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# Low lactose and lactose-free milk and dairy products – prospects, technologies and applications


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## Abstract

Reducing the lactose content or removing it completely from milk and other dairy products can expand availability of valuable dairy nutrients world-wide. The traditional approach to conversion of lactose by its hydrolysis to the constituent monosaccharides has been practiced industrially for almost 20 years. In Finland, the HYLA line of dairy products containing hydrolysed lactose comprises almost 100 different products. The patented chromatographic process for removal of lactose from milk offers new opportunities for marketing of lactose-free milk and dairy products with sensory properties indistinguishable from those of the comparable traditional products. The process is described and the marketing success of the new Valio lactose-free products is documented.


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## The lactose intolerance problem

Lactose, the most abundant component of milk of most mammals, is an important energy source for the newborn offspring. Upon weaning, the ability to digest lactose diminishes as the adult organism loses its ability to produce the enzyme lactase (ß-galactosidase, E.C. 3.2.1.23) needed for the lactose digestion. This is a 'normal case' found for most mammals in nature. The only notable exception are some ethnic groups of the most complex mammal – the human – which have developed the ability to keep producing the lactose-digesting enzyme as a result of milk becoming a food consumed by not only the infants but also adults. Even in this case, however, the inability to digest lactose (the so called 'lactose intolerance') is the more predominant case around the world, as shown in Figure 1 (Anon. 2001).

The debate about the various forms of the lactose intolerance, as well as the severity of the malady from the medical viewpoint, continues. At the last IDF World Dairy Congress in Paris, two contributions by the leading researchers in the field were devoted to the conditions, symptoms, and roles of the individual factors influencing the lactose digestion or maldigestion (Savaiano 2002; Marteau *et al.* 2002). Regardless of the possible medical implications of the lactose intolerance, even the most innocuous symptoms such as flatulence or intestinal discomfort cause many potential milk consumers to avoid drinking milk or consuming other lactose-containing dairy products. Sometimes even virtually lactose-free products such as cheese are avoided by consumers that consider themselves to be lactose intolerant (Jelen, personal communications). For the dairy industry, the potential market losses due to the real or perceived lactose intolerance problems are significant and some companies expend much effort to develop products that would satisfy lactose-intolerant consumers.

The market for lactose-hydrolysed dairy products has been growing steadily, at a rate of approximately 20% per year in the US alone, mainly stimulated by the awareness of the lactose-intolerance problem and the changing demographics (Mahoney 1997). In addition to milk, other products are also entering the markets with increasing frequency, as can be ascertained by a quick survey of the websites of some producers (Vasiljevic 2003). One of the significant providers of a large variety of lactose-hydrolysed dairy products is the Finnish dairy company Valio, where a general awareness of lactose intolerance arose in the early 1970s and a search for a solution to the problem has begun. Although the occurrence of lactose intolerance in Finland (ca. 17% of the total population) is relatively low by international comparison, the problem is nevertheless significant due to the high consumption of milk (approx. 130 L/person/ear). After the first commercial lactase enzymes became available, the use of these soluble preparations was perfected to hydrolyse enzymatically more than 80% of the lactose in milk into glucose and galactose. Valio launched the first lactose-hydrolysed product – HYLA milk powder – for test marketing in 1978. The product became fully available in 1980, after which the range began to grow slowly. Then from 1985 onwards the HYLA product range was vigorously expanded. A low-lactose alternative was introduced in each product group and the HYLA range has continued to grow. Valio currently offers some 100 different HYLA products; some examples of the more successful ones are listed in Table 1. About 15-20% of Valio's turnover comes from HYLA-products. However, this percentage varies largely between different product groups, ranging from 3% to 60%. For example, in dairy creams group HYLA-products represent about 60% of total sales.

