

Nutrition & Food



Food and Agriculture
Center for
Science Education

Lactic Acid Bacteria

Description of Event: Student A typically experiences cramps, diarrhea, and gas symptoms after eating dairy products, particularly those higher in lactose content. However, they were surprised to discover that a particular cheese produced no symptoms.	Stimuli: How will students experience and/or observe the phenomenon/problem? Students can experience and/or observe the phenomenon/problem through a scenario in which a relatable person notices that they do not experience symptoms after eating a particular type of cheese.
Essential Question(s): Why can those sensitive to lactose eat some fermented dairy foods without issues?	
Related Phenomena/Problems: • Compare and contrast the shelf lives of various dairy foods, including those that are fermented. • Using microorganisms to create other food products and different flavors. • Identifying and/or measuring the byproducts released during the process of fermentation. • Experiencing a burning sensation in muscles during high-intensity exercise as the formation of lactic acid produces free hydrogen ions as a byproduct of anaerobic cellular respiration. • Observing the holes in Swiss cheese and applying their understanding of the fermentation process to explain how the holes were formed. • Baking sourdough bread.	
Considerations for Instructional Design: • Students can study lactic acid bacteria as an introduction to: ◦ Bacteria and prokaryotes, in general ◦ Bacterial (prokaryote) pathology vs. use ◦ Fermentation processes ◦ pH • Students could use the smaller phenomena as a transfer task/assessment to indicate their mastery of the DCIs related to cellular respiration. • Similar to above, this could serve as an investigative phenomenon to help students answer a question they have related to energy/cellular respiration either by helping answer a direct question they have or by introducing it in the elaborate step of a lesson. "What about organisms without access to oxygen?" • Similar DCIs, and within the dairy context, lend themselves well using the rumen of a cow as an ecosystem. • As currently presented, this phenomenon can advance students' understanding of some of the DCIs, but it is limited to small pieces. • This phenomenon may fit as a precursor to investigations examining the chemical structures and/or reactions associated with cellular respiration and fermentation.	
Explanation: What factor(s) can account for a lactose intolerant person being able to eat a particular cheese without experiencing any of the traditional symptoms?	



In general, a key factor is a category of bacteria commonly used in the cheesemaking process and/or other fermented dairy products and the process by which it produces energy. The type of bacteria is known as Lactic Acid Bacteria (LAB). LAB is a broad label for many strains of bacteria that produce lactic acid as a byproduct of anaerobic respiration. This process is also called fermentation. LAB breaks down the sugars in milk (lactose) and converts them into energy via fermentation. Lactic acid bacteria prefer an environment without oxygen, so they use fermentation (as opposed to cellular respiration). The byproduct of fermentation is lactic acid. One molecule of glucose is converted to two smaller molecules of lactic acid plus some other products. The “other” products are dependent on the environment and particular bacteria, but volatile fatty acids and carbon dioxide are common. By the time some cheese is ready for consumption, most of the lactose has been broken down.

Sidenote not related to the phenomena specifically, but rather to dairy cattle: When it comes to dairy, lactic acid bacteria serve different roles. First, LAB, as well as many other types of bacteria, allow cattle to digest the grasses they eat. The main carbohydrate in mature grasses is cellulose. The enzyme, cellulase, is required to break down cellulose. Humans do not produce cellulase and neither do most animals. The digestive system of certain animals (including most ruminants) allows them to convert cellulose into usable energy. The animal itself does not do the digesting. It's the microorganisms within the rumen that are the actual digesters. It's in the rumen that houses the bacteria, and it's the bacteria (not the cow itself) responsible for producing cellulase. The relationship between a cow and lactic acid bacteria in the rumen is symbiotic because the bacteria produce the cellulase needed to digest cellulose, and the bacteria also feast on the carbohydrates swallowed by the cow.

Why might ingesting dairy cause uncomfortable gastrointestinal symptoms for someone?

