



Lactose: Technological Aspects and Usage

Chemical and physical properties of lactose

Lactose (4-O-(β -galactopyranosyl-D-glucopyranose) is a disaccharide containing the monosaccharides glucose and galactose in β -1 \rightarrow 4 linkage. Lactose occurs naturally and almost exclusively in the milk of mammals, where it constitutes the main carbohydrate and is often referred to as “milk sugar” (Figure 1). The average lactose content in milk ranges from 2 – 8%; bovine and human milk contain on average 4.5% and 7% lactose respectively. Lactose occurs in two molecular forms (α and β), and in aqueous solution a process termed mutarotation interchanges the α - and β -forms until an equilibrium of about 37% α lactose and 63% β -lactose is reached at neutral pH and ambient temperature (20°-25°C). The solubility of lactose is low when compared to other disaccharides (e.g. sucrose), and the sweetness of lactose is about one-third that of sucrose. Lactose can be hydrolysed into its constituent monosaccharides (glucose and galactose) through the action of the enzyme β galactosidase (lactase)



Figure 1: Typical crystals of lactose isolated from bovine milk.

Lactose digestion, lactose malabsorption and lactose intolerance

Lactose digestion in humans is variable and changes with the age of the individual.

Healthy infants successfully digest lactose which is also a component of human breastmilk. However, sometime after weaning in the majority of the world's children, there may be a genetically programmed decrease in the synthesis of the lactase enzyme. This decrease is referred to as primary lactase deficiency or lactase non-persistence. The exceptions to this deficiency are the descendants of populations that traditionally practice cattle domestication (e.g. from northern Europe) who continue to synthesize lactase and therefore maintain the ability to digest milk and other dairy products into adulthood (lactase persistence).

In lactase persistent individuals, lactose is hydrolysed and its component monosaccharides are digested in the small intestine. In lactase-non-persistent individuals, there is a degree of lactose malabsorption which results in some lactose being released into the colon where it is fermented by intestinal microbiota.

The release of lactose into the colon due to malabsorption produces few or no symptoms in most individuals. However, in some consumers the bacterial fermentation of lactose can result in adverse gastrointestinal symptoms including flatulence, osmotic diarrhoea, or intestinal cramps. These symptoms are collectively referred to as lactose intolerance. Generally, a 15 g/day limit is used as a threshold above which lactose can cause symptoms in lactose intolerant individuals.

It is important to note that the majority of people with lactose malabsorption do not have clinical lactose intolerance. Undigested lactose in the colon can also act as a food source for gut microbiota, and can stimulate growth and activity of beneficial microorganisms comparable to prebiotic oligosaccharides.

The complexity of lactose digestion, malabsorption and intolerance highlights the importance of the lactose

content of dairy foods, ingredients and other food products, and the various approaches to reduce and/or eliminate lactose from such products/ingredients.

Lactose content of dairy foods and products containing dairy ingredients

The lactose content of dairy products and ingredients is dependent on the production process. The average lactose content of typical dairy products and ingredients, and food products containing dairy ingredients is shown in Table 1.

Table 1: Average lactose content of typical dairy ingredients and products, and food products containing dairy ingredients

Product/Ingredient	Lactose (% w/w)
Bovine milk (full fat)	4.5
Human breastmilk	7
Yoghurt	3.2-4
Mature cheeses (e.g. Cheddar, Gouda)	0-0.1
Feta cheese	0.5
Butter	0.1-1
Sour cream	3
Milk chocolate	2-9
Skim milk powder	~50
Whey powder	~73

Reduction of the lactose content of dairy products is achieved by creaming, fermentation, whey removal, and/or hydrolysis. The latter process usually results in products/ingredients that are considered lactose-free (typically <0.1% lactose w/w) or zero-lactose (typically <0.01% lactose w/w).

Creaming

Lactose is concentrated in the aqueous phase of milk. Thus, (sour) cream and butter have a lactose content that is reduced in proportion to the increased fat content. For example, butter contains <1% lactose. In addition, some fermented fat-containing dairy products contain reduced levels of lactose through the action of lactic acid bacteria.

Fermentation

Fermentation of milk to obtain fermented dairy products (e.g. yoghurt, kefir and buttermilk) reduces the lactose content by 10-40% through the action of fermentative bacterial cultures that consume the lactose. By contrast, fortification of yoghurt with skim milk powder increases the lactose content. Dairy cultures produce β galactosidase and this bacterial enzyme remains active after consumption of yoghurt and aids to some extent during intestinal lactose digestion even when intestinal lactase activity is absent. Yoghurt is therefore a more tolerable lactose-containing dairy product for lactose-intolerant individuals. It is important to note however, that yoghurt subjected to high heat treatment in order to extend shelf-life may contain inactivated β galactosidase and thus may not be as tolerable to lactose-intolerant individuals as the non/low heat-treated product.

Cheese-making and whey removal

During cheese-making, most of the lactose present in milk is removed with the whey. Additional lactose reduction is achieved by fermentation. In fresh cheeses, including cottage cheese and quark and Greek yoghurt, whey removal is incomplete and the lactose content thus ranges from 1-3% in the final product. In soft and some hard cheeses, including Camembert, Gouda and mild Cheddar, bacterial metabolism further reduces the lactose content during the (short) ripening period and lactose levels in the final product are typically <2%. In most hard cheeses, whey removal is more complete, and the lactose content of unripened hard cheeses is typically <1%.