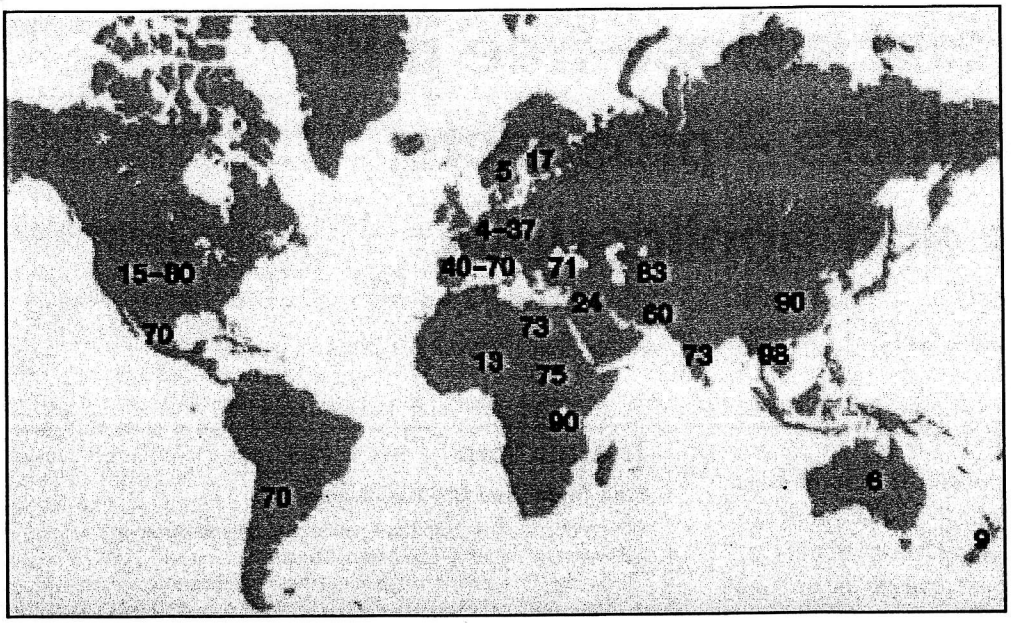


**Figure 1: Lactose intolerance (% of total populations) around the world.**

## Technological alternatives for lactose hydrolysis

While several technologically feasible approaches to production of lactose-hydrolysed milk and dairy products exist (Table 2), most processors resort to the enzymatic route for the breakdown of the lactose molecule using either the free (soluble) or, rarely, the immobilised enzyme variant of the process. In both cases the resulting milk contains both glucose and galactose, the end products of the enzymatic hydrolysis, making the milk much sweeter and thus, for many consumers, unnatural. Both processes are also relatively expensive as evidenced by the much higher prices of the lactose-hydrolysed milk on the retail markets, thus further discouraging consumers' purchases.

In mid- 1980, Valio began a new line of research into chromatographic separation of lactose from whey, in order to improve the yield of its lactose manufacturing operation (Harju 1990a). Chromatography was already commonly used in the sugar industry to improve the yield in sugar production. The test results showed that the developed chromatography process was also suitable for a specific separation of lactose from skim milk, and, consequently, resulted in another product besides lactose – a fraction containing all the salts and proteins of milk (Harju 1990b). This way of separating lactose from skim milk was new to milk separation technology. The well-established process of ultrafiltration also enables the separation of lactose from milk, but the salts are removed from the protein fraction at the same time.

The patent-protected process of removing bulk of the lactose from milk chromatographically enabled the production of a lactose-free milk drink, with the taste no different from ordinary milk. In its final version (Figure 2) the milk is split into two streams; lactose is removed from the main stream while the traditional process of lactose hydrolysis by a soluble enzyme is carried out in the second stream. Combining the two streams results in the slight sweetness of the final product matching that of the ordinary milk.

