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WHEY AND LACTOSE

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INTRODUCTION

Cheese production in the U.S. has doubled in the last 10 years (Table 1),* and with it the amount of whey to be processed or disposed of as waste. Although the major portion of whey produced is utilized, in the past the excess was simply disposed of as waste. However, the various state and federal environmental regulations now in force prohibit whey disposal into rivers and streams and demand that it be disposed through sewage treatment facilities. The alternative to disposal is utilization; as a result, new technologies have been developed to achieve this goal.

Whey, the watery by-product of cheese manufacture, represents approximately 90% of the original milk volume and contains over half the original milk's nutrients. The more than 35 billion lb of whey produced in 1978 (Table 1) (6.5% average solids content) represents over 2 billion lb of nutrients, primarily lactose and protein. Detailed compositions of liquid and dried whey are compared with skim milk in Tables 2 and 3. The principal difference between the two is that whey contains about 40% more lactose and one third less protein, reflecting the removal of casein as cheese curds. The removal of casein, the major milk protein, means that whey protein is composed chiefly of β-lactoglobulin and α-lactalbumin, two proteins having unique functional characteristics. Despite these differences in protein composition, dried whey can serve as a nonfat milk replacer in a wide variety of food applications. Additional information on dried whey will be found in the chapter entitled "Dehydrated Dairy Products."

Whey proteins are an important component of whey not only because of their functional properties in food systems, but because they possess an excellent balance of essential amino acids.[1,2] A comparison of the essential amino acid profile of whey protein with the Food and Agricultural Organization (FAO) standard profile is presented in Table 4.[3] The FAO nutritional profile is required for optimal growth in humans and animals. Whey protein obviously exceeds the standard requirements in each of the essential amino acids and thus provides the rationale for upgrading protein quality in a number of foods through fortification with whey.

Two principal types of whey are produced in the U.S., sweet whey with pH of 5.9 to 6.3 originating from ripened cheeses (e.g., cheddar) and acid whey, pH 4.4 to 4.6 from unripened cheeses (e.g., cottage cheese). Acid whey contains more lactic acid, calcium, and phosphorus and presents greater difficulties in utilization than does sweet whey. Some specialized uses for acid whey are presented later. An example of variations in composition among selected wheys is shown in Table 5.

Whey is utilized in a variety of product forms. These are described below in a Food and Drug proposal to affirm the generally recognized as safe (GRAS) status of whey and whey products as direct human food ingredients.[4]

1. Whey is the liquid substance obtained by separating the coagulum from milk, cream, or skim milk, as in cheesemaking. Whey obtained from a cheesemaking procedure where a significant amount of lactose is converted to lactic acid is known as acid whey. Whey obtained from a cheesemaking procedure where there is insignificant conversion of lactose to lactic acid is known as sweet whey (meets maximal titratable acidity and alkalinity of ash requirements as set out in §

135.110(b) (21 CFR 135.110(b). The pH of the whey, sweet or acid, may be adjusted by the addition of safe and suitable pH adjusting ingredients.

2. Concentrated whey is the liquid substance obtained by partial removal of water from whey, while leaving all other constituents in the same relative proportions as in whey. The whey solids must be not less than 40%. The percent of solids, i.e., "concentrated whey (______% solids)," must be declared on the label of the finished whey product.
3. Dried (dry) whey is the dry substance obtained by the removal of water from whey, while leaving all other constituents in the same relative proportions as in whey.
4. Dried (dry) reduced lactose whey is the dry substance obtained by the selective removal of lactose from whey, followed by the removal of water. The percentage of lactose removed must be not less than 25% and the lactose content of the finished product must not exceed 60% on a solids basis. The percent of lactose present on a solids basis, i.e., "dried (dry) reduced lactose whey (______% lactose)," must be declared on the label of the finished whey product.
5. Dried (dry) reduced minerals whey is the dry substance obtained by the selective removal of at least 50% of the minerals from whey, followed by the removal of water. The finished product must contain not more than 7% ash on a solids basis. The percent of minerals present on a solids basis, i.e., "dried (dry) reduced minerals whey (______% minerals)," must be declared on the label of the finished whey product.
6. Dried (dry) whey protein concentrate is the dry substance obtained by the removal of sufficient nonprotein constituents from whey so that the finished product contains at least 30% protein on a solids basis, followed by the removal of water, the percent of protein present on a solids basis, i.e., "dried (dry) whey protein concentrate (______% protein)," must be declared on the label of the finished whey product.

