

THE PROCESS OF LACTIC ACID FERMENTATION AND ITS IMPORTANCE

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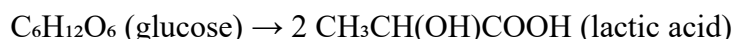
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Annotation: This article explores the biological process of lactic acid fermentation, detailing its biochemical mechanisms and types. It discusses the wide-ranging significance of lactic acid fermentation in food production, human physiology, gut health, and industrial applications. The process not only supports anaerobic energy production in cells but also enables the preservation and flavor enhancement of fermented foods. Its applications in biotechnology and agriculture highlight its ongoing importance in both traditional and modern contexts.

Keywords: lactic acid fermentation, anaerobic respiration, lactic acid bacteria, fermented foods, homolactic fermentation, heterotactic fermentation, industrial fermentation, food preservation.

Introduction. Lactic acid fermentation is a biological process that has been vital to human civilization for thousands of years. It not only plays a crucial role in food preservation and production but also significantly influences human health and various industrial applications. This anaerobic process allows certain organisms to produce energy without oxygen, offering both evolutionary and practical benefits. Lactic acid fermentation is a type of anaerobic respiration carried out by certain bacteria and animal cells, particularly muscle cells. During this process, glucose or other six-carbon sugars are broken down into cellular energy and lactic acid. Unlike aerobic respiration, this occurs without oxygen.

The overall chemical reaction is:



There are two main types of lactic acid fermentation:

1. Homolactic Fermentation – where glucose is converted almost entirely into lactic acid (common in *Lactobacillus* and muscle cells).
2. Heterolactic Fermentation – where glucose is broken down into lactic acid, carbon dioxide, and ethanol or acetic acid (typical in *Leuconostoc* species).

The process in detail

1. Glycolysis: Glucose is first broken down into two molecules of pyruvate via glycolysis, producing a net gain of 2 ATP molecules.
2. Conversion to Lactic Acid: In the absence of oxygen, pyruvate is reduced to lactic acid by the enzyme lactate dehydrogenase. This step also regenerates NAD^+ , which is essential for glycolysis to continue.

One of the most important uses of lactic acid fermentation is in the production of fermented foods such as yogurt, sauerkraut, kimchi, sourdough bread, and pickles. The lactic acid produced inhibits the growth of spoilage-causing microorganisms and pathogens, effectively preserving the food. It also contributes to the tangy flavor and improved texture of these products. In humans, lactic acid fermentation is a temporary solution when oxygen levels are low, such as during intense exercise. Muscles resort to anaerobic respiration to quickly generate ATP, producing lactic acid as a byproduct. Although this can lead to temporary muscle fatigue and soreness, it

allows continued muscle activity under oxygen-deprived conditions. Fermented foods often contain live lactic acid bacteria, which act as probiotics. These microorganisms help maintain a healthy gut microbiome, support digestion, and may strengthen the immune system. Species like *Lactobacillus* and *Bifidobacterium* are well-known for these benefits.

