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CHAPTER 22

POTENTIAL APPLICATIONS FOR LACTOSE-HYDROLYZED MILK AND WHEY FRACTIONS IN DAIRY FOODS

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The potential for the enzymatic modification of the lactose in dairy products has been recognized since the early 1950s. With the commercial development of effective lactases (β-galactosidases) isolated from microbial sources, the widespread production of lactose-modified dairy products became possible. At present, lactose-modified beverage milk may be purchased in some local supermarkets and in some dairy stores.

AVAILABLE ENZYMES

The two lactase enzymes of commercial significance are isolated from the yeast *Saccharomyces lactis* (*S. lactis*) and the fungus *Aspergillus niger* (*A. niger*). These lactases vary widely in their properties, particularly in pH and temperature optima. Lactase from *S. lactis* has a pH optimum of 6.8 to 7.0, a pH stability of 6.0 to 8.5, and a temperature optimum of 35°C. The lack of stability below pH 6.0 precludes the use of *S. lactis* lactase in treating acid whey (pH 4.5), although it is well suited for treating milk (pH 6.6) and sweet whey (pH 6.2). However, *A. niger* lactase, with a pH optimum of 4.0 to 4.5, wide pH stability (pH 3.0 to 7.0), and a temperature optimum of 55°C, is available for the enzymatic modification of acid whey (Woychik and Holsinger 1977).

Purity, activity, and cost of the lactases must be considered in the development of any large-scale enzymatic manufacturing process for lactose hydrolysis. The simplest method is to add the soluble enzyme directly to the milk; however, batch operations of this type are expensive because the enzyme is not recoverable for reuse.

Immobilized enzyme technology has been evaluated with lactases to improve the economics of lactose hydrolysis. A detailed discussion of the physical and chemical methods available for lactase immobilization is outside the scope of this chapter, but the subject has been reviewed (Wondolowski 1976). A satisfactory immobilized system has not been developed with *S. lactis* lactase because of a lack of stability after immobilization (Woychik et al. 1974). *A. niger* lactase, however, has proven adaptable to immobilized systems, although some operating difficulties still exist (Olson and Stanley 1973, Hustad et al. 1973, Hasselburger et al. 1974).

Applications. Hydrolysis of the lactose in milk or whey results in changes ir several physical and chemical properties of interest to the dairy manufacturer Benefits include reduction of lactose content, prevention of lactose crystalliza tion, increase in solubility and sweetness, and more readily fermentable sugars Applications are obvious, not only for modifying functional characteristics, bu also for providing low lactose dairy products for the lactase-deficient or lactos intolerant individual.

Test Products. Evaluation of lactase in product manufacture was conducted b preparing a series of dairy products from lactase-treated milk with 28% to 90% c the lactose converted to monosaccharides (Guy et al. 1974). The enzyme use was isolated from *S. lactis* as a colorless free-flowing powder; the enzyme is als available in fluid form in a glycerol carrier. Lactose hydrolysis was carried out

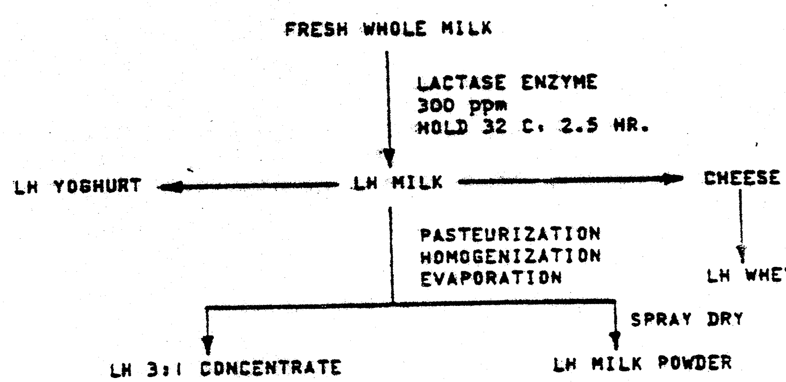

FIGURE 22.1. Preparation of low-lactose dairy products.

a batch operation by incubating fresh pasteurized whole or skimmed milk preheated to 32°C with 300 ppm lactase for 2.5 hours with continuous agitation (fig. 22.1) or by treating milk held in the silo at 4°C with 150 ppm for 16 to 18 hours (Thompson and Brower 1976). After treatment in this manner, the fluid milk could be used directly as a beverage or processed further into other products (fig. 22.1).

