Yoghurt

(Françoise Rul)

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Where is it predominantly made and used?
Yoghurt is a traditional milk fermented food that has been consumed daily for millennia by different civilizations in Europe and the Middle East, where it was discovered by nomadic peoples around 5 000 B.C. "Yogurt" comes from the Turkish word "yogurmak," which means to thicken, coagulate, or curdle. Nowadays, yoghurt is produced and consumed all over the world, with regional variations in its uses and the animal species used for its production.

What are its ingredients?
Yoghurt is basically composed of mammalian milk, most frequently cow milk, but also goat or sheep milks, that has been fermented by lactic acid bacteria. Several factors are involved in the final composition of yoghurt:

- the nature of the milk (full-fat, semi- or skimmed milk) and the animal from which it originates,
- the manufacturing processes (temperature, fermentation time…),
- the strains of lactic acid bacteria used as starters,
- the ingredients that are added (fruits, sugars, aromas).

Generally speaking, yoghurt contains a high level of lactose (4.5-4.8 g/100g) and proteins (3-4.5 g/100g), is poor in fats (0-4%) and salt. Because of the milk fermentation, yoghurt contains high quantities of lactic acid that arise from the metabolization of lactose by starters. This composition gives yoghurt its interesting and specific organoleptic and nutritional qualities.

How do we make it?

Yoghurt manufacture proceeds in the main following steps:

- milk is successively standardized (for fat, proteins concentrations),
- homogenized,
- pasteurized (heated for 3-5 min at 90-95°C),
- cooled to the optimal growth temperature of the starters (lactic acid bacteria),
- inoculated with the 2 specific lactic acid bacteria *Streptococcus thermophilus* (*S. thermophilus*) and *Lactobacillus delbrueckii* subsp. *bulgaricus* (*L. bulgaricus*), and
- incubated (several hours, at 42-45°C).
- The process ends by the harvesting that consists of cooling, filling, packaging and cold storage (4°C). This lactic fermentation process is conducted to reduce the pH – create an acidic product – which leads to casein precipitation and milk coagulation.
- Depending on the type of yoghurt, the process is completed by addition of ingredients such as fruits or sugar.
- For set yoghurts, packaging is performed just after bacterial inoculation and pots are then warmed (2-3 h at 42-45°C); for stirred yoghurts, after fermentation, the milk curd is stirred, cooled and packaged.

