, spread as fertilizer, or simply thrown out. Whey has supplemented pig feed for centuries, and the growth of computerized systems has allowed for more precise feeding of whey and other liquid feeds to weaned pigs and lactating sows (Meat and Livestock Commission 2003). A study

Table 1.1. Typical composition of liquid and dry whey (Jelen 2003).

Product	Protein	Lactose	Minerals
	g/L whey		
Sweet whey	6–10	46–52	2.5–4.7
Acid whey	6–8	44–46	4.3–7.2
	g/100 g powder		
WPC-35	35	50	7.2
WPC	65–80	4–21	3–5
WPI	88–92	<1	2–3
UF permeate	1	90	9

conducted in the early 1970s showed that spraying whey on the ground to a depth of 25 mm improved the yield of corn and hay without increasing groundwater pollution (Watson and Peterson 1977). Whey is a potent pollutant with a biological oxygen demand of 35–45 kg/L; 4,000 L of whey, the output of a small creamery, has the polluting strength of the sewage of 1,900 people (Marwaha and Kennedy 1988). Disposal of whey by dumping into rivers was frequently used in the United States before environmental regulations took hold (Cryan 2001). One cheese plant faced with a whey disposal problem looked at the deep abandoned well on its property, decided that "where there's a well there's a whey," and discarded their surplus in it. This method ended with explosive violence in 1942 when the whey, trapped and under pressure, developed enough gas to blow off the top of the well (Anderson 1970).

Nowadays whey is evolving into a sought-after product because of the lactose, minerals, and proteins it contains as well as the functional properties it imparts to food (Onwulata and Tomasula 2004). A number of products are obtained from whey processing, as shown in Figure 1.1. This chapter deals with the development of whey protein as a prized commodity.

Concentrating Whey—Early Efforts

The health benefits of whey led to the development of processes to isolate the solids by concentration and drying. The initial industrial attempts

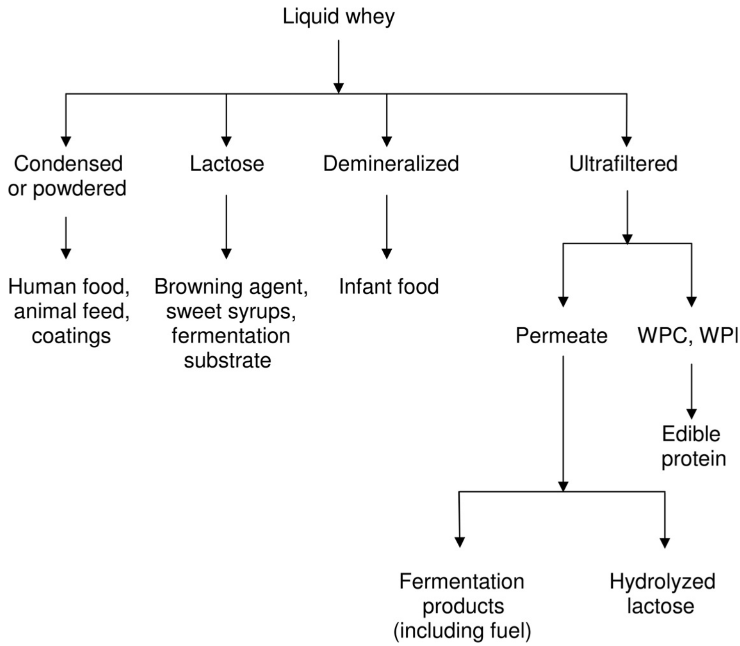

Figure 1.1. Liquid whey processing (Marwaha and Kennedy 1988; Siso 1996).

at concentrating and drying whey were in the 1920s and involved four different methods: conventional hot roller milk driers; heating until a concentrated liquid was obtained, cooling to solidification, and then extruding in a tunnel; two-stage steam heating; and a combination of spray drying and rotary drum drying (Gillies 1974). The high cost of the process and the hygroscopic nature of the lactose in the dry product prevented much progress from being made. Roller drying, in which whey is dried on the surface of a hot drum and removed by a scraper, is still used by some processors as part of whey powder production.

The first important development came in 1933 when the long-tube multiple-effect evaporator was applied to whey processing (Gillies 1974). The multiple-effect evaporator boils water in a sequence of tanks—in this case, two—with successively lower pressures. Since the boiling point of water decreases as pressure decreases, the vapor boiled off in one vessel is used to heat the next and an external heat source is needed for the first vessel only. Evaporation in the first effect takes place around 77°C and in the second at around 45°C (Kosikowski and Mistry

1997a). Water is evaporated from the whey in long slender vertical tubes within the steam chest (Perry and Green 1997), leaving concentrated whey with 45% solids (Kosikowski 1979).