If dairy regularly causes someone symptoms such as diarrhea, gas, cramping, and bloating, there's a chance that the person's body isn't producing enough of a specific enzyme required for humans to digest the lactose present in the dairy product. Lactose is the main carbohydrate present in milk. It is a large sugar molecule, too large to be absorbed without being broken down into its simpler components of glucose and galactose. Enzymes are proteins that allow for and speed up chemical reactions, including breaking down lactose. The name of the enzyme that breaks down lactose is lactase. Specific enzymes have unique shapes designed to perfectly fit the corresponding molecules they interact with. Lactase has a special shape that lactose can fit into to facilitate the breakdown into two smaller sugars (glucose and galactose). Lactase is formed and secreted in the small intestine, where most of the usable nutrients we eat are absorbed. (MS-LS1-1)

If lactase isn't present, or there's not enough lactase, lactose remains a large carbohydrate. Lactose is too large to be absorbed by the epithelial cells in the small intestine and is passed along to the large intestine with other non-absorbable wastes. Its presence in the large intestine causes a couple of things to happen. First, bacteria in the colon can digest the lactose and produce gas that can be uncomfortable in the process. Additionally, the lactose causes a concentration gradient where the contents in the large intestine have a higher density than the space surrounding the large intestine. Water seeps into the large intestine via osmosis. The extra water and gas can lead to diarrhea and other uncomfortable symptoms (e.g., diarrhea, gas, cramping, bloating, etc.) (HS-PS2-2) or (HS-LS1-1). If these symptoms are due to a lack of lactase, a person is said to have lactose intolerance. It should be noted that this should not be confused with a milk allergy or symptoms that are due to something other than lactose. The cause and possible effects of a milk allergy are not the same as lactose intolerance. It is estimated worldwide that about 70% of the population has lactase non-persistence. Anyone with lactase non-persistence would be considered to have lactose malabsorption (LM) (due to the inability to utilize the glucose and galactose from the lactose). Someone with LM may or may not exhibit the referenced symptoms above.

Why do other people not experience lactose intolerance?

People whose bodies continue to produce adequate levels of lactase are said to be Lactose Persistent (LP). Lactose persistence is due to a genetic polymorphism. Polymorphism is a term for a mutation that occurs in more than 1% of the general population. The gene that regulates the production of lactase levels is called the LTC gene. The LTC gene provides the instructions for making lactase. Starting as early as young childhood, the functioning of the LCT gene can start to decrease and may lead to lactose intolerance later in life. Those who continue to produce sufficient levels of lactase may have inherited specific changes to their MCM6 gene, which acts as a regulatory element for the LCT gene. These changes are small. In fact, a change in one allele can account for the function or non-function. (MS-LS3-1) (HS-LS1-1) (Swallow, Dallas. 2003.)

Six of the twenty-some known variations account for the overwhelming majority of those with LP and have been widely studied.

The key role of LAB in this phenomenon is serving as a “starter” in the cheese making process. Specially chosen LAB are added to milk and allowed to grow under controlled conditions. The type of lactic acid bacteria (added during the cheesemaking process) are carefully selected; the unique flavor and texture of cheese are determined (for the most part) by the LAB starter. This is akin to the sourdough starters that are used in the process of baking sourdough bread. LAB produces the enzyme lactase, which is required to digest lactose. The bacteria utilize the lactose* (among other sugars) as an energy source. Cheese is usually made in airtight containers without the presence of oxygen. When oxygen isn't available to the bacteria for cellular respiration, the fermentation process is responsible for the production of energy. (MS-LS1-1) (HS-LS2-3) (MS-LS1-7) By the time some cheeses are ready for consumption, the LAB has already broken down a significant amount of the lactose that might otherwise cause irritation for someone who experiences lactose intolerance. In other cheeses, particularly those aged for only a short period of time, the lactose content remains higher. (Lactic acid fermentation, 2022) The variety of LAB starter has a significant role in the relative amounts of lactose breakdown. Other factors influencing lactose levels include temperature, humidity, and pH during the phases of the cheesemaking process. (Facioni, et al 2021)

*Lactose is the primary sugar found in milk. However, there are small amounts of other sugars (e.g., glucose and galactose). These sugars can also undergo fermentation, but they do not contribute to the decline in lactose.

Fermentation differs from cellular respiration.