MODIFIED MILK APPLICATIONS

When the organoleptic qualities of lactase-treated milk were evaluated, some difficulties were encountered because hydrolysis of lactose to the constituent monosaccharides glucose and galactose resulted in a marked increase in sweetness intensity of the milk. An objective sweetness scale, developed to simplify reporting the changes brought about by lactose hydrolysis, permitted the results of lactase action to be equated with the addition of sucrose to untreated milk. Hydrolyzing 30%, 60%, and 90% of the lactose present had almost the same effects on flavor as adding 0.3%, 0.6%, and 0.9% sucrose, respectively, to the milk (Guy et al. 1974).

Although the only flavor change detected in lactase-treated beverage milk was the increased sweetness, there was some question as to whether this change would be acceptable to the consumer. In a study carried out at The Johns Hopkins University, Paige et al. (1975) reported that Negro adolescents, a target population for low-lactose milk, found milk with 90% of its lactose in the hydrolyzed form was acceptable to drink even though 56% of the respondents judged it to be sweeter than an untreated control.

Frozen 3:1 Concentrates. A highly attractive way of preserving milk with minimal flavor change is in the form of a frozen 3:1 concentrate. Unfortunately, such concentrates thicken and coagulate during storage because of the crystallization of lactose, which is brought to the saturation point by concentration of the milk.

Early research had shown that lactose hydrolysis led to improved physical stability of concentrated milks during storage (Tumerman et al. 1954). However, when milk with 90% of its lactose hydrolyzed by lactase was concentrated and frozen, storage stability was increased by only one month over that of an untreated control (fig. 22.2). Further examination of Tumerman's work has shown that the samples had been heated above pasteurization requirements. Subsequently, samples that were postheated at 71°C for 30 minutes after being canned showed only a moderate rise in viscosity after the nine months of storage (fig. 22.2). There was no significant difference in flavor score of the reconstituted concentrate containing 90% hydrolyzed lactose and an untreated fresh control with added sucrose (Guy et al. 1974, Holsinger and Roberts 1976).

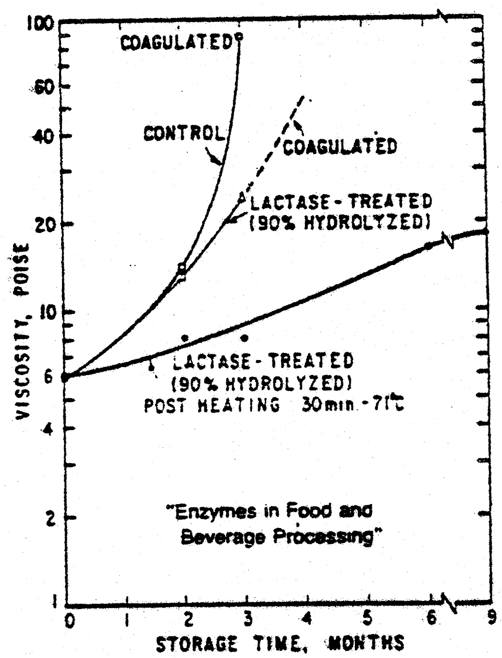

FIGURE 22.2. Effect of storage on viscosity o frozen 3:1 pasteurized whole milk concen trates. Source: Woychik and Holsinger 1977, p. 72, reprinted with permission.

Dried Products. Some problems were encountered in spray drying skim an whole milk concentrates. Because of the lactose hydrolysis, the powder, espe cially the skim powder, had a tendency to stick to the hot metal surfaces of th spray dryer. The powder also lumped in the cone and star valve unless coole with forced dry air as it left the cone. When the sticking properties of low-lactos nonfat dry milk were investigated, it was found that the "sticking" temperatur was lowered 10 to 15 degrees by the lactose treatment as compared with that o an untreated skim powder of comparable moisture content (table 22.1).

For efficient spray drying, the surfaces of the powder collecting apparatu should be held at temperatures below 60°C. Drying temperatures should b reduced to a minimum, and the powder should be cooled rapidly after collectio to avoid clumping.

