lactase-treated milk provides base to develop products for lactose-intolerant populations

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THROUGHOUT the world many people reject milk as an adult food. Although it seems incredible that humans refuse to consume such a nutritious food, adults in general do not drink milk (*1*). Nutritionists and child development experts regard milk as a nearly complete food, and, when confronted with a substandard diet, immediately try to increase a child's milk ration.

The enzyme lactase breaks down milk sugar, lactose, during digestion. Recently, it has been found that a majority of non-Caucasians cannot properly digest lactose because of lactase deficiency in their gastric tracts (*2*). The few populations in which the number of lactose-tolerant individuals exceeds those with lactose intolerance include most Western Europeans and white Americans. Research showed a correlation between lactase deficiency and milk rejection in black children in Baltimore (*3*).

An obvious approach in producing dairy products suitable for lactase-deficient persons is to employ lactase from nonhuman sources to hydrolyze milk's lactose during commercial processing. The consumer product would then contain the digestible monosaccharides, glucose and galactose. Study of this approach was recommended (*4*), and this paper analyzes several products which incorporate lactase-hydrolyzed milk.

Prior Research

Earlier studies showed that the coagulation of casein during storage of concentrated milk was a direct consequence of lactose crystallization (*5*). Lactase from *Saccharomyces fragilis* was used to hydrolyze 50 to 85 per cent of the lastose in three-to-one concentrated whole milk, permitting storage of the concentrate at −10°C for up to six months. However, up to 2.5 per cent enzyme to lactose was required for hydrolysis, and nothing was reported about the treated milk's flavor. The work is covered in a patent (*6*).

Other earlier research reported that using one per cent lactase enzyme with milk concentrate intended for ice cream permitted reduction of the formulation's sucrose level. The reduced lactose level permitted use of higher serum solids without lactose crystallization (*7*). Beneficial effects of enzymatic lactose hydrolysis for milk solids used in ice cream were reported (*8*). Lactose was hydrolyzed in whole milk solids treated with *Maxilact* enzyme, and the milk's flavor was unaltered except for sweetness (*9*).

The prior research provided a basis for experiments which successfully produced several standard milk products having markedly reduced lactose content because of processing with a commercially-available lactase.

Using Lactase Enzyme

Current research used an enzyme isolated from the yeast *Saccharomyces lactis* in the form of a colorless, free-flowing powder, *Maxilact*. Its pH optimum, 6.8 to 7.0, approaches that of milk, 6.6. In most instances, 0.03 per cent (300 ppm) enzyme by weight was added to pasteurized fluid milk; the mixture was held for 2½ hours at 30°C to hydrolyze 90 to 95 per cent of the lactose to monose sugars. Post pasteurization destroyed the enzyme. The extent of lactose hydrolysis was measured by determination of monoses in the presence of lactose (*10*). Lactose was determined colorimetrically in untreated milk (*11*). Products with lower hydrolyzed lactose levels were made by diluting hydrolyzed milk with untreated, pasteurized milk.

Table I lists products made by using the enzyme and enumerates product advantages.

Reconstituted Fluid Milk

Lactase-treated fluid whole milk can be produced with no off-flavor other than increased sweetness (*9*). Current research evaluated the sweet flavor's taste acceptability and determined effects of additional processing on flavor of reconstituted, lactase-hydrolyzed milk products. Fluid milk, reconstituted from freshly condensed, lactase-treated whole milk was judged by 15 to 20 persons using a nine-point hedonic scale (*12*). In addition, sweetness levels were quantified in relation to a control containing added sucrose.

To estimate sweetness, each judge used a form that had a series of parallel vertical lines with the top marked "full sweetness" and the bottom "no sweetness." A milk sample with 1.2 per cent sucrose added was tasted to register full sweetness; an unsweetened control was tasted to indicate no sweetness. Judges then marked each line on the sheet at a place corresponding to the sweetness perceived in a sample (Figure 1). To quantify the judgments, each mark's position was measured from the "no sweetness" position.

Figure 2 shows that the addition of 0.3 per cent sucrose equals about 30 per cent lactose hydrolysis; 0.6 per cent sucrose equals about 60 per cent hydrolysis, and 0.9 per cent, about 90 per cent.

Flavor acceptability of lactose-hydrolyzed whole milk was inversely related to the amount of lactose hydrolyzed in a sample; the greater the hydrolysis, the lower the flavor score. The addition of increasing levels of sucrose evoked a similar panel response for the control (Table II). However, the milk's flavor was acceptable to the adult panel even when the lactose was 90 per cent hydrolyzed. The sweetness would be a definite advantage in making chocolate milk to which sucrose is normally added.

