Effect of Fermentation on Lactose, Glucose, and Galactose Content in Milk and Suitability of Fermented Milk Products for Lactose Intolerant Individuals

LIVIA ALM
Mjölkcentralen Arla
S–106 46 Stockholm, Sweden
and
Department of Medical Nutrition, Research Center F69, Huddinge University Hospital
S–141 86 Huddinge, Sweden

ABSTRACT
The lactose, glucose, and galactose content in various fermented milk products was studied by enzymatic methods. Lactose was decreased in all fermented products. After 11 days storage of yogurt the lactose content decreased to about 2.3 g/100 g compared to 4.8 g/100 g in nonfermented milk. During the same period, galactose content increased from traces in milk to 1.3 g/100 g in yogurt. Results were similar with acidophilus and bifidus milk. Buttermilk, kefir, and ropy milk showed 26, 30, and 20% decreases in lactose content.

Eight lactose intolerant individuals showed symptoms of abdominal distress and diarrhea following consumption of 500 ml of low fat milk whereas ingestion of the same quantity of yogurt or acidophilus milk did not result in any symptoms. Fermented milk products should be considered in formulating diets for lactose-intolerant subjects.

INTRODUCTION
Lactose is the main carbohydrate in milk (32). The average content in cow's milk is slightly lower than 5% (wt/vol). During digestion lactose is hydrolyzed into glucose and galactose (23, 24) a process catalyzed by lactases (2, 3, 4) normally in the intestinal mucosal cells and released to the intestinal juice (26). Hydrolysis of lactose also will take place during fermentation (33, 39), and the monosaccharides produced are assumed to be utilized by the organisms. Fermentation reduces lactose in milk (8, 12, 14, 15).

Low lactase activity is a relatively common abnormality of the small bowel in man (1, 9, 10, 11). Extensive experiments have surveyed lactose intolerance in different populations (6, 21, 22). Lactose intolerance is prevalent in most areas where there are few dairy animals or where adults use little or no milk (25, 31, 35, 36). About 70% of black Americans and up to 95% of certain Asian people show a more or less advanced low lactase activity (28, 29) (Figure 1).

This study was to determine the decrease in lactose from fermentation and storage of some dairy products manufactured and utilized in Sweden to investigate their suitability for lactose intolerant individuals.

MATERIALS AND METHODS
The following milk samples were analyzed: regular milk, buttermilk (filmjölk), low fat milk, low fat buttermilk (lättil), kefir, ropy milk (langmjöl), yogurt, V-medium, acidophilus milk, and bifidus milk.

Production Methods
Regular Milk. Cow's milk, pH 6.7 to 6.8, 3.0% (wt/vol) fat, pasteurized at 75°C for 15 s.
Buttermilk. Regular milk, heat treated at 92°C for 3 min, inoculated with a commercial mixture of Streptococcus lactis, Streptococcus cremoris, Streptococcus diacetylactis, and Leuconostoc cremoris (citrovorum), and cultured at 20°C for 24 h. The final pH ranged from 4.4 to 4.5.
Low Fat Milk. Cow's milk, pH 6.7 to 6.8, .5% (wt/vol) fat, pasteurized at 75°C for 15 s.
Low Fat Buttermilk. Low fat milk, heat treated at 92°C for 3 min, inoculated with a commercial mixture of Streptococcus lactis, Streptococcus cremoris, Streptococcus diacetylactis, and Leuconostoc cremoris (citrovorum), and cultured at 20°C for 24 h. The final pH ranged from 4.4 to 4.5.
Kefir. Regular milk, heated at 92°C for 3 min, inoculated with a commercial mixture of kefir grains, and cultured at 20°C for 18 to 20 h. The final pH ranged from 4.3 to 4.5.
Ropy Milk. Regular milk, heated at 90°C for
3 min, inoculated with a mixture of starter culture of Streptococcus lactis var. longi and Leuconostoc cremoris (citrovorum), and cultured at 17° to 18°C for 20 to 22 h. The final pH ranged from 4.5 to 4.6.