TABLE 22.1
"Sticking" temperatures of low-lactose nonfat dry milk

Sample	Percentage lactose hydrolyzed	Sticking point (°C)
Control	0	75.4
Low-lactose A	80	59.2
Low-lactose B	87	64.6

Source: Guy et al. 1974, table 10, reprinted with permission.

Cultured Products. Cultured products always have been of interest to the lactase-deficient individual because of the fermentation of the lactose. Cultured products manufactured from lactase-treated milk include buttermilk, yogurt, and cottage and cheddar-type cheeses.

Low-lactose cultured buttermilk has been prepared readily from lactase-treated milk. However, the increased sweetness brought about by lactose hydrolysis was objectionable to most consumers even though the coagulation time was reduced (Gyuricsek and Thompson 1976).

Yogurt, particularly the fruit-flavored types, is enjoying a rapidly increasing popularity. Yogurt generally has been thought to contain low levels of lactose because of the utilization of lactose during the fermentation process. However, only about 15% to 20% of the lactose is utilized during fermentation, and the practice of fortifying yogurt with nonfat milk results in appreciable amounts of added lactose. Lactose values of 3.3% to 5.7% have been reported in commercial yogurts, amounts comparable to that found in fluid milk (Goodenough 1975).

Lactase treatment of milk prior to yogurt manufacture resulted in accelerated acid development, which may be due to the more rapid utilization of total available carbohydrate when free glucose is present. For example, from a starting lactose concentration of 7.11%, only about 26% of the lactose was utilized, yielding a lactose concentration of 5% in a control (table 22.2). Yet when the milk was lactase-treated before being cultured, the sugar utilization pattern was quite different; the galactose was not utilized at all by the organisms and an appreciable amount of the lactose was still present (table 22.2) (O'Leary and Woychik 1976).

The manufacture of yogurt from lactase-hydrolyzed milk also made plain yogurt more acceptable to the consumer. On a nine point hedonic scale (Peryam and Pilgrim 1957), lactase-treated yogurt was rated 6.1 compared to 4.9 for the control (Holsinger 1978). The acid flavor appeared to be reduced by the lactase treatment, and consumers in the United States generally prefer less acid yogurts.

TABLE 22.2
Sugar concentrations in control and lactase-treated yogurts

	Percentage	
Sugar	Control	Lactase-treated
Lactose	5.0	1.5
Glucose	0.0	1.6
Galactose	0.2	2.1

Source: O'Leary and Woychik 1976, table 1, copyright © Institute of Food Technologists, reprinted with permission.

The manufacture of cheddar and cottage cheeses from lactase-treated milk has been described (Thompson and Brower 1976, Gyuricsek and Thompson 1976). In the case of cheddar cheese manufacture, lactose prehydrolysis is advantageous from an economic standpoint; there is virtually no lactose present in aged cheese. Cheddaring time is reduced, and, more important, the ripening time is accelerated so the cheese can be marketed more quickly. Set time is reduced when cottage cheese is made from lactase-hydrolyzed milk, and, in some cases, increased yields have been found.

WHEY APPLICATIONS

A spin-off of the manufacture of cheddar and cottage cheeses from lactase-treated milk is that the whey produced contains hydrolyzed lactose. Economic whey disposal is a problem that has plagued the dairy industry for many years. In 1978, 37.9 billion pounds of whey were produced in the United States, only about 60% of which was utilized (Crop Reporting Board 1979). Because of stringent antipollution regulations, whey is finding its way into more and more food products instead of being disposed of in streams and municipal sewage systems. Modification of the whey by lactase treatment offers considerable potential for new avenues of utilization.

Whey is the greenish-yellow fluid drained from the vat after the casein portion of the milk has been coagulated during cheese manufacture. Its solids contain about 50% of the nutrients of milk (Holsinger et al. 1973); although small amounts of high quality protein equivalent to that of egg are present, fluid whey is essentially a crude solution of lactose (table 22.3).

The increased sweetness brought about by lactose hydrolysis suggests that lactase-modified whey might be useful as an ingredient in sweet foods. The low sweetness level of unhydrolyzed lactose in solution relative to sucrose and other sweeteners does not permit its use as a sweetener, but both glucose and galactose are sweeter than the lactose (table 22.4). In addition, the increase in solubility brought about by treatment with lactase permits the manufacture of noncrystalliz-

TABLE 22.3
Composition of whey solids

Component	Sweet whey	Acid whey
Total protein	11.5%	11.4%
Lactose	74.4%	66.8%
Ash	7.4%	10.2%
Lactic acid	<1.0%	9.8%
Fat	2.7%	<1.0%
pH	6.5	4.7

Source: Holsinger 1976, table 1, reprinted with permission.