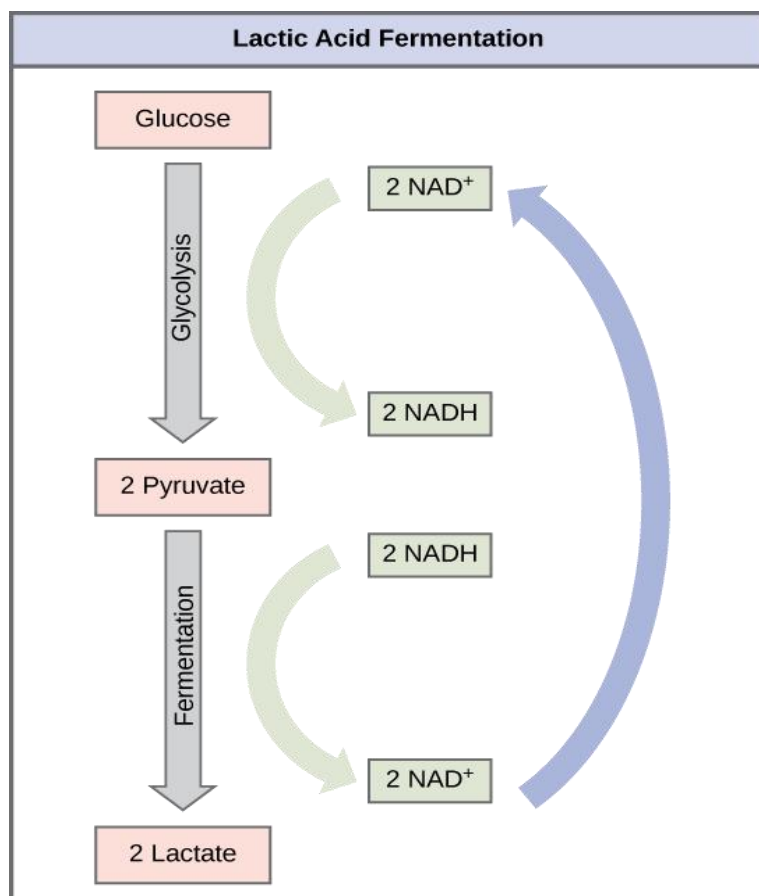


Figure 1. Lactic acid fermentation

Lactic acid is used in the production of biodegradable plastics (like polylactic acid, or PLA), cosmetics, and pharmaceuticals. The fermentation process is favored in industry due to its sustainability and cost-effectiveness. Fermentation of silage (preserved pasture or forage crops) through lactic acid fermentation ensures that livestock have nutritious feed available year-round. This enhances animal health and farm productivity. Lactic acid fermentation is a cornerstone of both ancient and modern biological processes. Its role extends from food preservation and health to industrial manufacturing and agriculture. As society grows more interested in sustainable and health-conscious living, the relevance of this natural fermentation process continues to expand.

Research methodology. This study employed a qualitative and descriptive research design to explore the biochemical process of lactic acid fermentation and examine its applications and significance in various domains including food science, human physiology, and industry. The research is primarily literature-based, supported by scientific articles, textbooks, and case studies. Data was gathered from existing academic sources including peer-reviewed journal articles, books on microbiology and biochemistry, online databases (e.g., PubMed, ScienceDirect), and reputable educational websites. Documented examples of lactic acid fermentation in food production (e.g., yogurt, kimchi) and industrial applications (e.g., polylactic acid production) were reviewed. The

mechanisms and outputs of homolactic and heterolactic fermentation were compared to illustrate variations in process and application.

A thematic analysis approach was used to organize information into major themes:

- Biochemical mechanisms of fermentation
- Types of lactic acid fermentation
- Functional benefits in food and health
- Industrial and agricultural relevance

Scientific explanations were cross-referenced across multiple sources to ensure accuracy and reliability. Although no experimental setup was conducted for this study, the following informational tools were used:

- Scientific databases for sourcing journals
- Textbooks on microbiology and biochemistry for foundational knowledge
- Documentation from food science research and industrial fermentation reports

Analysis of literature. Lactic acid fermentation is an anaerobic metabolic pathway that converts glucose into lactic acid, primarily through the action of lactic acid bacteria (LAB) such as *Lactobacillus* and *Leuconostoc*. This process begins with glycolysis, where glucose is broken down into pyruvate, which is then reduced to lactic acid by lactate dehydrogenase. This regeneration of NAD^+ is crucial for sustaining glycolysis under oxygen-limited conditions. Lactic acid fermentation plays a pivotal role in the preservation and flavor development of various foods. The production of lactic acid lowers the pH of the food, inhibiting the growth of spoilage microorganisms and pathogens. This acidification not only extends shelf life but also imparts characteristic sour flavors to fermented products like yogurt, kimchi, and sauerkraut. Fermented foods are rich in probiotics—live microorganisms that confer health benefits to the host. LAB contribute to gut health by enhancing the intestinal microbiota, improving digestion, and potentially boosting the immune system. The presence of bioactive compounds such as bacteriocins produced by LAB also adds to the antimicrobial properties of fermented foods. Lactic acid is a valuable chemical used in the production of biodegradable plastics (e.g., polylactic acid), pharmaceuticals, and cosmetics. Microbial fermentation of renewable resources, including agricultural by-products, offers an eco-friendly alternative to chemical synthesis. However, challenges such as substrate inhibition, by-product accumulation, and the need for high optical purity in lactic acid production remain areas of active research. The practice of lactic acid fermentation dates back thousands of years, with evidence of its use in ancient civilizations for food preservation. In East Asia, LAB play a central role in the fermentation of various non-dairy foods, including vegetables, cereals, and fish. These traditional fermentation practices not only preserve food but also enrich it with unique flavors and textures.