Yogurt. Regular milk, heated at 95°C for 3 min, inoculated with a commercial mixture of Lactobacillus bulgaricus and Streptococcus thermophilus, and cultured at 43° to 44°C for 3 to 4 h. The final pH ranged from 3.8 to 4.2.

V-Medium. Manufactured from low fat milk, .5% (wt/vol) fat, pH 6.7 to 6.8, pasteurized at 75°C for 15 s, and fortified with a protein concentrate (67% (wt/wt) protein content) from skim milk. The protein content of the milk was increased from about 3.4 to 5.0 g/100 g. The mixture was allowed to swell for 15 to 18 h at 4°C and then was heat treated at 140°C for 3 to 4 s.

Acidophilus Milk. V-medium, inoculated with Lactobacillus acidophilus (NCDO 1748) and cultured at 37°C for 40 h. The final pH ranged from 4.4 to 4.5.

Bifidus Milk. V-medium, inoculated with Bifidobacterium bifidum (Lactobacillus bifidus NCDO 11863) and cultured at 37°C for 40 h. The final pH ranged from 4.2 to 4.4.

Evaluated materials consisted of both lyophilized and reconstituted samples taken during the fermentation process and of commercially available fermented dairy products.

Methods for Evaluation of Carbohydrate

Quantitative evaluations of carbohydrate were by enzymatic methods (17, 37, 38). As in Table 1 the coefficient of variation was 3% in 13 lactose determinations on heat treated uninoculated milk samples from 13 batches.

Lactose Intolerance Studies

Twelve healthy volunteers, five females and seven males, ranging from 18 to 50 yr, participated. The subjects originated from India, Bangladesh, Pakistan, China, Japan, Nigeria, and Sweden. All subjects were informed about

Figure 1. Frequency of lactose intolerance in percent of the population in some parts of the world (1, 34).
the purpose of the study, and their consents were obtained. The subjects were interviewed about their milk consuming habits. All except the subjects from Sweden declared that they avoided consumption of fresh milk because of gastrointestinal disorders arising soon after intake of one glass of milk (250 ml).

**Experimental Design**

Three tests were performed on every individual on 3 consecutive days. All tests were in the morning after an overnight fast. Before any milk was administered (t = 0), a capillary blood sample and a urine sample were taken. The blood was analyzed for glucose by a routine enzymatic method (used at St. Eriks Hospital, Clinical Chemistry Department, Stockholm, Sweden), and the urine was tested for glucose content by Clinistic® (Ames Comp. Div. of Miles Laboratories Ltd., Stoke Pages, Slough SL2 4LY, England). A test dose of 500 ml of low fat milk, yogurt, or acidophilus milk was consumed within 5 min. Capillary blood samples were taken after 15, 30, 45, 60, 90, 120, 150, and 180 min for determination of glucose. Urine samples were collected and tested for glucose content after 60, 120, and 180 min. The degree and type of discomfort of the subjects was registered by experienced medical personnel. Their 24-h recall of discomfort also was registered.

To control the experimental design, an oral lactose tolerance test (LTT) was performed on two Swedish individuals: 1 to 2 g of lactose per kg body weight was diluted in tap water and was ingested within 3 min. The glucose in capillary blood was measured at 0, 15, 30, 45, 60, 90, 120, and 180 min following ingestion of the lactose solution.

Nine individuals who considered themselves lactose intolerant declared that they were not able to consume more than one glass of milk (250 ml) and claimed that even this quantity caused immediate discomfort. The LTT, therefore, could not be performed on these subjects. They agreed, however, to consume 500 ml of the test milk types on 3 subsequent days.

**RESULTS**

**Carbohydrate Analysis**

Lactose decreased generally in the fermented products (Figures 2 and 3). This was least pronounced for buttermilk, kefir, and ropy milk but marked for yogurt, acidophilus milk, and bifidus milk. The greatest decrease was from about 4.8 g/100 g in unfermented milk to about 2.4 g/100 g in yogurt on the 11th day.