Each of the above product forms has its own special application; nevertheless, greatest utilization of whey is still as dried whole whey. Dried whey production in the U.S. has grown from over 200 million lb in 1960 to over 700 million lb in 1978 (Table 6). A comparison of the production of whey and modified whey products is shown in Table 7. Animal feed use is included and represents a substantial portion of whey utilization. It should be particularly noted that the percentage of total whey utilization is approximately 55%; this portion has remained fairly constant over the past 10 years. The volumes produced and end uses of whey and whey products in human food and animal feed are shown in Tables 8 and 9.

WHEY PROCESSING

Concentrates

Since whey is over 93% water and is highly perishable, it must be converted rapidly to a more storable product pending final utilization. This is accomplished most readily through evaporation of pasteurized whey to 40 or 50% total solids; above 55% solids, the condensate will gel or solidify after cooling. Condensation of whey is usually accomplished through vacuum evaporation in multiple effect evaporators containing two, three, four or up to ten units, with the efficiency of water removal per pound of steam increasing with each added effect.[5] Under certain circumstances, initial concentration can be accomplished more economically by use of reverse osmosis membrane technology, discussed later.

Dried Whey

The production of quality dried whey depends upon a variety of factors such as degree of acid development, removal of casein fines, fat removal, and hygroscopicity. A typical drying process consists of pasteurization and evaporation to 40 to 50% solids followed by cooling and holding sufficiently to obtain lactose crystallization, usually in the range of 40 to 60%. Maximal lactose crystallization in the final product is essential to produce a free-flowing nonhygroscopic powder. Following crystallization, the whey is spray dried in a direct fired drier to a final moisture content of 6 to 14%. Maximal lactose crystallization can be obtained in a two-stage process wherein final crystallization takes place in a secondary drier such as a tunnel, shelf, or internal drum to remove approximately 8% additional moisture. The powder is then bagged at a final 3% moisture. Whey drying has been reviewed in detail by Young[5] and Hall and Hendrick.[7]

Demineralized Whey

Demineralization of whey is desirable in a variety of products, notably infant foods wherein the ash content is reduced below 4%. The two most widely used demineralization processes for whey are electrodialysis (ED) and ion-exchange (IE), both having been used commercially for more than 20 years. In the U.S., electrodialysis has been the preferred system. Both processes are ion-exchange techniques relying on cation and anion exchange resins or ion-permeable membranes. Each process has its advantages and disadvantages. ED has high capital costs and is best justified with a high degree of use. Effective demineralization by ED is practically limited to between 60 to 70% but requires no regeneration and can therefore be used in a continuous process. IE can be used for the complete demineralization of whey. However, although there are effluents streams in both processes, with IE the effluent can be 2.5 times the volume of whey. Loss of ion-exchange resin due to attrition and costs of regenerating chemicals can affect the economics of demineralization. Significant loss of product occurs in both processes and can reach 10%, contributing significantly to the effluent BOD. Electromembrane technology has been reviewed by Ahlgren,[8] and ion-exchange by Delaney and Donnelly.[9]

Ultrafiltration

Processing of whey by ultrafiltration (UF) represents a newer technology capable of producing a wide range of whey protein concentrates (usually 30 to 50% protein) and a lactose rich by-product permeate. Like reverse osmosis, UF is a membrane separation process utilizing membranes made of cellulose acetate or newer alkali and acid resistant polymers. These membranes have pores capable of passing small molecules while retaining larger molecules such as proteins. The history and properties have been reviewed by Sourirajam.[10] Various configurations have been devised including tubular, plate and frame, cast plates, hollow fiber, and spiral wound sheets. Each of these designs is currently in production. All configurations permit filtration at pressures of 50 p.s.i.g. or less. A recent review of the types of processing equipment available has been prepared by Glover et al.[11] A variety of factors (e.g., pH, temperature, ions) affect the membrane flux rates, and a series of pretreatment steps can have remarkable effects. These have been reviewed by Harper and Raman.[12] The process of cleaning and sanitizing membranes has taken a major leap forward with the development of noncellulosic membranes capable of withstanding strong alkalis or acids. The economical application of UF processing to whey requires a good understanding of whey pretreatment and its relation to performance and functionality of the protein concentrates.