The lactose-free milk drink was launched in Finland in autumn 2001. The product was named 'milk drink', because according to the present EU Directive lactose may only be removed from milk products enzymatically. The physical separation of lactose

**Table 1: Examples of Valio's HYLA® products. (In all HYLA-products more than 80% of lactose is hydrolysed).**

| Product | Description | Package | Launched |
|---|---|---|---|
| HYLA skimmed milk powder | Spray-dried | 500 g pouch<br>25 kg bag | 1980 |
| HYLA low fat milk | UHT-treated, 1.5% fat | 0.2 L, 0.5 L, 1 L aseptic carton | 1983 |
| A-yogurt | Flavoured stirred yogurt with acidophilus and bifidus | 150 g cup | 1986 |
| Gefilus yogurt with fruit | Skimmed milk yogurt with Lactobacillus GG | 150 g cup | 2002 |
| Evolus fermented milk | Fermented milk with bioactive peptides (lowering blood pressure) | 1 L carton | 2000 |
| HYLA whipping cream | UHT-treated, 38% fat | 0.2 L, 0.5 L, 1 L | 1988 |
| HYLA cooking cream UHT | Dairy-based cooking cream product. UHT, 15% fat | 0.2 L, 0.33 L, 1 L, 10 L carton | 1998 |
| HYLA cottage cheese | Cottage cheese 2% fat, natural | 200 g cup | 1991 |
| Gefilus-whey drink | Fermented apricot-peach whey drink with live lactic acid bacteria | 1 L carton | 1990 |
| HYLA ice-cream | Vanilla ice-cream | 4.5 L (catering)<br>750 g | 1990 |

**Table 2: Industrially applicable methods for lactose hydrolysis.**

| Process | Principle |
|---|---|
| Acid-catalysed hydrolysis | Aqueous lactose solution heated @ 150 C, pH 1.2 |
| Immobilised enzyme technology | Lactase immobilised on suitable carrier in a column |
| Membrane-based enzyme reactors | Soluble enzyme separated by UF and reused |
| Free (soluble) purified enzymes | Enzyme preparation added to final product |
| Crude cellular extracts | Homogenate of lactase-producing microbial culture used as the enzyme source |

using chromatography necessitated this approach to the labelling of the product. However, such a labelling requirement is not unusual; as an example, in Switzerland, a reduced-fat UHT milk is also labelled as a milk drink to satisfy the local regulatory requirements.

The composition of the lactose-free Valio milk (Table 3) is similar to that of partly skimmed milk, except for its low carbohydrate content. It contains less than 0.01% lactose, the maximum permitted for lactose-free products by the Finnish authorities. The glucose and galactose content is approximately 1.4% each. Due to the lower carbohydrate content, the product also contains less energy than a corresponding traditional product, with approximately 83% of the energy content of the partly skimmed milk.

## Crude cellular extracts

At the University of Alberta, an alternative approach to the production of lactose hydrolysed dairy products has been under investigation for several years. Although the research is based on the traditional use of the lactase enzyme, the novel idea is to produce the enzyme 'in-house', in the form of a crude cellular extract from a well-established dairy bacterium. The enzyme source in our work has been the traditional yogurt culture *Lactobacillus delbrueckii* ssp. *bulgaricus*; its ATCC strain 11842 has been selected as a particularly effective producer of the enzyme (Shah and Jelen 1991). The envisioned process involves growing the enzyme-producing culture just like in the case of a traditional starter culture for cheesemaking; concentrating the cell biomass and disrupting the concentrated culture by a high pressure homogeniser or a similar device; and using the homogenate (termed 'crude cellular extract' or CCE) without further purification or other treatment. The conceptual schematic diagram of the proposed process is shown in Figure 3.