This information is provided in the event that an investigative phenomenon involves a more detailed look at the reactants, products, and chemical reactions involved with fermentation and/or cellular respiration. (Note that the table below compares the reactants and products applicable to humans and differ slightly for cattle. (HS-LS1-7)

	Fermentation	Cellular Respiration
Reactants	Sugar (often lactose) and water	
End products	Lactic acid	
Efficiency	Low (approximately 2 ATP per cycle)	High (approximately 36 ATP per cycle)
Phases	2 Phases (see below)	4 Phases (see below)
	Glycolysis (sugar broken down to 2 molecules of pyruvate)	Glycolysis
	Fermentation (pyruvate converted to byproduct/lactic acid in the case of lactose)	Pyruvate oxidation (pyruvate is transferred to the mitochondria and converted to acetyl-CoA)
		Krebs cycle (acetyl-CoA further broken down to ATP and electron carriers, such as NADH and FADH ₂)
		Electron transport chain (The electron acceptors interact with protein complexes in the inner membrane of the mitochondria. In the process of moving the electrons, energy is released and protons/H ⁺ ions are pumped into the intermembrane space. A carrier in the membrane then transports the electrons to the next protein complex along the membrane and the process repeats itself two more times. Oxygen then comes along and accepts the electrons. The H ⁺ ions that gather in the intermembrane space create a positively charged gradient across the membrane. The H ⁺ ions diffuse back through the membrane through a channel created

		by the protein ATP-synthase. As they diffuse, they cause ATP-synthase to spin and produce ATP when the H ⁺ ion bonds with ADP. This process produces approximately 30-34 ATP in each cycle.)
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Student- and teacher-generated questions about this phenomenon/problem that could be instructionally productive:

- How is cheese made?
- How is lactose free milk made?
- Was the person not actually lactose intolerant?
- Was the cheese lactose free?
- Was the cheese made with lactose free milk?
- Are there other dairy products that can be consumed by someone who is lactose intolerant as well?
- Can someone be more sensitive to lactose when they are sick or less sensitive if their body and immune system are healthy?
- Did the person take something like a Lactaid?
- Had the person been taking probiotics?
- Was the cheese made from a non-dairy product?
- How does someone test if they are lactose intolerant?

Explaining the phenomenon/problem or related phenomena could lead students toward developing the following DCIs:

LS1.A: Structure and Function

- All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular). (MS-LS1-1) Built toward as students begin to look at the metabolism of single cell bacteria. This is complimented by needing to understand the differences in human metabolism where we see cells arranged as tissues supporting entire systems that cooperate and rely on one another.

LS1.C: Organization for Matter and Energy Flow in Organisms

- Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. Built toward the metabolism of the lactic acid bacteria, which use lactase to break down lactose into its smaller and simpler sugars glucose and galactose. The food is broken down further and transformed during their fermentation process during cheesemaking. (MS-LS1-7)
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another and releases energy to the surrounding environment to maintain body temperature. Cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken, and new compounds are formed that can transport energy to muscles. (HS-LS1-7) Built toward as students compare the efficiency of fermentation to cellular respiration, and where is efficiency and energy lost from the system along the way? Is it escaping as heat, as gas, or storing the chemical bonds of the acid?
- LS2.A: Interdependent Relationships in Ecosystems
- Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1) Built toward lactic acid bacteria and it's reliance on lactose as a food source and run its energy generating process of fermentation.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1)
- Growth of organisms and population increases are limited by access to resources. (MS-LS2-1) Built toward if students are able to get curious about what would happen to the bacteria without the presence of milk. What

are the requirements for life and how resilient are lactic acid bacteria. Or, what happens in the cheese making process lactose had nearly been depleted by the fermentation?

- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2) *With an expanded scope, looking at the LAB in the rumen of cattle and its existence within the gut of the cow would be interesting.*

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- ~~Photosynthesis and~~ Cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3) Built toward as students make sense of the products and reactants involved in fermentation carried about by the LAB to create energy for themselves. A comparison of the efficiency of the anaerobic pathway would likely have a natural fit.

Notes about relevance and authenticity (funds of knowledge, interests, identity) *Why might students be engaged?*

- Lactic acid may be a term they associate with sore muscles.
- It is very likely that students know someone with lactose intolerance. They may be curious to ask if that person can tolerate some dairy foods without experiencing symptoms.
- Many students enjoy fermented foods, such as yogurt or kimchi, but may not know they are fermented.
- In recent years, fermented foods have been touted for being healthy and referenced in “gut health.”
- The cheesemaking process may spark interest in the field of Food Science.

Resources/References

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