Reverse Osmosis

Reverse osmosis (RO) membrane processing is limited essentially to the concentration of whey as an alternative to thermal evaporation. As fuel costs escalate, RO can become a desirable process for removal of 50 to 70% water. Membrane fouling is not the problem that it is with UF, and generally the only pretreatment increasing RO flux rates is demineralization. A detailed review of the types of plants available has been prepared by Short and Doughty,[13] and economics of RO reported by Boer et al.[14]

WHEY FRACTIONATION

Protein Isolation

Protein is generally recognized as the whey component with the greatest potential economic return to the processor. This is attributable to its nutritive quality and functional properties. Protein can be isolated from whey in either a denatured or undenatured form; although specific functionaliiies can be attributed to each, most effort has been directed toward isolating undenatured protein. The simplest process for isolating whey protein is heat coagulation achieved by steam injection and holding for 8 min at 250°F,[15] 60% of the crude protein (25% ash) was obtained in this manner and products with greater than 85% protein content were achieved by washing the coagulated slurry with acetic acid to redissolve calcium salts before centrifugation. The resulting denatured protein was found to be an excellent product for the fortification of a variety of pasta products.[16]

Soluble protein concentrates have been obtained by a variety of processes including metaphosphate complexes, electrodialysis, ultrafiltration, gel permeation, dialysis, carboxymethyl cellulose precipitation, and iron complexes. These procedures have been reviewed by Morr et al.[17,18] The compositions of the protein concentrates obtained by these processes are shown in Table 10. A number of additional complexing agents have been investigated but, except for those described by Morr et al,[17,18] and a polyacrylic acid precipitation reported by Sternberg et al.,[19] appear to offer little commercial potential. Widespread commercial adaptation of ultrafiltration indicates that this is the most appropriate method for concentrating whey protein.

Lactose Crystallization

Processes for the crystallization of lactose are well established, with production generally limited to very few plants having a very large output. A variety of wheys or ultrafiltrates can serve as raw materials for lactose crystallization, although sweet whey or ultrafiltrates are generally preferred. The yield and purity of lactose crystals are greatly affected by protein and mineral content; demineralized-deproteinized wheys provide best yields and crystal purity. The crystallization process consists of three basic steps: (1) concentration of whey to between 50 to 70% s-lids by use of multieffect evaporators; (2) crystallization initiated either spontaneously or by "seeding" with a small quantity of lactose crystals; and (3) separation of the crystals from the supernatant by centrifugation. Each of these steps involves many considerations; the reader is referred to a review on the subject.[20] Various commercial grades of lactose together with their chemical and physical data are listed in Table 11.

Uses for Lactose

Utilization of lactose is based on its rather unique physical and chemical properties.[20,21] It is substantially less soluble in water than is sucrose (Table 12) and at low concentrations is only about one sixth as sweet as sucrose. The sweetness of lactose relative to that of sucrose increases with increasing concentration, e.g., a 25% lactose solution is equivalent to a 10% sucrose solution in sweetness. Lactose is considered to be a flavor enhancer and an excellent carrier for flavors, colors, and aromas. In bakery applications it improves emulsifying properties of shortening and contributes browning properties and tenderness to baked products. The principal uses for lactose are presented in Table 8.

Potential applications for lactose are restricted by its limited solubility and low sweetness. These qualities are considerably improved by acidic or enzymatic hydrolysis of lactose to glucose and galactose. Acidic hydrolysis in solution can be obtained with either sulfuric[22] or hydrochloric acids[23] or by use of cation exchange resins in the hydrogen form at elevated temperatures.[24] Enzymatic hydrolysis with commercially available microbial β-galactosidases (lactases) has been obtained by the addition of free enzyme to lactose solutions.[23,25] While this is the simplest approach, it suffers from the disadvantage of requiring relatively large amounts of expensive enzyme. Enzyme costs can be substantially reduced by a variety of processes wherein the enzyme is "immobilized" either by chemical bonding to solid supports or retention by fibers or membranes. These processes are reviewed by Zaborsky[26] and Wondolowski.[27] The basic physical and chemical effects of full or partial lactose hydrolysis, which may form the basis of new or improved utilization, are increased solubility, higher osmotic pressure, lower viscosity, increased sweetness, universally fermentable sugars, and increased levels of reducing sugars.