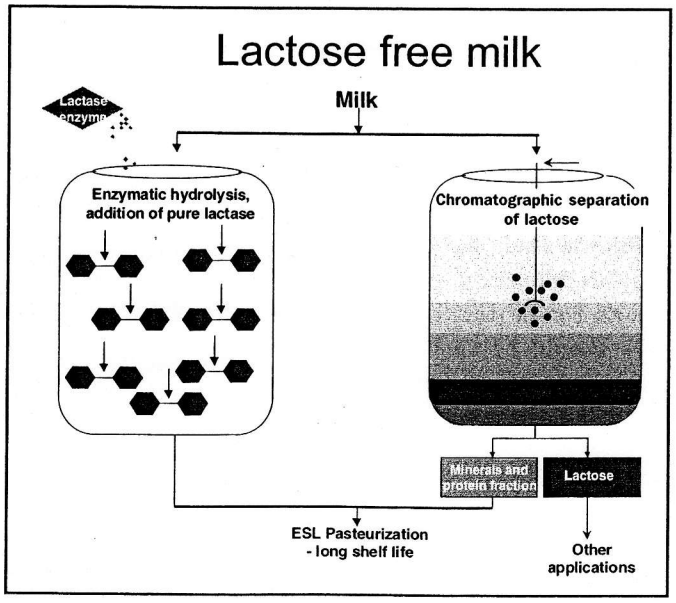


**Figure 2: Schematic representation of the Valio production process for lactose-free milk.**

In a series of papers published recently, we have shown the general technical and perhaps even economic feasibility of the approach (Kreft *et al.* 2001; Bury *et al.* 2000); we investigated the enzyme production alternatives (Vasiljevic and Jelen 2001); compared several alternative enzyme sources and several alternative cell disruption techniques (Bury *et al.* 2001; Geciova *et al.* 2002a); determined the technical feasibility of drying the CCE with minimal loss of enzymatic activity (Vasiljevic and Jelen 2003a,b); and conducted confirmative sensory evaluations of the resulting lactose-hydrolysed products (Vasiljevic *et al.* 2003). Since the approach not only does not solve the problem of increased sweetness of the resulting milk, but produces some additional flavour modifications related to the fermentation process used for the enzyme production, the resulting lactose-hydrolysed drinking milk certainly cannot compete with the Valio chromatographic process! However, for other applications, in the cases where the sweetness and the fermented flavour may not be detrimental – or may even be welcome as in the case of whey or yogurt drinks or similar products – this latest twist in the traditional lactose hydrolysis technology may be worth investigating further.

Beyond the core subject of lactose hydrolysis, other uses of the CCE technology may also be considered and some have been studied. In particular, the transferase reactions catalysed by the lactase enzyme contained in the CCE may result not only in hydrolysis of the lactose but in formation of new disaccharides and/or production of other oligosaccharides (Vasiljevic and Jelen 2003c). The proteolytic activity of the

**Table 3: Proximate analysis of the lactose free milk drink compared with other market milk products.**

| | Lactose-free milk | Pasteurised low-fat milk lactose hydrolysed (HYLA) | Pasteurised low-fat milk |
|---|---|---|---|
| Protein (%) | 3.3 | 3.2 | 3.2 |
| Carbohydrates (%) | 2.8 | 4.8 | 4.8 |
| Lactose (%) | <0.01 | <1 | 4.8 |
| Ash (%) | 0.7 | 0.7 | 0.7 |
| Fat (%) | 1.5 | 1.5 | 1.5 |
| Calcium (mg/100 g) | 120 | 120 | 120 |
| Energy (kJ) | 160 | 193 | 193 |

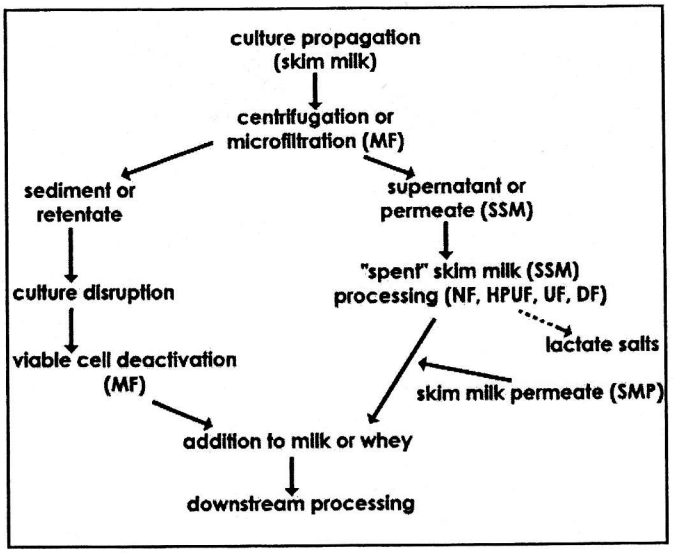


**Figure 3: Schematic diagram of the proposed lactose hydrolysis process based on the use of crude cellular extracts of a lactase-producing microbial culture.**