Only traces of free glucose were in all products. In yogurt, acidophilus and bifidus milk, there was a gradual increase in the galactose content from traces in milk or V-medium to about 1 g/100 g in yogurt at day 1, and to less in the other two products (Figures 2 and 3). In buttermilk, ropy milk, and kefir no galactose was detected.

![Figure 2. Decrease of lactose and increase of galactose during fermentation and storage from two fermentation studies. a = buttermilk; b = yogurt; c = kefir. —— = lactose; —— = galactose.](image-url)
Fermented Milk and Lactose Intolerance

Table 1 shows the results of comparative determinations of the lactose content in fresh samples and those which were lyophilized and reconstituted prior to determination of lactose. Table 2 summarizes lactose and galactose in various milk products on day 1 of fermentation.

Lactose Intolerance Studies

Means of carbohydrate contents \( (n = 8) \) in the test milks were: low fat milk = 4.9 g lactose/100 g; acidophilus milk = 2.8 g lactose and .8 g galactose/100 g; yogurt = 2.3 g lactose and 1.1 g galactose/100 g. When 500-ml milk sample was ingested, it provided the test subjects with 24.6 g, 18.1 g, and 11.4 g lactose from low fat milk, acidophilus milk, and yogurt.

Table 3 indicates that most non-Swedish subjects showed a small increase in blood glucose (less than 20 mg/100 ml blood following consumption of 500 ml of low fat milk, acidophilus milk, or yogurt).

Clinical signs of abdominal pain appeared in all non-Swedish subjects except BS when sweet unfermented milk was consumed. However, none of these subjects complained about gastrointestinal discomfort after ingesting yogurt or acidophilus milk. MW from Nigeria and AS from Pakistan showed increases in blood glucose concentration of the same magnitude as the Swedish subjects following ingestion of milk products. In contrast to Swedish subjects, who were free from symptoms, both MW and AS experienced abdominal pain following milk intake. BS from India displayed a significant increase in concentration of glucose in blood after milk consumption and did not report any abdominal discomfort.

Table 1. Lactose content in unfermented milk samples with and without lyophilization.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Lactose content (g/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
</tr>
<tr>
<td>Fresh sample</td>
<td>9</td>
</tr>
<tr>
<td>Lyophilized and reconstituted</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^{a}\)The hypothesis that means of lactose contents are equal in the two kinds of samples cannot be rejected at 5%.

Figure 3. Decrease of lactose and increase of galactose during fermentation and storage from two fermentation studies. d = ropy milk; e = acidophilus milk; f = bifidus milk. Lactose: copyrighted. Galactose: copyrighted.

Table 2 summarizes lactose and galactose in various milk products on day 1 of fermentation.
### Table 2. Content of lactose and galactose in various milk products on day 1 of fermentation (n = 5). (.....) = Nondetectable amounts.

<table>
<thead>
<tr>
<th>Milk product</th>
<th>Lactose content Range (g/100 g)</th>
<th>X</th>
<th>SD</th>
<th>Galactose content Range (g/100 g)</th>
<th>X</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular milk</td>
<td>4.80–5.25</td>
<td>5.0</td>
<td>.17</td>
<td>.....</td>
<td>.05</td>
<td>.06</td>
</tr>
<tr>
<td>Buttermilk</td>
<td>3.51–3.90</td>
<td>3.7</td>
<td>.16</td>
<td>.05–.10</td>
<td>.90</td>
<td>.08</td>
</tr>
<tr>
<td>Yogurt</td>
<td>2.25–2.48</td>
<td>2.4</td>
<td>.09</td>
<td>.90–1.10</td>
<td>.98</td>
<td>.08</td>
</tr>
<tr>
<td>Kefir</td>
<td>3.40–3.70</td>
<td>3.6</td>
<td>.11</td>
<td>.....</td>
<td>.60</td>
<td>.70</td>
</tr>
<tr>
<td>Ropy milk</td>
<td>3.50–3.70</td>
<td>3.6</td>
<td>.09</td>
<td>.....</td>
<td>.60</td>
<td>.70</td>
</tr>
<tr>
<td>Acidophilus milk</td>
<td>2.48–2.77</td>
<td>2.6</td>
<td>.11</td>
<td>.....</td>
<td>.60</td>
<td>.70</td>
</tr>
</tbody>
</table>

### Discussion

The intestinal flora of the small bowel and colon metabolizes lactose forming lactic acid, butyric acid, and other volatile and nonvolatile substances (5). In small amounts, lactic acid is beneficial to the human, but in larger amounts the acid causes irritation of the intestinal mucosa leading to abdominal cramps and diarrhea.