Attempts have been made to expand the nonfood uses for lactose, especially through chemical modifications to produce derived compounds having a commercial utility. Lactitol, produced by reduction, is the lactose equivalent of sorbitol,[28] with possible utilization as a noncaloric sweetner or food humectant. Microbial or air oxidation of lactose yields lactobionic acid, which has potential as a food acidulant or industrially as a chelator. Esterification with long chain fatty acids yields surfactants having detergent and emulsifier properties.[29] Isomerization yields the ketose derivative, lactulose,[30] which has potentials in infant nutrition, as a food humectant, and in a variety of pharmaceutical applications.

FERMENTATION

Whole whey and whey permeates have long been considered as substrates for the fermentative production of either single cell protein or other industrially useful products. Single cell protein (SCP) production from whey with *Kluyveromyces fragilis*, reported by Wasserman in 1960,[31] served as a basis for commercial SCP production for many years. A more recent study on SCP production from sweet or acid whey was reported by Bernstein and Tzeng[32] also using *K. fragilis*. Although the quality of the protein as animal feed is good, the overall outlook for SCP production through whey fermentation is poor owing to rather high capital costs and poor economic return. Coupling SCP production together with alcohol production has led to the development of the Milbrew process, which has been reviewed by Everson.[33] Aerobic and anaerobic processes investigated in this study have been in commercial operation as part of an Environmental Protection Agency grant. Generally, it is recognized that alcohol production from whey is not economical at present fuel costs.

The production of food grade acidulants through whey fermentation has been reviewed by Short.[34] Lactic acid production from whey with *Lactobacillus bulgaricus* has been reported by Cox and MacBean.[35] Continuous anaerobic fermentation with *L. bulgaricus* served as a basis for the production of ammonium lactate[36] for use as a feed source for ruminants. Citric acid can also be produced successfully from acid whey with mutant strains of *Aspergillus niger*.[37]

Table 1

ESTIMATED U.S. FLUID WHEY AND WHEY SOLIDS PRODUCTION (BY TYPE) AND RESULTING QUANTITY OF WHEY SOLIDS "FURTHER PROCESSED" (IN MILLIONS OF POUNDS)

	1972	1973	1974	1975	1976	1977	1978
Sweet whey							
Cheese production[a]	2,605	2,685	2,937	2,811	3,337	3,344	3,519
Calculated fluid whey[b]	23,445	24,165	26,433	25,299	30,033	30,096	31,671
Calculated whey solids[c]	1,524	1,571	1,718	1,645	1,952	1,956	2,058
Acid whey							
Cottage cheese production[a]	784	763	690	701	711	709	688
Calculated fluid whey[b]	4,704	4,578	4,140	4,206	4,266	4,254	4,128
Calculated whey solids[c]	306	297	269	273	277	277	268
Total whey production	28,149	28,743	30,573	29,505	34,299	34,350	35,799
Total equivalent whey solids (Sweet + acid)	1,830	1,868	1,987	1,918	2,229	2,233	2,326

[a] Crop Reporting Board, SRS, U.S. Department of Agriculture — Da 2—1.

[b] Whey production: approximately 9 lb/1 lb cheese produced (except cottage); approximately 6 lb/1 lb cottage cheese produced.

[c] Average total solids content of whey: 6.5%.

Table 2

COMPOSITION OF SKIM MILK AND WHEY (AMOUNT PER 100)

	Skim milk	Whey
Water (g)	90.5	93.1
Food energy (kilocal)	36	26
Protein (g)	3.6	0.9
Fat (g)	0.1	0.3
Lactose (g)	5.1	5.1
Ash (g)	0.7	0.6
Calcium (mg)	121	51
Phosphorus (mg)	95	53
Iron (mg)	Trace	0.1
Sodium (mg)	52	—
Potassium (mg)	145	—
Vitamin A (IU)	Trace	10
Thiamine (mg)	0.04	0.03
Riboflavin (mg)	0.18	0.14
Niacin (mg)	0.1	0.1
Ascorbic acid (mg)	1	—

From Watt, B. K. and Merrill, A. L., Agriculture Handbook, U.S. Department of Agriculture, Washington, D.C., 1963.