CCE, while potentially detrimental for the primary lactose hydrolysis goal unless controlled by the judiciously selected hydrolysis conditions (Vasiljevic and Jelen 2002), could be advantageous in using the CCE as a 'fermentation enhancer'. The proteolytic as well as lactolytic properties of the CCE can be possibly utilised in production of various cheese starter cultures, for enhancement of growth rates of slow growing probiotic organisms, even in production of various fermented dairy products (Gaudreau, Champagne and Jelen 2003).

The basis of the emerging CCE technology is the rapidly expanding availability of mechanical equipment suited for bacterial cell disruption, now well established in the pharmaceutical industry. Table 4 lists some of the alternative designs potentially suitable for applications in the dairy industry (Geciova *et al.* 2002b), as an alternative to the more traditional approach to enzyme release from bacterial cells by the induced cell lysis route.

## Marketing of lactose-hydrolysed and lactose-free milk products

Valio's marketing strategy is to differentiate consumer products in the home market. An illustration of such differentiation is shown in the Figure 4. Outside the home market, Valio is licensing production technologies and product concepts.

Lactose-hydrolysed products have attracted constant demand among consumers in Finland. Since the 1980s, when the HYLA-products were launched, their share in each product group has grown steadily. At the present time – 20 years after the original decision to include lactose-hydrolysed dairy products in the manufacturing program – the average share of HYLA-products in all product categories is still growing steadily, between 10% and 20% per year.

The new line of lactose-free products is showing even more enthusiastic response from the consumers than the HYLA products 20 years ago. So far, Valio's experience comes mainly from marketing the lactose-free milk drink. The product was eagerly received despite very limited advertising. Its innovative

**Table 4: Industrially applicable mechanical methods for disruption of bacterial cells (from Geciova *et al.* 2002b).**

| Process | Characteristics |
|---|---|
| Ultrasound | Scale-up for continuous industrial use difficult |
| High pressure homogeniser | Instantaneous cooling difficult |
| Microfluidiser | Easy to cool, limited throughput capacity |
| Bead mill | Cumbersome separation of the glass beads |

value is so great that it generated press coverage in national newspapers. The product reached the sales target set for the whole year in just three months. Sales grew vigorously and continue to do so. Exports to Sweden commenced in November 2002 and again exceeded all expectations. In spring 2002, Valio's lactose-free milk drink was selected as a star product of the year in the drinks category of the Finnish Food Product of the Year competition.

Based on consumer feedback, the product has obviously attracted a new group of milk users: people who had given up milk due to lactose intolerance and who dislike the sweetness of the HYLA milk. These consumers are once again able to enjoy the good taste of milk without the fear of suffering from stomach disorders. The revolutionary chromatographic separation technology enabled Valio to develop a new kind of dairy product based on selective modification of the composition of the original raw milk.

## Conclusion – lactose intolerance as an opportunity

In the US alone, the potential market for dairy products targeted specifically for lactose-intolerant individuals has been estimated to be about 50 million consumers (Sloan 2000). In Finland the figure is about one million, while in South-East Asia more than 90% of the population is lactose intolerant. The potential for innovative market development in this part of the world is enormous, but the consumers are not used to consuming dairy products as adults. Offering them suitable products based on modifications of the traditional cow's milk could open up new markets for the dairy industry world-wide.

Lactose-hydrolysed and lactose-free dairy products should be considered as important physiologically functional dairy foods. Their rapidly expanding availability will mean not only more satisfied milk drinkers world-wide, but will lead to improved nutritional status due to increased availability of dairy calcium and thus, ultimately, to reduction of health-related societal expenses. For the dairy industry, the possibility of increased markets should be an important incentive to continue the technological developments leading to many new dairy products that will satisfy even the most lactose-intolerant consumers.

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**Figure 4: Example of HYLA product differentiation in domestic Finnish market.**

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