TABLE 22.4
Relative sweetness of sugars

Concentration to give equivalent sweetness (percentage)				
Sucrose	Glucose	Fructose	Lactose	Galactose
1.0	1.8	0.8	3.5	2.1
5.0	8.3	4.2	15.7	8.3
10.0	13.9	8.6	25.9	15.0

Source: Holsinger 1976, table 3, reprinted with permission.

ing high solids syrups for use in beverages, ice creams, and in other foods (table 22.5).

Whey Beverages. The use of whey and its fractions for beverage manufacture has been studied extensively, especially in Europe (Holsinger et al. 1974). Such beverages include alcoholic and snack drinks, milk analogues, and liquid breakfasts with protein contents ranging from less than 0.5% to more than 3.5% (table 22.6).

Wines. The consumption of table wines is increasing rapidly in the United States. In 1978, 2.81 gallons per capita were consumed, representing a market value of more than $2 billion (1979 Market Index 1979). A major problem, however, in utilizing whey as a fermentation substrate has been that relatively few organisms can ferment lactose, *Kluyveromyces fragilis* being the most efficient (O'Leary et al. 1977a). These organisms are also much less alcohol tolerant than glucose fermenting wine yeasts such as *Saccharomyces cerevisiae*.

The availability of lactase-hydrolyzed wheys and whey permeates prepared by ultrafiltration led O'Leary et al. (1977a, 1977b) to compare alcohol production in these media with *S. cerevisiae* and *K. fragilis*. A diauxic fermentation pattern was found in the lactase-treated media, with glucose being fermented before galactose; although *S. cerevisiae* produced alcohol from glucose more rapidly

TABLE 22.5
Solubility of sugars in water at room temperature

Sugar	Solubility
Sucrose	67.9%
Glucose	45.4%
Fructose	80.3%
Lactose	18.0%
Galactose	40.6%

Source: Holsinger 1976, table 2, reprinted with permission.

TABLE 22.6
Types of whey beverages

Beverage use	Percentage protein
Alcoholic beverages	
Kwas, beer, kefir, wine	<0.5
Snack beverages	
Soft drinks	0.5–1.0
Drink powders	
Imitation milks	1.0–1.5
Liquid breakfast, dietary supplements	2.5–3.5

Source: Holsinger et al. 1974, reprinted with permission.

than did *K. fragilis*, galactose was fermented only when *S. cerevisiae* was pregrown on galactose. With *S. cerevisiae*, alcohol yields as high as 6.5% were obtained in lactase-treated permeates condensed to 30% to 35% total solids before inoculation; maximum yield with *K. fragilis* was 4.5% at 20% total solids. It was concluded from these studies that, although prehydrolysis of the lactose in wheys and whey permeates is advantageous in that microbial species unable to ferment lactose may be used, commercial processes must consider diauxic problems and must efficiently convert galactose to alcohol.

Researchers at Oregon State University demonstrated the possibility of making a whey wine using a wine yeast. As an extension of this work, the Foremost Food Company,* under an EPA grant, investigated the technical and economic feasibility of whey wine production under commercial conditions.

After the whey protein was removed by ultrafiltration, the whey permeate was given an infusion of glucose, inoculated with wine yeasts, and fermented for 8 to 12 days; 8% to 12% alcohol developed in the mixture. After this was racked, demineralized, and decolorized, a crystal clear product was obtained that then could be processed further into a lightly carbonated "pop" wine (fig. 22.3). All of the lactose was still intact and present in this wine. Processing with a lactose fermenting organism was not practical because lactose fermentation is more time consuming, and thus more costly (Palmer and Marquardt 1978).

Nonalcoholic Beverages. Carbonated beverages of the soft drink type containing whey components are available commercially. Probably the best known of these is Rivella, which appeared on the market in Switzerland in 1952 (Holsinger et al. 1974). Rivella is a sparkling, crystal clear, herbal infusion of deproteinized whey, promoted as something of a therapeutic tonic. This product contains about 9.7% total solids, 45.5% of which are lactose.