Remaining lactose (and galactose) are further removed by bacterial metabolism during ripening. Depending upon the cheese, a ripening period of 1-12 months reduces lactose (and galactose) concentrations to <0.1% and these cheeses are thus considered lactose-free.

Foods containing dairy ingredients

Addition of milk or dairy ingredients in food manufacturing can add lactose to these foods. Common examples include baked goods, breakfast cereals, soups, deli salads containing cream and confectionery such as milk chocolate. Corresponding to the low level of dairy/lactose addition, the lactose content of non-dairy foods containing milk-derived ingredients is generally <1%. However, based upon the higher content of milk solids, milk chocolate can contain as much as 9% lactose. Lactose and/or skim milk powder are also used for standardization of starter cultures, and to improve their survival during dry or frozen storage. However, the dosage (<0.1%) of starter cultures in food fermentations introduces only trace amounts of lactose to the final product. These trace amounts of lactose can be further reduced through the fermentation process.

Pharmaceuticals

Lactose is widely used for standardization and delivery of pharmaceuticals. Pharmaceutical-grade lactose is often the excipient of choice for the delivery of pharmaceutical preparations and drugs because of the low price, availability in pure form as lactose monohydrate or the anhydrous form, and because of its suitable physical characteristics including hygroscopicity and compressibility. Lactose intake from pharmaceuticals is generally well below the level (~15 g/day) that may cause symptoms in lactose intolerant individuals.

Production of lactose-free dairy products by lactose hydrolysis

The industrial production of lactose-free or zero-lactose dairy products is achieved by addition of soluble β -galactosidase, lactose hydrolysis with immobilized lactase, or chromatographic separation of lactose from

other milk components. Following such treatment, the 'lactose status' of products varies considerably depending upon the jurisdiction and ranges from <0.1% lactose (considered lactose-free in many jurisdictions), <0.01% lactose (considered zero-lactose in many jurisdictions) to zero detectable lactose. Lactose hydrolysis with soluble or immobilized enzymes increases the sweetness of the products because the combined sweetness of glucose and galactose is 3 – 4-fold higher when compared to lactose. The combination of lactose hydrolysis with lactose removal by membranes or chromatographic techniques allows production of lactose-free milk with a sweetness that is comparable to normal milk.

Manufacture of lactose for use as an ingredient

Millions of tonnes of lactose are manufactured annually by the dairy industry for use as an ingredient, primarily in the pharmaceutical industry as an excipient in tablets and capsules, and in the production of infant formula as the primary carbohydrate component, noting that human breastmilk contains about 60% more lactose than found in bovine milk.

Following whey collection after cheese production or from other sources and the isolation of valuable proteins from the whey, the deproteinized whey permeate is concentrated to 60-65% solids using multi-stage evaporation. Prior to evaporation, the permeate can optionally be pre-concentrated and/or demineralized using reverse osmosis and/or nanofiltration. Lactose crystallization occurs upon cooling of the concentrated permeate and the crystals are isolated by decantation or centrifugation. After isolation, the wet crystals (~10% moisture) are dried using flash or fluidized bed dryers. This food-grade lactose can be further refined or polished for more demanding applications, such as a pharmaceutical excipient, by recrystallization or by various chromatographic techniques (e.g. ion exclusion chromatography).

Further reading

1. Belitz, H.D., Grosch, W., & Schieberle, P. (2009) Food Chemistry, Springer-Verlag, Berlin Heidelberg.
2. Gänzle, M.G., Haase, G., & Jelen, P. (2008) Lactose - Crystallisation, hydrolysis and value-added derivatives. *Int. Dairy J.* 18, 685-694.
3. Gille, D., Walther, B., Badertscher, R., Bosshart, A., Brügger, C., Brühlhart, M., Gauch, R., Noth, P., Vergères, G., & Egger, L. (2018) Detection of lactose in products with low lactose content. *Int. Dairy J.* 83, 17-19.
4. Harju, M., Kallioinen, H., & Tossavainen, O. (2012) Lactose hydrolysis and other conversions in dairy products. *Int. Dairy J.* 22, 104-109.
5. Hourigan, J.A., Lifran, E.V., Vu, L.T.T., Listiohadi, Y., & Sleigh, R.W. (2013) Lactose: Chemistry, processing, and utilization in *Advances in Dairy Ingredients* (Augustin, M.A., & Smithers, G.W., eds.) pp. 31-70, Wiley-Blackwell, Ames, Iowa.
6. Kolars, J.C., Levitt, M.D., Aouji, M., & Savaiano, D.A. (1984) Yogurt – An autodigesting source of lactose. *N. Engl. J. Med.* 310, 1-3.
7. Oku, T., & Nakamura, S. (2002) Digestion, absorption, fermentation, and metabolism of functional sugar substitutes and their available energy. *Pure Appl. Chem.* 74, 1253-1261.
8. Swallow, D.M. (2003) Genetics of lactase persistence and lactose intolerance. *Annu. Rev. Genet.* 37, 197-219.



International Dairy Federation
www.fil-idf.org