Drying Whey

The second major innovation that aided whey processing was the spray drier, which was developed in the 1860s, applied to whey starting in 1937, and is still in use. The lactose, which is amorphous and hygroscopic, is cooled and crystallized to nonhygroscopic α-lactose monohydrate. The concentrated whey is then dispersed by a rotary wheel or nozzle atomizer into a drying chamber through a hot-air stream, producing a powder with 10–14% moisture. The evaporation keeps the temperature down, preventing denaturation (Deis 1997). The wet powder is dried to 3–5% moisture in a vibrating fluid bed (Kosikowski and Mistry 1997a).

Concentrating Whey—Modern Techniques

Until the 1970s whey protein was available only in the heat-denatured form, a water-insoluble, gritty, yellowish-brown powder that found limited use (Wingerd 1971). Membrane filtration then arrived, which allowed for the separation and fractionation of whey proteins while retaining their solubility. Membrane filtration is a molecular sieving technique that employs a 150-μm-thick semipermeable surface supported by a more porous layer of similar material on a reinforcing base. The permeate (soluble compounds of low molecular weight) flows through while passage of the retentate (other materials) is blocked. The filter is made from cellulose acetate, ceramic, polysulfone, or zirconium oxide, and the configuration is usually spiral wound in a stainless steel housing (Henning et al. 2006; Wagner 2001).

The principle of membrane filtration was developed for water desalinization in the 1950s and applied to food processing starting in 1965. Whey processors employ five types of membrane filtration, sometimes in combination: ultrafiltration (UF), microfiltration (MF), electrodialysis (ED), nanofiltration (NF), and reverse osmosis (RO). All are followed by spray drying to obtain a dry (<5% moisture) product, and

Table 1.2. Pressure-driven membrane separation of milk components (Kelly 2003; Wagner 2001).

Type	Pore size (nm)	Components retained	Molecular weight of component (kDa)
MF	20–4,000	Bacteria, casein micelles, fat globules	100–500
UF	20–200	Whey proteins	1–100
NF	<2	Lactose	0.1–1
RO	<2	Ions	<0.1

combinations of these processes are utilized to create whey protein powders with different protein contents. Table 1.2 shows a comparison of the whey filtration techniques.

Whey separation by UF began in 1971. The dividing line between permeate and retentate, known as the molecular weight cutoff (MWCO), is between 3 and 100 kDa for UF membranes; a MWCO of 10 kDa is usually employed for whey (Kosikowski and Mistry 1997b). Whey separation by UF is normally performed at temperatures below 55°C, with an inlet pressure around 300 kPa and a membrane pore size of 250 nm (Wagner 2001). Whey retentate consists of protein, fat, and insoluble salts; lactose, soluble minerals, and much of the water are in the permeate (Table 1.1). Diafiltration (DF), the addition of water to the retentate followed by a second UF, has been developed for the removal of salts and lactose (Scott 1986). Pretreatments such as pH adjustment and preconcentration may improve performance (Muller and Harper 1979).

MF is similar to UF, but with a MWCO of 200 kDa. The membrane pore size may be varied from 0.05 to 10 μm, allowing for selective separation of microbial flora, the different whey proteins, and other components (Kosikowski and Mistry 1997b). This setup would have an internal volume of 800 L, a flow rate of 30,000 L/h, and a concentration ratio of 30:1, meaning that 1,000 L of concentrate and 29,000 L of permeate will be produced each hour (Wagner 2001).

ED is another method for demineralizing whey. In this electrochemical process (the other membrane filtration techniques used for whey are pressure-driven processes), direct current is passed through whey inside chambers with ion-permeable walls.

NF, sometimes called ultra-osmosis, removes particles smaller than 300–1,000 Da, and is also suitable for desalting and demineralizing whey. The method also selectively separates lactose (Kelly and Kelly 1995). An operating pressure between 1.5 and 3 MPa is sufficient to increase the total solids of whey from 5 to 40% while removing 40% of the minerals (van der Horst et al. 1995).