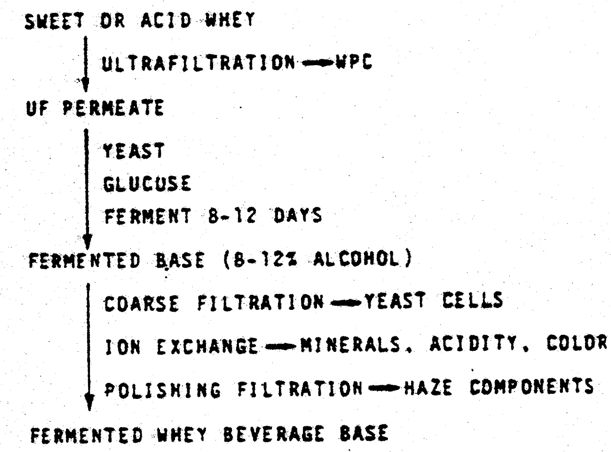

FIGURE 22.3. Process flow chart for whey wine production. Source: Palmer and Marquardt 1978, p. 31, reprinted with permission.

A lactase-hydrolyzed whey permeate has been used to develop a prototype snack-type soft drink, "Lactofruit," projected to be cheaper to produce and sell than other whey beverages because of the unique process employed (Fresnel and Moore 1978). The process involves ultrafiltration of the whey, followed by lactose hydrolysis by enzymatic electrocatalysis. Enzymatic electrocatalysis is advantageous in that it is able to counterbalance the loss of enzyme activity with time; the current is regulated continuously so that local pH variations are compensated for and enzyme activity is maintained at a constant level. The basic composition of Lactofruit shows that, in spite of lactase treatment, only 50% hydrolysis was attained; some lactose does remain in the beverage (table 22.7). However, since the drink is not fermented, the taste quality is sweet and different from that of most other whey beverages.

The soft drink market in the United States is enormous; in 1978, 7.6 billion gallons, sufficient to supply 369 12-ounce bottles per capita per annum and

TABLE 22.7
Proximate composition of Lactofruit

Component	g/liter
Glucose	12.5
Galactose	12.5
Lactose	25.0
Ash	4.0–5.0
Nitrogenous components	2.0
Sucrose + flavorings	20.0

Source: Fresnel and Moore 1978, p. 45, reprinted with permission.

representing an estimated wholesale value of $12 billion, were produced (1979 Market Index 1979). Consequently, the whey producers would be very interested in penetrating this market. At the present time, Rivella is undergoing test marketing. Therefore, it is a good possibility that soft drinks containing various levels of lactose, glucose, and galactose soon may be available in the United States; they are already widely available in Europe.

High Protein Beverages. An example of a high protein beverage containing significant amounts of lactose is whey-soy drink mix, a milk analogue designed for use in child feeding programs in developing countries (Holsinger et al. 1977). The formulation, containing 41.3% whey solids, yields a finished product containing about 50% carbohydrate, the bulk of which is lactose.

Because the product was designed for preschool children, no problems with lactose intolerance were anticipated. However, it has been shown that as much as 50% of the population could be lactase deficient by 3 years of age in developing countries, where whey-soy drink mix was distributed (Paige et al. 1972); it seemed advisable to investigate lactose-modified whey-soy drink mix. After trial production runs and storage tests were made with whey with 90% of its lactose hydrolyzed, it was concluded that no production difficulties existed. An additional benefit was conferred by lactase treatment, since consumers preferred the hydrolyzed lactose whey-soy drink mix because of the noticeably sweeter taste (Holsinger and Roberts 1976).

Frozen Desserts. Ice cream and other frozen desserts represent a large outlet for milk. In 1978, 1.20 billion gallons were produced (Crop Reporting Board 1979).

Present ice cream standards permit whey to be used in ice cream up to a level of 25% of the milk-solids-not-fat. Because there had been plans to alter these standards, Guy (1980) evaluated the use of lactase-treated whey as an ingredient in ice cream. Formulation with lactase-treated whey permitted a reduction of 10% or more in the concentration of the cane sugar without loss of quality (table 22.8). This suggests that lactase-treated whey might be used effectively as an ingredient in calorie-reduced sweet foods. Unfortunately, reduction of the milk-solids-not-fat with increasing levels of whey amounted to a 30% increase in the ash and a 20% decrease in the protein content of an ice cream prepared with 11% whey solids.