Table 3
COMPOSITION OF DRIED SWEET WHEY AND NONFAT MILK

	Approximate content	
Nutrient	Whey	Nonfat milk
Protein	12.9	35.9
Fat	1.1	0.8
Ash	8.0	8.0
Lactose	71.2	52.3
Lactic acid	2.3	—
Water	4.5	3.0

Table 4
COMPARISON OF ESSENTIAL AMINO ACID CONTENT OF WHEY PROTEIN, CASEIN AND THE FAO STANDARD

	Grams per 100 g protein		
Amino acid	FAO standard	Whey protein	Casein
Methionine	4.2	4.3	3.4
Leucine	9.0	15.5	16.4
Lysine	4.2	8.2	8.2
Phenylalanine	2.8	4.0	5.5
Threonine	2.8	5.5	4.5
Valine	4.2	5.5	7.3
Tyrosine	2.8	3.7	6.2
Tryptophan	1.4	2.5	1.4

Table 5
COMPOSITION OF DRIED WHEYS

	Type of Whey						
					Cottage		
	Swiss	25% Cheddar 75% Swiss	Cheddar	Skim milk cheddar	A	B	Control
Total nitrogen, %	2.3	2.4	1.8	1.9	2.0	2.0	1.8
Nondialyzable nitrogen, % total N	69.0	70.5	77.2	71.5	79.0	64.4	72.2
Crude protein, % (total N × 6.38)	14.7	15.3	11.5	12.1	12.8	12.8	11.5
"True" protein, % (non-dialyzable N × 6.38)	10.1	10.8	8.9	8.7	10.1	8.2	8.3
Lipids, %	4.3	0.8	2.7	0.4	0.5	0.5	0.4
Lipid Nitrogen, % total N	0.7	0.3	—	—	—	—	—
Lactose, %	69.2	72.5	74.4	74.6	68.2	74.3	72.4
Ash, %	9.4	8.8	7.4	7.7	11.5	11.3	11.3
Water, %	2.6	6.0	4.8	7.1	4.0	5.1	6.8

Table 6
DRY WHEY PRODUCTION IN U.S. (IN THOUSANDS OF POUNDS)

Year	
1960	276,860
1961	271,485
1962	284,845
1963	316,923
1964	371,947
1965	404,301
1966	470,931
1967	492,815
1968	495,173
1969	516,474
1970	621,031
1971	679,447
1972	762,020
1973	772,440
1974	851,351
1975	595,590
1976	661,761
1977	625,249
1978*	708,411

* **Preliminary.**

Table 7
PRODUCTION OF WHEY AND MODIFIED WHEY PRODUCTS[a] (IN THOUSANDS OF POUNDS)

Product	1976[b]	1977[b]	1978
Condensed whey solids content[c]			
Sweet			
Human food	107,702	115,353	118,207
Animal feed	23,822	17,278	25,724
Acid			
Human food/animal feed	11,143	12,862	10,811
Total	142,667	145,493	154,742
Dry whey			
Human food	480,118	472,512	534,741
Animal feed	181,643	152,737	173,670
Total	661,761	625,249	708,411
Modified dry whey products			
Partially delactosed			
Human food	32,145	26,345	32,280
Animal feed	98,161	117,058	130,196
Total	130,306	143,903	162,476
Partially demineralized			
Human food	26,176	27,604	28,677
Animal feed	0[d]	0[d]	0[d]
Total	26,176	[illegible]	[illegible]
Partially delactosed demineralized			
Human food	8,108	7,475	8,909
Animal feed	529	0[e]	0[e]
Total	8,637	7,475	8,909

Table 7 (continued)
PRODUCTION OF WHEY AND MODIFIED WHEY PRODUCTS[a] (IN THOUSANDS OF POUNDS)