Lactose intolerance may occur as a disease among subjects in countries with generally lactose tolerant individuals. In lactose-intolerant children (9) lactose may be toxic and damage the intestinal mucosa (13) giving rise to symptoms similar to those in coeliac disease. Steatorrhea has been reported in individuals with low lactase activity (7, 18, 40).

Bayless (5, 69 found that individuals with reduced lactase activity could not consume one glass of milk (250 ml) without symptoms, whereas others (19, 20) claim that one or two glasses of milk can be tolerated by many adults with reduced lactase activity (15, 16).

Lactase deficiency among the Swedish population until recently was thought to be fairly low. However, the number of adult...
immigrants to Sweden has risen during the last decades and so has the number of adopted children from other countries where the majority of the population is lactose intolerant.

In view of the widespread occurrence of lactose intolerance, it is of interest to reduce the concentration of lactose in milk. A natural way to accomplish this is via fermentation. Gallagher et al. (12) suggested that fermented milk products should be recommended for lactase-deficient patients, but data on the influence of fermented milk products on lactose intolerant persons is limited.

Fermentation significantly decreases the lactose content of milk especially in yogurt but also in acidophilus and bifidus milk. The decrease was still significant but less pronounced in ropy milk, buttermilk, and kefir. The popularity of yogurt is spread over many parts of the world, and consumption is still increasing. Acidophilus milk is also subject to increasing interest, but its suitability for lactose intolerant individuals until now has not been investigated.

Common to both products is the claim that the microorganisms partly will survive passage through the alimentary tract. This also could mean that hydrolysis of lactose through the gastrointestinal tract could be continued (19, 20).

It was determined by blood glucose determinations that yogurt and acidophilus milk, with their viable lactobacilli are tolerated better that unfermented milk by lactose intolerant subjects.

Following ingestion of lactose corresponding to 50 g/m² body surface, a normal individual shows a rise of at least 20 to 25 mg glucose/100 ml serum (27, 30). Individuals with low lactase activity show a “flat” blood glucose response curve and have more or less massive clinical symptoms.

Following consumption of 500 ml low fat milk, four normal Swedish subjects showed maximum blood glucose increases from 21 to 30 mg/100 ml whereas six of eight non-Swedish individuals had glucose below 20 mg/100 ml. Eight of nine non-Swedish subjects complained about abdominal pain after ingestion of unfermented milk products whereas none had symptoms after consuming a similar amount (500 ml) of yogurt or acidophilus milk.

Fermented milk appears to be tolerated in lactose intolerant subjects because of the lower concentrations of lactose compared with low fat milk. It is also possible that lactase-containing microorganisms originating from the fermented milk continue to be active in the intestinal tract and participate in hydrolysis of ingested lactose.

Fermented milk products, especially yogurt and acidophilus milk, should be considered as an alternative in formulating diets for lactose intolerant subjects. They should be encouraged to test their degree of intolerance by using fermented milk products to convince themselves that moderate amounts (500 ml) can be consumed without any of the symptoms that usually occur.

ACKNOWLEDGMENTS

This work was supported by grants from the Swedish Dairy Association, SMR, Sweden. The author is indebted to Jan-Ake Gustafsson for his encouragement and help in preparing this manuscript, and to Marianne Melin for valuable and skillful assistance.

REFERENCES

16 Hargrove, R. E., and J. A. Alford. 1977. Nutritional superiority of yogurt as compared to other fermented and nonfermented milks. J. Dairy Sci. (Suppl. 1) 60:34. (Abstr.)