Another possibility for utilization of lactase-treated whey is as an ingredient in novelty water ices on a stick. According to Guy et al. (1966), cottage cheese whey could be incorporated into water ices at a 2.3% solids level. This is advantageous in that addition of acid whey permits the manufacture of less acid water ice; the calcium and phosphate present in the whey also are present in the ice pop and could be beneficial in reducing dental cavities (Wagg et al. 1965). With only slight formula modifications, lactase-hydrolyzed whey also could be used in water ices.

TABLE 22.8
Formulation of ice creams

Percentage		
Whey solids*	Milk-solids-not-fat	Cane sugar
0.00	11.00	15.00
2.75	9.50	13.75
5.50	8.00	12.50
8.25	6.50	11.25
11.00	5.00	10.00

Source: Guy 1980, table 2, copyright © Institute of Food Technologists, reprinted with permission.
Note: Based on 12% fat and 0.14% stabilizer.
*67% or 79% hydrolyzed lactose.

Sherbet formulations containing whey solids also have been developed; whey is added at the 5% level (Whittier and Webb 1950). Lactase-treated whey might be a suitable ingredient for sherbet manufacture with only minor formula alterations.

Syrups. Clear, noncrystallizing high solids syrups may be prepared from hydrolyzed-lactose or lactase-treated whey for use as food ingredients. A syrup may be prepared readily with *S. lactis* lactase by treating a lactose solution at pH 6.4 for 6 hours at 30°C. After being heated to inactivate the enzyme, the low-lactose mixture is then decolorized, filtered, demineralized with ion exchange resins, and condensed to 60% total solids (fig. 22.4) (Guy 1978).

At high concentrations, hydrolyzed-lactose syrups are just as sweet as equiva-

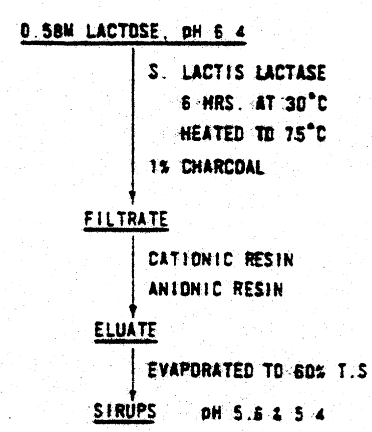

FIGURE 22.4. Process flow chart for enzyme-processed syrups. Source: Guy and Edmondson 1978, p. 544, reprinted with permission.

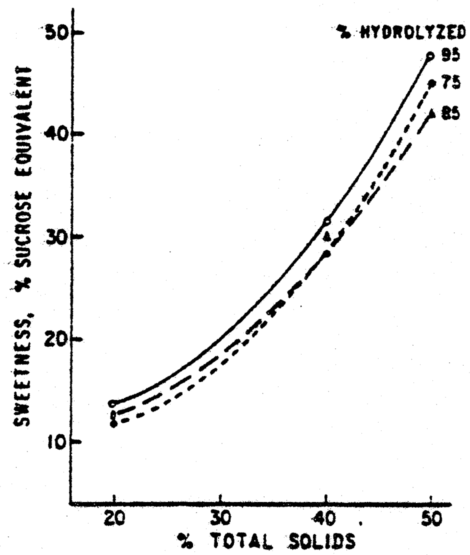

FIGURE 22.5. Sweetness equivalence to sucrose for hydrolyzed-lactose syrups. Source: Guy and Edmondson 1978, p. 546, reprinted with permission.

lent solutions of sucrose (fig. 22.5). Although these syrups cannot compete economically with corn syrups in the United States, in Europe lactase-hydrolyzed syrups from lactose or whey are finding a market as ingredients in some sweet foods.

Confections. Whey has been used for many years as an ingredient in candy. Webb (1966) described a variety of confections in which whey has been used successfully as an ingredient (table 22.9). At present, whey finds its greatest use in caramel manufacture (Alikonis 1973).