Product	1976[b]	1977[b]	1978
Lactose			
Human food	100,258	102,841	108,886
Animal feed	37,141	5,974	5,299
Total	137,399	108,815	114,185
Whey solids in wet blends			
Human food	27,252	23,867	34,409
Animal feed	46,528	44,438	60,851
Total	73,780	68,305	95,260
Grand total	1,180,726	1,126,844	1,272,660
Percent of total whey solids further processed	56.7	56.4	54.7

[a] Crop Reporting Board, Economics, Statistics and Cooperatives Service, U.S. Department of Agriculture.
[b] Revised.
[c] Final marketable product only. Does not include quantity used or shipped to another plant for further processing into dry whey or modified whey products.
[d] None reported.
[e] Not published to avoid disclosure of individual plant operations.

Table 8
COMPARISON OF 1977—78 END-USES, WHEY AND WHEY PRODUCTS IN HUMAN FOOD (IN MILLIONS OF POUNDS)

	1977			1978		
	Sweet	Acid	Total	Sweet	Acid	Total
Dry whey						
Bakeries	97.1	0.6	97.7	113.9	0.1	114.0
Blends	55.0	0.3	55.3	60.7	0.6	61.3
Dairies	145.8	2.0	147.8	152.6	1.0	153.6
Meat processors	0.7	0.1	0.8	0.7	—	0.7
Candy	15.5	—	15.5	10.1	—	10.1
Soft drinks	0.4	—	0.4	0.4	—	0.4
Prepared dry mixes	25.1	—	25.1	23.2	—	23.2
Soups	0.7	—	0.7	1.1	—	1.1
Margarine	0.7	—	0.7	0.4	—	0.4
Institutions	0.5	—	0.5	0.4	—	0.4
Chemicals; pharmaceuticals	0.3	—	0.3	0.4	—	0.4
All others	38.3	—	38.3	20.4	—	20.4
Total	380.1	3.0	383.1	384.3	1.7	386.0
Modified whey[a]						
Bakeries	7.6	—	7.6	1.7	0.4	2.1
Dairies	11.8	—	11.8	15.1	4.1	19.2
Candy	2.0	—	2.0	2.1	0.4	2.5
Soups	—	—	—	—	—	—
Infant foods	10.2	—	10.2	9.9	0.2	10.1
Institutions	—	—	—	0.1	—	0.1
Prepared dry mixes	0.3	—	0.3	0.1	0.1	0.2

Table 8 (continued)

COMPARISON OF 1977—78 END-USES, WHEY AND WHEY PRODUCTS IN HUMAN FOOD (IN MILLIONS OF POUNDS)

	1977			1978		
	Sweet	Acid	Total	Sweet	Acid	Total
Macaroni	—	—	—	0.1	0.1	0.2
All others	4.5	—	4.5	7.5	0.4	7.9
Total	36.4	—	36.4	36.6	5.7	42.3
Condensed whey						
Bakeries	3.2	—	3.2	1.8	—	1.8
Dairies	11.6	1.0	12.6	12.7	0.5	13.2
Candy	8.7	—	8.7	8.5	—	8.5
Infant foods	—	—	—	—	—	—
Prepared dry mixes	7.4	—	7.4	6.5	—	6.5
Soups	0.1	—	0.1	—	—	—
Institutions	—	—	—	—	—	—
All others	31.2	7.3	38.5	39.6	—	39.6
Total	62.2	8.3	70.5	69.1	0.5	69.6
Lactose						
Pharmaceuticals			14.3			12.4
Infant foods			34.6			46.9
Fruits and vegetables			0.3			—
Dietetic foods			16.9			11.4
Dairy products			6.6			10.2
Fruit jellies and jams/preserves			—			—
All others			18.3			12.5
Total			91.0			93.4

* Includes partially delactosed, partially demineralized, partially delactosed/demineralized, and whey protein concentrate.

Prepared by the Whey Products Institute, Chicago, Ill. With permission.