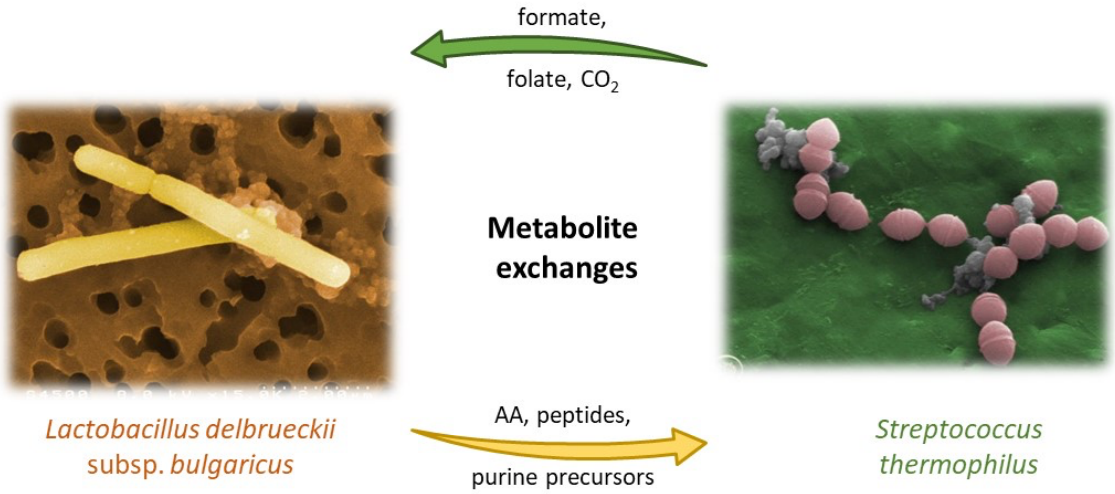
The microbiology of the process

Yoghurt results from the simultaneous fermentation of milk by the 2 thermophilic ('heat-loving') lactic acid bacteria (LAB) *S. thermophilus* (ovococci, or ovoid cells associated in long chains) and *L. bulgaricus* (rod shape) (see figure below). In 1984, the Food and Agriculture Organisation (FAO)/World Health Organisation (WHO) defined yoghurt as "the coagulated milk product obtained by lactic acid fermentation through the action of *Lactobacillus delbrueckii* ssp. b*ulgaricus* and *Streptococcus thermophilus* from milk and milk products. The microorganisms in the final product must be viable and abundant." The Codex Alimentarius entry for fermented milk (Codex STAN 243-2003) specifies that yoghurt should contain a minimum of 10 million microorganisms per gram of product. Depending on the countries, the legislation differs; for some (such as in France), if other bacteria – such as Bifidobacteria or other lactobacilli - are present in the fermented milk product, the product must be called "fermented milk" and cannot carry the "yoghurt" label; for other, the addition of a third starter is allowed.

Typically, yoghurts are produced at temperatures around 42°C, which promotes the optimal growth of both *S. thermophilus* and *L. bulgaricus*. Usually, when milk is inoculated with these two bacteria, *S. thermophilus* initially grows exponentially while *L. bulgaricus* remains at its seeding level, after which growth of *S. thermophilus* slows and *L. bulgaricus* starts to grow exponentially. As the milk becomes acidified, reaching a pH of around 5.2, *S. thermophilus* stops growing, whereas *L. bulgaricus* continues to grow until pH levels drop to around 4.4. Despite *S. thermophilus* being more sensitive than *L. bulgaricus* to acidity, it generally numerically dominates at the end of fermentation, probably because *L. bulgaricus* is nutritionally more demanding than *S. thermophilus*, which often gives the latter a more competitive edge when they grow together in milk.

The growth of *S. thermophilus* and *L. bulgaricus* in milk largely depends on their ability to efficiently use the major carbon and nitrogen sources of milk, as well as to synthesize nucleotide bases that are lacking in milk. The main source of carbohydrate in milk is lactose which is very efficiently metabolized by both yoghurt LABs. On the other hand, their optimal growth depends on the availability of amino acids (AAs) as nitrogen sources, as they are auxotrophic for several AAs (= unable to synthesize the AAs themselves: from 3-4 for *S. thermophilus* to 15-20 for *L. bulgaricus*,

depending on the strain). As milk is poor in free AAs and peptides (combinations of a few AAs), yoghurt bacteria growth depends on their complex and efficient proteolytic system that digest the milk proteins, which are long polymers of AAs – the main ones of which are the caseins – into their constituent AAs. This multiproteic system is very well characterized in many LABs; it consists in the hydrolysis of the caseins, the transport of the resulting oligopeptides (protein fragments)/AAs into the bacteria, and the hydrolysis of the internalized peptides into free AAs that are used for intracellular protein synthesis.



Scanning electron microscopy of the 2 yoghurt species of lactic acid bacteria after growth in cow milk. AA: amino acids. (© T. Meylheuc, MiMa2, INRAE, with permission)

The association between these 2 bacteria in milk represents the archetype of proto-cooperation interactions: each bacterium is able to grow independently in the medium but the association can improve the growth of the 2 bacteria. It contributes to cover the nutritional needs through metabolite exchanges: *S. thermophilus* provides *L. bulgaricus* with CO_2, formic acid and folate, whereas *L. bulgaricus* provides *S. thermophilus* with peptides and free AAs. The result of the association depends on a variety of bacterial interactions, both positive ones, such as mutualism (e. g. supply of growth stimulating metabolites) and commensalism, as well as negative ones, such as competition (e. g. for the nutrients in the milk) and amensalism (e. g. production of lactate, bacteriocins, H_2O_2), that depend in the strains themselves. Finally, the interactions that take place between the 2 yoghurt bacteria will drive the technological properties (e. g. acidification rate) as well as the organoleptic ones, texture via the production of lactate and thus formation of the curd and exopolysaccharide production, and flavor via the production of the typical aromatic compounds of yoghurt.

How/when do we use and enjoy it?

The typical and appreciated flavor of milk yoghurt mainly comes from its acidity and the presence of different carbonyl compounds resulting from the proteolysis and the degradation of amino acids into alcohol, aldehydes, and esters by the yoghurt bacteria. The 2 main compounds that define its flavor are diacetyl and acetaldehyde that is responsible for the fresh and fruity note of yoghurt. This delicate and unique flavor together with its specific texture give yoghurt its attractivity and universal consumption in different ways.