Guy (1978) evaluated lactase-hydrolyzed whey and hydrolyzed-lactose syrups as humectants in caramels. Caramels prepared without humectant showed much more sugar crystallization and shrinkage than those containing hydrolyzed-

TABLE 22.9
Candy from whey

Variety	Whey as percentage of total candy solids
Wheyfers	40
Whipped fudge	14
Caramel	21
Taffy	26
Fudge	20

Source: Webb 1966, table 2, reprinted with permission.

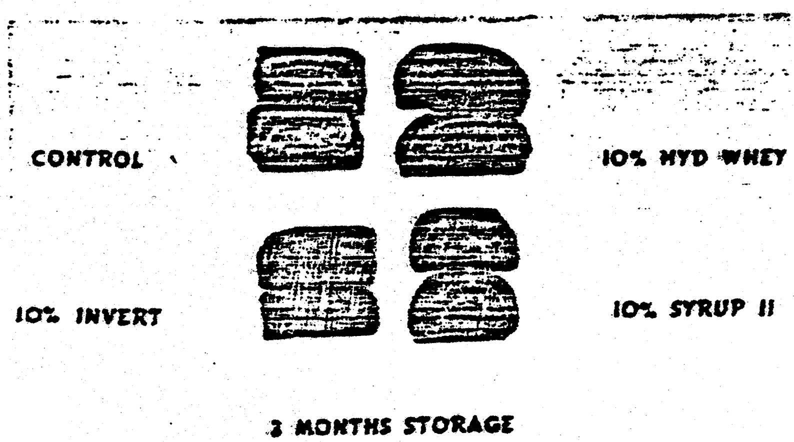

FIGURE 22.6. Physical appearance of caramels after three months of storage at 23°C. Source: Guy 1978, p. 983, copyright © Institute of Food Technologists, reprinted with permission.

lactose syrup or whey (fig. 22.6). After six months of storage, the caramels that contained hydrolyzed-lactose syrups had lost significantly less moisture than had the controls. The sample with the best taste quality was a caramel prepared with the hydrolyzed-lactose syrup.

Presently, whey is not permitted to be added to chocolate because it is not an optional ingredient within the chocolate standards (U.S., Office of Federal Register 1973). However, a successful chocolate formulation containing whey has been developed (O'Connell 1975). The particular whey was 25% demineralized and was used not only as a sucrose replacement but also as a replacement for part of the chocolate liquor (table 22.10). No examples of the lactase-hydrolyzed whey being used in this type of application are currently available; however, if the price of cacao keeps rising, economic factors may bring about the addition of whey to chocolate as well.

TABLE 22.10
Chocolate formulation from whey

	Percentage	
Ingredient	Control	Experimental
Chocolate liquor	12.5	10.0
Whole milk solids	18.0	18.6
Cocoa butter	21.0	21.6
Sucrose	48.0	35.9
Whey solids	—	13.3
Lecithin and vanillin	0.5	0.5

Source: O'Connell 1975, p. 116, reprinted with permission.

SUMMARY AND CONCLUSIONS

Possibilities for widespread production of lactose-modified dairy products have been opened up by the development of commercial sources of the enzyme lactase (β-galactosidase). Low-lactose fluid milk is commercially available. Such milk, when condensed, may be used to manufacture frozen 3:1 concentrates that do not thicken and coagulate during storage. Lactose-modified nonfat dry milk may be manufactured for use as a food ingredient. Cultured products such as yogurt also may be prepared successfully from lactase-treated milk.

Antipollution regulations have brought about the increased use of cheese whey in foods. Lactose-modified whey may be condensed to high solids noncrystallizing syrups for use in soft drinks and confections. Some traditional wine yeasts will ferment low-lactose whey for the manufacture of whey wine. Lactase-treated whey, when added as an ingredient in ice cream, permits a 10% sucrose reduction. Use of lactase-treated products may lead to production efficiencies and permit monetary savings as well as provide nutritional advantages to the lactase-deficient segment of the population.

The dairy industry today has the technology available for the enzymatic hydrolysis of the lactose in milk and milk products. Lactose-modified milks and dairy products may be used with confidence by the lactose-intolerant or lactase-deficient individual. Because of the increased sweetness, some lactase-treated products could be utilized in calorie-reduced sweet foods. Whey production is increasing every year and raises special utilization problems. However, application of lactase enzyme technology offers new opportunities for innovative whey processing into more profitable outlets.

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