Table 9

COMPARISON OF 1977—78 END-USES, WHEY AND WHEY PRODUCTS IN ANIMAL FEED (IN MILLIONS OF POUNDS)

	1977			1978		
	Sweet	Acid	Total	Sweet	Acid	Total
Dairy/calf/cattle feeds						
Dried whey	109.8	4.5	114.3	136.3	2.5	138.8
Dried whey product	28.8	30.5	59.3	31.6	21.8	53.4
Condensed whey (solids base)	10.5	—	10.5	19.3	2.2	21.5
Whey *solids* in whey blends	47.4	0.1	47.5	32.3	—	32.3
Poultry feeds						
Dried whey	6.4	5.2	11.6	0.1	3.7	3.8
Dried whey product	—	—	—	—	—	—
Condensed whey (solid basis)	—	—	—	—	—	—
Whey solids in whey blends	—	—	—	—	—	—
Swine feeds						
Dried whey	60.0	—	60.0	55.8	—	55.8
Dried whey product	—	61.9	61.9	—	44.3	44.3

Table 9 (continued)

COMPARISON OF 1977—78 END-USES, WHEY AND WHEY PRODUCTS IN ANIMAL FEED (IN MILLIONS OF POUNDS)

	1977			1978		
	Sweet	Acid	Total	Sweet	Acid	Total
Condensed whey (solids basis)	—	2.9	2.9	—	—	—
Whey *solids* in whey blends	0.2	—	0.2	—	—	—
Pet foods						
Dried whey	0.2	—	0.2	0.2	—	0.2
Dried whey product	7.8	0.5	8.3	7.3	0.4	7.7
Condensed whey (solids basis)	—	—	—	—	—	—
Whey *solids* in whey blends	16.5	—	16.5	—	—	—
Other feeds						
Dried whey	4.1	—	4.1	4.4	0.2	4.6
Dried whey product	—	5.1	5.1	—	3.7	3.7
Condensed whey (solids basis)	—	—	—	—	—	—
Whey *solids* in whey blends	—	—	—	—	—	—
Feed use, undesignated	18.5	15.3	33.8	32.5	10.5	43.0
Total	310.2	126.0	436.2	319.8	89.3	409.1

Prepared by the Whey Products Institute, Chicago, Ill. With permission.

Table 10
COMPOSITION OF WHEY PROTEIN CONCENTRATES (WPC)

Preparation process	Protein (%)	Lactose (%)	Ash (%)	NPN* (%)	Fat (%)
Metaphosphate complex	55.7	13.0	13.7	1.2	5.3
Electrodialysis	32.9	51.8	9.0	6.7	3.3
Ultrafiltration	56.5	27.2	3.4	4.8	7.3
Sephadex®	41.9	24.9	11.5	4.9	0.8
Dialysis	66.0	26.2	2.0	1.5	2.0
CMC complex	49.8	20.1	8.0	—	1.2
Iron complex	35.1	0.8	54.0	1.1	0.6

- Nonprotein nitrogen expressed as percentage of total WPC N that was soluble in 12% TCA.

From Morr, C. V. Some functional properties of whey proteins, in Proc. Whey Products Conf., Chicago, Agric. Res. Serv. U.S. Department of Agriculture, Washington, D.C., 1972, 19.

Table 11
TYPICAL PHYSICAL AND CHEMICAL DATA FOR VARIOUS GRADES OF LACTOSE

Analysis	Fermentation	Crude	Edible	USP	USP spray process
Lactose, %	98.0	98.4	99.0	99.85	99.4
Moisture, nonhydrate %	0.35	0.3	0.5	0.1	0.5
Protein (N × 6.38), %	1.0	0.8	0.1	0.01	0.05
Ash, %	0.45	0.4	0.2	0.03	0.09
Lipids, %	0.2	0.1	0.1	0.001	0.01
Acidity, as lactic, %	0.4	0.4	0.06	0.04	0.03
Heavy metals, as Pb, ppm	—	—	<2	<1	<2
Specific rotation $[\alpha]^{25}_D$	—	—	+52.4°	+52.4°	+52.4°

From Nickerson, T. A., *Lactose in By-Products from Milk*, Webb, B. H. and Whittier, E. O., Eds., AVI Publishing, Westport, Conn., 1970, chap. 12. With permission.

Table 12
SOLUBILITIES OF LACTOSE AND SUCROSE IN WATER*

Temperature °C	Lactose	Sucrose
0	11.9	179
15	16.9	197
25	21.6	211
39	31.5	—
40	—	238
79	98.4	—
80	—	362
100	157.6	487

* g/100 g water.

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