Recent work shows that whole milk with 90 per cent of its lactose converted by *Maxilact* had high acceptability

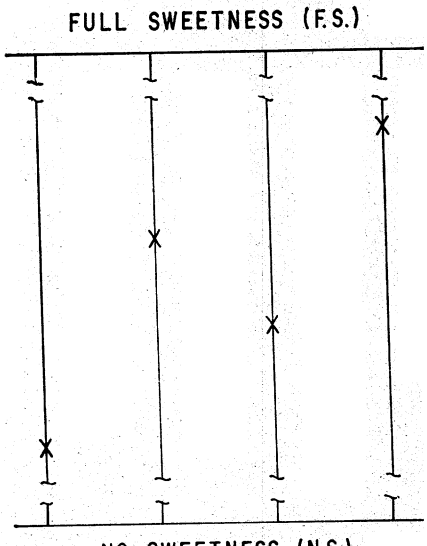

Figure 1. Score sheet to measure sweetness intensity of lactase-hydrolyzed milk

Figure 2. Relative sweetness of lactase-treated whole milk and untreated whole milk with added sucrose. Milks reconstituted to 12.7% total solids from 3:1 concentrate ▶

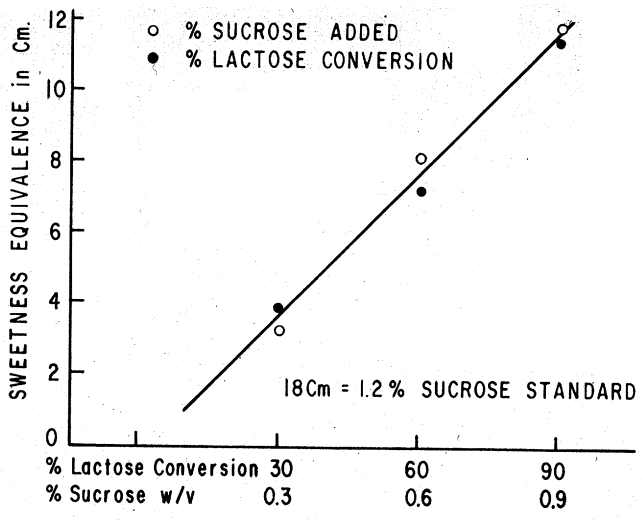

Table I. Products with lactose hydrolyzed by lactase

Product	Advantage
Fluid whole milk	Increased sweetness
Frozen whole milk (3:1 concentrate)	Increased storage stability with lactose crystallization prevented
Condensed skim milk	
Ice cream	Lactose crystallization prevented and reduced sucrose levels possible
Spray dried whole milk	Retain properties of fluid counterparts
Spray dried NFDM	

Table II. Panel ratings of lactase-treated whole milk and untreated whole milk with sucrose added (nine-point hedonic scale). Milks reconstituted to 12.7% total solids from 3:1 concentrate

Lactose Hydrolyzed, %	Panel 1	Panel 2
0	6.8	—
30	6.4	—
61	6.2	6.41
89	5.85[a]	—
Sucrose Added, %		
0	—	7.0
0.3	—	6.92
0.6	—	6.13[a]
0.9	—	5.25[b]
1.2	5.05[b]	4.80[b]

[a]Significantly different from the control at 5% confidence level
[b]Significantly different from the control at 1% confidence level

among Negro adolescents who received eight-ounce servings after an all night fast (*13*). Only one of 27 respondents described the product as unacceptable. The other 26 youngsters stated that they liked the milk and would drink it. Of the respondents, 56 per cent reported that the 90 per cent lactose-hydrolyzed milk was sweeter than regular milk. More criticism was voiced about the untreated control; seven said it was more stale than normal, and five called it more sour. Thus, the reported sweetness of 90 per cent hydrolyzed milk enhanced the product's desirability.

Frozen Condensed Whole Milk

Fresh whole 3:1 concentrated milks show excellent flavor upon reconstitution, and it seems desirable to find a method to store them without losing quality. They can be frozen, but lactose crystallizes and thickening or gelation occurs. Experiments demonstrated that hydrolyzing the milk's lactose with lactase before concentration extended the concentrates' storage life with no gelation or lactose crystallization occurring. In addition, taste scores of such milks did not change with time.