In RO, whey is preheated to 50–55°C and pumped at high pressure (between 2.7 and 10 MPa) through a membrane to remove minerals (Scott 1986). The MWCO is only 150 Da, which may result in membrane-fouling problems (Muller and Harper 1979). Two-thirds of the water in whey can be removed by RO, leaving a concentrate that can be dried or shipped more efficiently (Cryan 2001).

Whey Protein Concentrate and Whey Protein Isolate

UF of whey leads to a selective concentration of the protein, which when dried is whey protein concentrate (WPC). WPC may contain anywhere between 20 and 89% protein; WPC with 35% protein (WPC-35) is a common product. A combination of UF and DF removes minerals and lactose from the retentate, allowing for production of WPC with >50% protein (Kelly 2003). Almost 170 million kilograms of WPC were produced in the United States in 2005, and 86% of it was for human consumption (Gould 2006).

Whey protein isolate (WPI) contains at least 90% protein, with virtually all the lactose removed. An ion-exchange tower, which separates components by ionic charge instead of molecular size, is often used in conjunction with membrane filtration (Foegeding and Luck 2003). The U.S. production of WPI in 2005 was 15.6 million kilograms (Gould 2006).

Benefits of WPC and WPI in food applications include its high protein and amino acid content; low calorie, fat, and sodium content; lack of pathogens, toxic compounds, and antinutritional factors; good emulsification capacity; compatibility with other ingredients; ready availability; and the perception that it is a "natural" product (Renner and Abd El-Salam 1991). WPC and WPI are bland products with typical dairy flavors, such as sweet aromatic and cooked/milky, although heat-generated and lipid oxidation compounds may lead to nondairy flavors (Carunchia Whetstine et al. 2005). The WPI's high protein purity and solution clarity lend itself to use in beverages and nutritional supplements (Foegeding and Luck 2003).

Nutritional Aspects

Whey was prescribed for therapeutic purposes, starting with Hippocrates in 460 BC and continuing through the Middle Ages (Süsli 1956). Whey became a fashionable drink in English cities in the mid-seventeenth century, prompting the opening of whey houses, which were analogous to today's coffee shops. In several of his diary entries in 1663, Samuel Pepys mentioned patronizing the whey house at the New Exchange in London (Pepys 2006). Products made with whey included whey-borse (a broth), whey-butter, whey-porridge, and whey-whig (a drink with herbs) (Trelogan 1970). Whey baths were popular in nineteenth-century spas (Trelogan 1970), and as late as World War II, Central European spas served up to 1.5 kg of whey daily to patients suffering from a variety of ailments (Holsinger et al. 1974).

Serious research on the nutritive value of whey began late in the nineteenth century. Until then milk proteins were classified as casein or whey protein, and the solid obtained from heating whey was called lactalbumin. Around 1890, research showed that a precipitate, named lactoglobulin, was formed from the addition of magnesium sulfate or ammonium sulfate at low pH (Creamer and Sawyer 2003). The lactalbumin fraction was first crystallized in the 1930s (Palmer 1934) and the major whey proteins that were eventually isolated were named β-lactoglobulin (β-LG) and α-lactalbumin (α-LA). Later discoveries included bovine serum albumin, lactoferrin, lactoperoxidase, numerous types of immunoglobulins, and other minor proteins.

Table 1.3 shows the types and amounts of whey proteins and other components in bovine milk. Over half of ruminant and porcine whey protein consists of β-LG; it is not an abundant protein in the milk of other species (Walzem et al. 2002). β-LG is stable against stomach acids and proteolytic enzymes, is a rich source of the essential acid cysteine, and may be responsible for carrying the vitamin A precursor retinol from the cow to its calf (Said et al. 1989). α-LA, which binds calcium, is similar to the primary protein in human breast milk and is thus used in infant formula. The many branched-chain amino acids it contains are used by muscles for energy and protein synthesis, making it a popular

Table 1.3. Typical composition of bovine milk (de Wit 1998; Fox et al. 2000).

Component	Concentration (g/L)
Water	873
Fat	37
Lactose	48
Ash (minerals and salts)	7
Casein	28
Whey proteins	6.0
β-Lactoglobulin	3.2
α-Lactalbumin	1.2
Bovine serum albumin	0.4
Immunoglobulins	0.8
Lactoferrin	0.2
Lactoperoxidase	0.03
Enzymes	0.03

sports food nutrient (Tawa and Goldberg 1992). Bovine serum albumin is identical to blood serum albumin and transports insoluble free fatty acids (de Wit 1998). Immunoglobulins carry passive immunity to the newborn calf via colostrum. The iron-containing bioactive protein lactoferrin has antibacterial, antiviral, and antioxidant properties and also modulates iron metabolism and immune functions (Walzem et al. 2002). Lactoperoxidase, another bioactive protein, is part of a bactericidal system (de Wit 1998). There are also perhaps 60 enzymes in whey (Fox et al. 2000) and a few other proteins in miniscule amounts. In addition, whey protein promotes muscle synthesis, the calcium and mineral mix may mediate body composition by shifting nutrients from adipose to lean tissue, and bioactive compounds isolated from whey may improve immune function and gastrointestinal health (Ha and Zemel 2003).