Research discussion. Lactic acid fermentation is a well-established biochemical process that allows organisms to generate energy in the absence of oxygen. The fundamental reaction involves the conversion of glucose into lactic acid, which serves as a byproduct while enabling ATP production. This process is essential for cells in conditions where oxygen is limited, such as during intense physical exertion in humans or in environments that favor anaerobic conditions. One of the primary applications of lactic acid fermentation is in food preservation. The production of lactic acid lowers the pH of fermented foods, creating an environment that inhibits the growth

of harmful microorganisms. This is crucial in preventing spoilage and extending the shelf life of food products. In addition, the process imparts distinctive flavors to foods such as yogurt, sauerkraut, kimchi, and pickles. The acidic environment also alters the texture and consistency of food, improving digestibility and enriching the sensory qualities that many consumers value. These effects are widely observed in various cultures, particularly those in East Asia and Europe, where fermentation has been central to food traditions for centuries. Lactic acid bacteria (LAB), which are responsible for carrying out lactic acid fermentation, also have significant health implications. These bacteria act as probiotics, which have been shown to support gut health, enhance digestion, and even boost immune function. The beneficial strains of LAB found in fermented foods help maintain a healthy balance of the gut microbiota. Additionally, their production of bioactive compounds, such as bacteriocins, provides antimicrobial effects that could further improve human health. The growing body of research on the link between fermented foods and overall well-being is an exciting area of study, particularly as gut health is increasingly recognized as a key factor in the prevention of many chronic diseases.

In the industrial sector, lactic acid fermentation has proven its value as a sustainable alternative to traditional chemical processes. Lactic acid is a key raw material for producing biodegradable plastics like polylactic acid (PLA), which are an environmentally friendly substitute for petroleum-based plastics. Furthermore, the use of renewable resources, such as agricultural by-products, as substrates for fermentation aligns with current global efforts to promote sustainability and reduce reliance on fossil fuels. However, challenges remain in improving the efficiency of lactic acid production, such as overcoming substrate inhibition and managing the accumulation of by-products. Continued research in optimizing fermentation conditions and microbial strains is critical to advancing the commercial viability of lactic acid-based industrial products. The historical and cultural importance of lactic acid fermentation cannot be overstated. It is an age-old practice that has contributed not only to food preservation but also to the development of distinct culinary traditions worldwide. In many societies, fermentation has been a natural solution to the seasonal abundance of crops and the need for long-term food storage. This cultural aspect of fermentation is often underappreciated in modern food systems, which rely heavily on refrigeration and chemical preservatives. A renewed interest in fermentation, particularly in artisanal and health-conscious food movements, underscores the importance of reconnecting with traditional food preparation techniques.

While the benefits of lactic acid fermentation are well-established, there are still several avenues for future research and development. First, the optimization of fermentation processes for both food and industrial applications is an area of active exploration. This includes genetically modifying microbial strains for higher yields and improved tolerance to various substrates. Second, further investigation into the therapeutic potential of lactic acid bacteria and their metabolic byproducts could reveal additional health benefits. Finally, as global awareness of sustainability issues rises, lactic acid fermentation could play an increasingly important role in the development of eco-friendly packaging and materials. Lactic acid fermentation is a multifaceted process that plays an essential role in food preservation, human health, industrial manufacturing, and cultural traditions. While the process itself is ancient, its applications are more relevant than ever in light of modern challenges related to sustainability, health, and food security. By continuing to explore the biochemical mechanisms, health benefits, and industrial uses of lactic acid fermentation, we can unlock new opportunities for advancing both science and society.

Conclusion. Lactic acid fermentation is a critical biological process with widespread applications in food production, human health, and industrial sectors. This anaerobic metabolic pathway,

primarily carried out by lactic acid bacteria, allows for the conversion of glucose into lactic acid, playing an essential role in energy production under oxygen-limited conditions. Its ability to preserve food, impart distinctive flavors, and promote health through probiotics has made it invaluable in both traditional and modern culinary practices. In the food industry, lactic acid fermentation has not only contributed to the preservation and flavor enhancement of products but has also fostered the development of functional foods that offer significant health benefits, including improved gut health and immunity. The use of lactic acid bacteria as probiotics further underscores the growing interest in fermentation-based products for their potential therapeutic effects. Industrial applications of lactic acid fermentation, particularly in the production of biodegradable plastics and eco-friendly materials, align with global efforts toward sustainability. However, challenges remain, especially in optimizing fermentation processes and improving production efficiency. Future research into microbial strain improvement and fermentation optimization holds the promise of making lactic acid an even more viable resource for a variety of industries.

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