Yoghurt is consumed as a dessert during lunch or dinner, for breakfast or as a snack, alone or associated with sugar, fruits, jam/marmalade, honey, or cereals. It is also used in cakes as a sweet and texturing ingredient. In numerous countries, yoghurt is the base of sauces, soups, or beverages. Yoghurt is indeed the main ingredient of sauces and side dishes with vegetables (e. g. Greek tzatziki, with cucumber, garlic, aromatic herbs) or marinated meats, giving them a soft texture and a subtle taste. Yoghurt is also used for avocado, cucumber or beetroot soups and yoghurt-based beverages that are very popular in India and (Eur)Asia as lassi, or the sparkling koumiss and kefir.

Variations, regional variations

The milk fermented family present a huge variety of products that mainly comes from the diversity of milk species present in the world and that are specific to each region. Cow yoghurts are produced all over the world whereas yoghurts from ewe are present in Mediterranean, Central Europe or occidental Asia regions, bufallo ones in South Asia, camel ones in deserts, and mare ones in Central Asia. More than 400 different fermented milks have been referenced, with a prevalence in Asia, e. g., yaourt, yaourti, yoghurt from Central Asia and Balkans, kefir from Russia and Central Asia, koumiss from Russia, Mongolia, Kazakhstan or Dahi from India. In Lebanon, laban is often used in local cooking and, after it has been drained (labne), it is consumed seasoned with oil and olive during breakfast. Armenian people eat madzoun, a yoghurt that is consumed with vine leaves and numerous salty dishes; it also an ingredient of yoghurt soup.

On the other hand, numerous industrial and modern types of yoghurt and fermented milks exist and new ones are continually being developed/released on the market: some are farm, stirred, thermised, supplemented with sugar, fruits or aromas, some don't contain any fat, and other are enriched in cream, proteins, vitamin D, iron, omega 3 or probiotic bacteria (such as Bifidobacteria, lactobacilli). The emergence of new food consumption patterns and of health consciousness on part of the consumers, as well as the global aging of the population, are reasons to further promote fermented foods, such as yoghurt, and to develop new ones.

Beneficial properties

The virtues attributed for yoghurt are ancient. Yoghurt can be first considered as a probiotic food as yoghurt starters meet the definition of probiotics: "Live microorganisms [that] when administered in adequate amounts confer a health benefit on the host" (FAO-WHO). Yoghurt possesses the healthful property to help alleviate lactose intolerance which is the basis of a health claim (EFSA). Lactose intolerance is manifested by abdominal pains, and digestive discomforts because lactose present in milk is fermented by resident microbiota in the colon, leading thus to the production of organic acids, hydrogen, methane and carbon dioxide. This is due to a reduction or deficiency of the small intestine lactase activity that occurs rapidly after weaning in most children and which depends also on ethnic origin; the prevalence of lactase deficiency (hypolactasia) is over 50% in adult Africans, American Hispanics, and American Indians, and close to 100% in some Asian populations. In yoghurt, bacteria are alive and metabolically active all along the digestive tract which contributes to the lactose digestion.

Yogurt has highly attractive nutritional properties—it is low in calories (around 60-90 kcal per serving) but contains enough macro- and micronutrients (proteins, fatty acids, calcium, phosphorus, and vitamins) to cover a person's daily needs.

In addition, yoghurt consumption has been reported to limit chronic diarrhea in children by reducing both its frequency and duration, to stimulate the immune system – in particular in immune-compromised people, to decrease allergies in adults and is negatively associated with the appearance of type II diabetes. The high proteolytic activity of the yoghurt bacteria leading to the production of bio-active peptides contributes to the potential antihypertensive effect of yoghurt.

Cultural roots and importance

Cultural habits concerning the type of yoghurt consumed vary according to the countries and regions of the world; some populations prefer natural yoghurts, others flavored or Greek-type ones. Traditionally present in the Middle East and Europe, the yoghurt market is currently expanding across the globe with a demand that has dramatically grown in North and South America as well as in Asia; at present, more than 30% of the world's population eats yogurt. Traditional yogurts—produced at small scales or at home—currently coexist with industrially produced yogurts. The main drivers of these new markets are i) search for functional yoghurts with beneficial health properties, particular nutritional properties (e. g. with low calories, low fat, or enriched in proteins, vitamins), or naturality, depending on the populations (young/elderly people, athletes) and ii) diversification of the food matrices (e. g. plant-based, mix of animal/plant), to respond to consumer demand for new flavors, textures and more sustainable yoghurts.