Functionality

Whey protein is used in many food applications because of its functionality and nutritive value. Whey protein foams well, meaning that it creates and stabilizes air bubbles in a liquid (Renner and Abd El-Salam 1991). Whey protein also remains soluble from pH 2 to 10 and stabilizes emulsions by forming interfacial films between hydrophobic and hydrophilic food components (Burrington 2005; Haines 2005). Ice creams, soufflés, frothed drinks, and other food foams and emulsions are stabilized by surface-active agents for which whey protein products are frequently chosen (Foegeding et al. 2002). Processed cheeses, which are also emulsions, contain whey protein to improve melting, slicing, and spreading (Foreign Agricultural Service 2003).

Acid whey powder improves the crust color and enhances flavor in bread, biscuits, crackers, and snack foods, providing a golden surface on baking (Kosikowski 1979). Whey proteins unfold and aggregate on heating, and are capable of binding large amounts of water depending on pH, ionic strength, and thermal conditions (Hudson et al. 2000). Addition of WPI to muscle protein, for instance, improves moisture retention (McCord et al. 1998). WPC has been used to increase solids and protein content in milk and cheese and to replace fat in low-fat dairy products.

Protein gelation may be defined as a balance of protein–protein and protein–water interactions, enabling the formation of a three-dimensional network (Renner and Abd El-Salam 1991). β-LG, the primary protein in whey, does not heat-denature until about 78°C, providing good thermally induced gelation properties (Paulsson and Dejmek 1990). β-LG also has a high solubility at low pH, making it an ideal active ingredient in fortified acidic beverages (Smithers et al. 1996). Lactoferrin has potential as a natural antimicrobial agent in such products as personal health items, pharmaceuticals, and specialty dietary formulations (Smithers et al. 1996). Whey proteins can also be extruded and added to other foods to improve nutritional value and texture (Onwulata and Tomasula 2004). Variations in whey functionality depend on the variety of cheeses and the processes used in manufacturing them, the severity of heat treatment required to isolate the whey protein, and other factors (Dybing and Smith 1991; Onwulata et al. 2004).

Applications

WPC and WPI are used in baked goods and baking mixes; cakes and pastries; candy, chocolate, and fudge; coffee whiteners; crackers and snack foods; diet supplements; fruit beverages; gravies and sauces; infant formulas and baby food; mayonnaise; pasta; pie fillings; processed dairy products including ice creams; processed fruits and vegetables; salad dressings; soups, meats, and sausage; and sports drinks (Cryan 2001; Kosikowski 1979). WPC with lower protein content tends to be used more in the lower-value food products, such as dairy and bakery items, and higher concentrated WPC is generally used in higher-value products, such as meat and seafood (Foreign Agricultural Service 2003). Medicinal and nutritional products are obtained by fractionation of whey by membrane filtration into its various proteins (Zydney 1998).

Outlook

The cost of purchasing and installing whey-processing equipment has prevented some smaller, older cheesemaking plants from processing and selling whey. Some 30% of the whey from U.S. cheese manufacture is not sold as a result, but in modern plants in the major cheese-producing regions, whey is actively marketed and supplies approximately 11% of the revenue (Balagtas et al. 2003). Texturization of whey proteins by extrusion of WPC and WPI will soon be applied to meat extenders, snack foods, and other products (Onwulata and Tomasula 2004), and the functional properties of these texturized whey products are still being investigated (Onwulata et al. 2003; Tunick and Onwulata 2006). Whey protein has been tested in clinical trials of cancer, hepatitis B, and HIV patients with promising results (Marshall 2004). Nonfood applications such as oxygen barriers and film coatings made from denatured WPC-80 and WPI show a good likelihood of adoption by industry (Balagtas et al. 2003).

There is a new expression in the dairy business: “Cheese to break even, whey for profit.” This adage should hold true for the foreseeable future as new whey protein products and applications continue to be introduced.

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