The 3:1 concentrates were prepared by pasteurizing clarified milks containing 3.3 per cent fat at 79°C for 16 seconds; the products were treated with 0.03 per cent lactase and held two hours at 30°C. The milks were again pasteurized at 79°C for 16 seconds over an elapsed time of an additional hour. Milk was homogenized at 2,500/500 psi and concentrated in a *Harris-Wiegand* falling-film evaporator to 38 per cent total solids. Products containing 30 and 60 per cent hydrolyzed lactose were made by diluting hydrolyzed milk with untreated whole milk concentrates.

Concentrates were placed in No. 1 enameled cans leaving one inch head space; cans were sealed and heated for 30 minutes at 71°C in an *FMC Steritort* sterilizer. After cooling, containers were stored at −13°C.

Panel acceptability of hydrolyzed milks after reconstitution did not change significantly through six months of frozen storage of the concentrates (Table III). The progressive decrease in panel acceptability noted with higher lactose hydrolysis was attributed to the milks' increased sweetness. Concentrates with 89 per cent lactose conversion and no retort processing showed no change in panel acceptability upon reconstitution even though the six month sample was somewhat coagulated.

Viscosities of lactose-hydrolyzed, heated concentrates increased slightly to moderately through six months' storage. On the other hand, viscosities of control concentrates and the viscosity of the unheated, hydrolyzed concentrate increased rapidly (Table IV). Best results were obtained with 30 per cent lactose hydrolysis; at this level, little or no change in panel acceptability of the reconstituted product occurred, and viscosity changes were the same as in samples with a greater percentage of lactose hydrolyzed (Tables III and IV).

Table III. Panel acceptability (nine-point hedonic scale) of reconstituted milks from stored, heat-processed, whole milk concentrates treated with lactase before condensing

Lactose Hydrolyzed, %	Months Stored, −13°C		
	0	3	6
0	6.80	7.0	—[a]
30	6.40	7.10	6.3
61	6.20	6.15	5.9
89	5.85[b]	5.35[c]	5.8
89[d]	5.75[b]	5.90	5.6[a]

[a]Coagulated
[b]Significantly different from control at 5% confidence level
[c]Significantly different from control at 1% confidence level
[d]Not heat processed in *Steritort*

Condensed Skim Milk

One problem in storing condensed milk for short periods at cold temperatures is the deposition of hard-to-remove lactose crystals along the container's sides and bottom. Adding 40 to 160 ppm of lactase to skim milk concentrate (42 per cent total solids) and holding the concentrate in a small plastic container for up to six days will hydrolyze sizable quantities of lactose (Table V). Little or no lactose deposition was observed when the

Table V. Effect of lactase on lactose hydrolysis in a skim milk concentrate (42% total solids) held at 5°C for six days

Lactase, ppm	Lactose Hydrolyzed, %		Sediment Deposited, mm[a]
	3 Days	6 Days	
0	—	—	18
40	23	33	1
80	37	50	2
160	50	64	1.5

[a]Total column height, 180mm

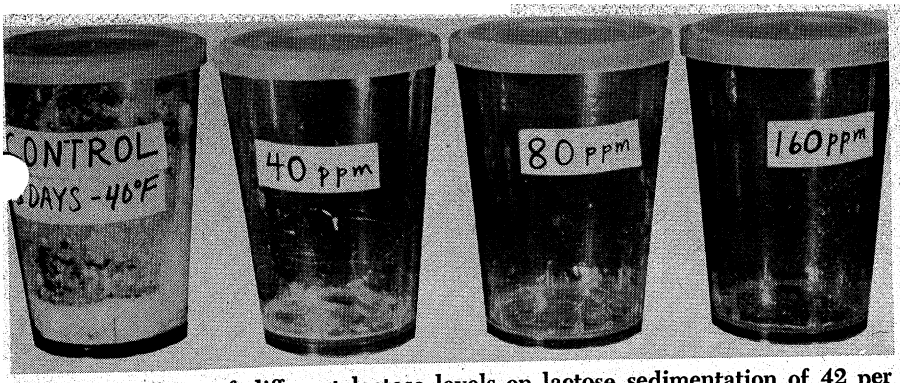

Figure 3. Effects of different lactase levels on lactose sedimentation of 42 per cent total solids skim milk concentrates held for 6 days at 5°C

container contents were inverted and the sediment remaining measured. The control, on the other hand, deposited large quantities of lactose, observed as hatchet shaped crystals on the container's sides and bottom. Figure 3 compares sediment deposition in emptied containers after concentrate was held six days at 5°C.

Ice Cream

Sandiness is no problem in modern ice cream because of improved stabilizer systems. However, lactose crystallization was retarded in ice cream made with lactase-treated serum solids when a stabilizer-modified formula was employed. Caloric density of ice creams can be reduced with no loss of acceptability, and ice creams can be made for lactose-intolerant individuals by enzymatically reducing lactose content.

Test ice creams were made from skim milk concentrates held five days at 5°C with 27 ppm lactase. A second group of ice creams was made with lactase-treated wheys incorporated at a 25 per cent level of total serum solids.

Table VI. Ice cream formula

Ingredient	%
Sucrose	13.5 or 15
Milk fat	12
Serum solids	11
Gelatin, 270 bloom	0.3
Vanilla extract	0.5

Table VI shows formulations. Gelatin, blended into the sucrose, was added as a stabilizer to impart a smooth texture and permit development of sandiness. Mixes were pasteurized for 16 seconds at 88°C and homogenized at 2,500 to 500 psi before aging overnight at 3°C. Twelve-pound lots of mix were made into ice creams in an *Emery Thompson* batch freezer. Drawing temperature was −4.5 to −3.9°C, and ice creams were hardened at −18°C before storage at −18 and −13°C.

Ice creams were judged on a nine-point hedonic scale (*12*). Samples of frozen ice creams were taken from gallon containers and scooped into two-ounce wax paper cups. Sampling was conducted within 20 minutes after product was removed from the freezer.

Effect of Treated Concentrate

Overrun and meltdown times of mixes made with and without lactase-treated skim solids were similar (Table VII). One and one-half per cent less sucrose was added to the third sample, and consequently, its total solids were similarly reduced.

The control's texture rating dropped significantly; it became sandy after 11 weeks storage at −13°C and after 15 weeks storage at −18°C (Table VIII). The ice creams containing lactase-hydrolyzed ingredient showed no significant change in texture ratings during the same period. The ice cream with the sucrose level reduced because of hydrolyzed lactose's sweetening effect rated as good or better than the ice cream made with the same mixes but with 15 per cent added sucrose.

Taste panel scores of the ice creams containing lactase-treated milk solids remained unchanged over the 15 week storage period (Table VIII). The control's taste scores declined somewhat, possibly because of the sandy texture's influence. No off-flavors developed in any product.

Effect of Treated Whey

Fluid wheys of 6.5 to 6.7 per cent total solids (cheddar cheese whey as is, and cottage cheese whey neutralized to pH 6.6 with KOH) were incubated with 300 ppm lactase at 30°C for 2½ hours and pasteurized at 71°C for one minute. They were then added to ice cream mix at 25 per cent of the total serum solids. Untreated skim milk solids constituted the remaining serum solids.

Ice creams made with lactase-treated wheys developed no sandiness during 11 weeks storage at −13 or −18°C. However, the control became sandy after six weeks at −13°C and 10 weeks at −18°C (Table IX).

Taste scores for the control and lactase-treated whey ice creams were very similar to those reported in Table VIII with the control losing up to 1.0 hedonic unit at 10 and 11 weeks storage, while lactase-treated samples did not change. Mix overruns were similar (92 to 95 per cent). Meltdown time for the third ice cream was longer and less uniform than for the other two.

Spray-Dried Milk

Lactase-treated milks can be spray dried to yield products with unchanged taste acceptability. Samples of lactase-treated condensed skim and whole milks were spray dried in a *Gray Jensen* dryer to produce powders that could be reconstituted. Difficulties arose because powder lumped in the cone and star valve unless the powder was specially cooled with

Table IV. Viscosity of 3:1 stored, heat-processed whole milk concentrates treated with lactase before condensing

Lactose Hydrolyzed, %	Months Storage, −13°C; Viscosity, Centipoise			
	0	2	3	6
0	600	1400	8600[a]	—[a]
30	600	800	800	1600
61	600	800	800	1600
89	600	800	800	1600
89[b]	600	1300	2400	—[a]

[a]Coagulated
[b]Not heat processed

Table VII. Effect of lactose-hydrolyzed skim milk concentrates on properties of ice cream mixes, ice creams

Sample	Lactase in Concentrate, %	Lactose Hydrolyzed in 5 Days, %	Total Solids in Mix, %	Overrun, %	Meltdown, min
30% total solids (TS) skim milk (control)	0	0	37.6	80	53
40% TS skim[a]	27	28	37.5	85	53
40% TS skim[b]	27	28	36.0	81	53

[a]15% Sucrose added to the mix
[b]13.5% Sucrose added to the mix

Table VIII. Taste and texture scores (nine-point hedonic scale) of ice creams made with lactase-treated skim milk contentrates[a]

Sample	−18°C (1 wk) Taste	−18°C (1 wk) Texture	−13°C (11 wk) Taste	−13°C (11 wk) Texture	−18°C (15 wk) Taste	−18°C (15 wk) Texture
30% TS skim[b] (control)	7.06	6.81	6.50	5.15[c]	6.16	4.06[c]
40% TS skim[b]	6.56	6.05	7.00	6.42	6.89	6.00
40% TS skim[d]	6.97	6.66	7.30	6.42	7.12	6.52

[a]27 ppm lactase added, 28% of lactose hydrolyzed
[b]15% sucrose added to ice cream
[c]Lactose sandiness and texture differs significantly from others at 1% level for any one storage period
[d]13.5% sucrose added to ice cream

Table IX. Texture scores (nine-point hedonic scale) of ice creams made with lactase-treated wheys

Sample	Storage, Weeks −18°C 2	−18°C 6	−18°C 10	−13°C 2	−13°C 6	−13°C 11
Skim milk control[a]	6.90	6.42	4.32[b,e]	7.75	6.00[b]	3.12[b,e]
75% skim milk serum solids[c]; 25% lactase-treated sweet whey serum solids[d]	6.92	7.00	6.41	7.05	6.67	6.78
75% skim milk serum solids[c]; 25% lactase-treated cottage whey serum solids[d]	6.70	6.70	6.20	7.00	6.85	6.90

[a]15% Sucrose added
[b]Lactose sandiness and texture differs significantly from others at 5% level for any one storage period
[c]13.5% sucrose added
[d]83% of lactose hydrolyzed
[e]Significantly different from others at 1% level for any one storage period

forced dry air as it left the cone. The condition of insulation on the test dryer made it difficult to hold wall and product temperatures below 60°C. Despite problems, high yields of powder were obtained when proper conditions were maintained. Successful runs were made by injecting nitrogen gas into a concentrate (42 per cent total solids) which was atomized through a 0.1 cm nozzle using an inlet temperature of 132°C. Powder left the cone at 68 to 70°C and was quickly cooled with forced air to 35°C.

The need to quickly cool the powder was demonstrated by measuring the powders' sticking temperatures with a "stickometer," a device with a rotor and a stator between which the powder was placed. The stator's temperature was raised gradually, and the temperature at which the powder stuck, producing a drag on the rotor, noted. Sticking temperatures of low-lactose skim milk powders of comparable moisture content were considerably lower than sticking temperatures of the control skim milk powder (Table X). To prevent lumping, it would be necessary to quickly cool the powder to less than 60°C to collect it.

A panel of 40 persons tested the powders (Table XI). The control was rated significantly higher than hydrolyzed milks which still earned satisfactory ratings. The fact that ratings of fluid, hydrolyzed milk, and the reconstituted powder were the same indicated that no quality loss occurred during drying.

Table X. Sticking temperatures of low-lactose, foam-spray-dried, nonfat milk powder

Sample	Moisture, %	Lactose Hydrolyzed, %	Sticking Point, °C
Control	3.26	0	75.4
Low-lactose	3.40	80	59.2
Low-lactose	3.35	87	64.6

Table XI. Taste panel scores (nine-point hedonic scale) of skim milk products

Product	Mean Rating
Skim milk (control)	6.35
90% hydrolyzed skim milk	5.40[a]
90% hydrolyzed skim milk powder	5.40[a]

[a]Significantly different from control at 1% confidence level

Implications of the Work

Earlier efforts to make products in which the lactose was hydrolyzed with lactase suffered because of low enzyme activity and because the enzyme preparations themselves generated off-flavors. *S. lactis* (*Maxilact*) produces no detectable off-flavors and exhibits very high activity.

Research indicates that low-lactose dairy products can be produced with properties equal or superior to untreated controls. The increased sweetness caused by lactose hydrolysis offers the possibility of using such products and ingredients in sweet foods having fewer calories. Most importantly, low-lactose products can be utilized with confidence by a new consuming population, lactose-intolerant individuals, and, as a result, milk consumption could increase.

Acknowledgement

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