Home / Microbiology / Food Microbiology / Fermentation – Definition, Types, Principle, Products, Stages, Limitations Fermentation is a metabolic pathway characterized by the enzymatic conversion of organic substrates, predominantly carbohydrates, into simpler compounds, resulting in the production of energy, primarily in the form of adenosine triphosphate (ATP).This process occurs in the absence of oxygen, rendering it anaerobic in nature. The primary objective of fermentation is the regeneration of the coenzyme nicotinamide adenine dinucleotide (NAD+), which is essential for glycolysis, a preliminary step in energy extraction.From a biochemical perspective, fermentation is defined by the extraction of energy from carbohydrates without the involvement of an electron transport chain or the final electron acceptor, oxygen.Instead, in fermentation, organic molecules such as pyruvate or acetaldehyde act as the terminal electron acceptors. This distinguishes fermentation from anaerobic respiration, where molecules like sulfate ions (SO4–2) or nitrate ions (NO3–) serve as the final electron acceptors in the electron transport chain.The products of fermentation vary based on the pathway and organisms involved. Two common types include lactic acid fermentation, resulting in the production of lactic acid, and alcoholic fermentation, yielding ethanol and carbon dioxide.The net energy gain from fermentation is modest, producing only 2 ATP molecules per glucose molecule, a stark contrast to the up to 32 ATP molecules generated through aerobic respiration.Historically, the significance of fermentation was first elucidated by Louis Pasteur in the mid-19th century, marking the inception of zymology, the study of fermentation processes. Microorganisms, both prokaryotic and eukaryotic, are the primary agents of fermentation.While some organisms, known as obligate anaerobes, rely solely on fermentation for energy production, others, termed facultative anaerobes, can switch between fermentation and aerobic respiration based on environmental conditions. For instance, under oxygen-limited conditions, human muscle cells can shift to lactic acid fermentation to meet energy demands.Commercially, fermentation has profound implications, particularly in the food and beverage sector. The conversion of sugars into ethanol by yeasts is foundational for the production of alcoholic beverages. Similarly, the production of organic acids through fermentation is pivotal for the preservation and flavoring of various food products, from dairy items like yogurt and cheese to fermented vegetables like kimchi.In summation, fermentation is an ancient, yet sophisticated, metabolic process that facilitates energy production in the absence of oxygen. Its applications span from fundamental biological processes to the production of a myriad of food products and beverages that have been integral to human culture and diet for millennia.Fermentation is an anaerobic metabolic process in which organic substrates are converted into simpler compounds, producing energy, primarily ATP, without the use of oxygen or an electron transport chain. Commonly associated with the production of gases, acids, or alcohols, fermentation is utilized by various microorganisms and is fundamental in many food and beverage preparations.History of FermentationFermentation, as a practice, traces its roots back to ancient civilizations. Historically, communities harnessed the principles of fermentation to produce a myriad of beverages, including beer from malted barley, wine from grapes, chicha from maize, and octli, now referred to as “pulque,” derived from the agave plant. Despite the widespread application of this technique, the underlying biological mechanisms remained an enigma for centuries.The dawn of the 17th century marked a pivotal shift in our understanding of fermentation, propelled by advancements in microscopy. Antoni van Leeuwenhoek’s pioneering work with microscopes unveiled the existence of microorganisms, including yeasts. Subsequent enhancements in microscopic technology further elucidated the diverse realm of microorganisms. Among the early revelations was Charles Cagniard de la Tour’s discovery that yeasts, being living microorganisms, played a potential role in the fermentation process. He noted their proliferation through a budding mechanism during alcoholic fermentation.However, the most significant strides in comprehending fermentation were made by Louis Pasteur in the mid-19th century. Through meticulous experimentation, Pasteur conclusively demonstrated that living yeasts were instrumental in converting glucose into ethanol in fermented beverages, a process he aptly termed “respiration without air.” Furthermore, Pasteur discerned two primary forms of fermentation: alcoholic fermentation, facilitated by yeasts, and lactic acid fermentation, driven by bacteria. His observations underscored that the transformation of sugars to alcohol was contingent on the presence of live yeast, while the acidification of beet juice, resulting in acetic acid production, was attributed to live bacterial species.Yet, the exact modus operandi of these microorganisms in fermentation remained elusive until the late 19th century. Eduard Buchner, a German chemist, made a groundbreaking discovery by demonstrating that crushed yeast cells could still catalyze the conversion of sucrose into alcohol and carbon dioxide. He introduced the term “zymase” to describe the enzyme complex extracted from yeast responsible for this transformation.In the subsequent years, the scope of fermentation expanded, with the identification of various organisms, including human muscle cells, capable of executing this metabolic process. Today, our understanding of fermentation stands on the shoulders of these scientific giants, who meticulously unraveled its intricacies over centuries.Principle of fermentationFermentation is a fundamental biochemical process that facilitates the extraction of energy from carbohydrates, particularly glucose, in an environment devoid of oxygen. The process is characterized by a series of enzymatic reactions that ensure the efficient production and utilization of energy molecules.Initially, glucose undergoes partial oxidation through the glycolytic pathway, resulting in the formation of pyruvate. This process, known as glycolysis, can proceed via the Embden–Meyerhoff (EMP) or Entner–Doudoroff (ED) pathways. As a result, molecules of ATP and NAD(P)H are generated, which are crucial for cellular energy transactions.In the subsequent phase of fermentation, in the absence of external electron acceptors, pyruvate becomes the focal point. It undergoes reduction, leading to the regeneration of the coenzyme NAD+(P). This regeneration is pivotal for the continuity of the glycolytic pathway, ensuring a steady production of ATP. The reduction of pyruvate culminates in the formation of specific fermentation end-products, such as ethanol or organic acids, depending on the microbial species and environmental conditions.For instance, in the lactic acid fermentation pathway exhibited by bacteria like Streptococcus lactis, pyruvate is reduced to lactic acid. This reduction facilitates the regeneration of the NAD+ coenzyme, and concurrently, two ATP molecules are synthesized. Conversely, in certain yeasts, such as Saccharomyces, pyruvate is transformed into ethyl alcohol (ethanol), leading to the reformation of NAD+.It’s noteworthy that fermentation, while essential for many microorganisms, is energetically less efficient compared to aerobic respiration. Specifically, fermentation harnesses merely 5% of the energy that could be potentially obtained through aerobic pathways. Nevertheless, the primary objective of fermentation is the production of ATP via substrate-level phosphorylation and the maintenance of redox balance through the regeneration of NAD+ from NADH.In essence, the principle of fermentation revolves around the anaerobic metabolism of glucose, ensuring energy production and redox equilibrium in the cell, even in the absence of oxygen.Fermentation EquationFermentation, a metabolic process that occurs in the absence of oxygen, involves the breakdown of organic compounds to produce energy. The specific chemical equation for fermentation depends on the substrates and products involved. Here, we elucidate the primary equations associated with two common types of fermentation: ethanol fermentation and lactic acid fermentation.Ethanol Fermentation: Ethanol fermentation, primarily carried out by yeasts, involves the conversion of glucose into ethanol and carbon dioxide. The chemical representation of this process is as follows: C6H12O6(glucose)→2C2H5OH(ethanol)+2CO2(carbon dioxide)+energyC6H12O6(glucose)→2C2H5OH(ethanol)+2CO2(carbon dioxide)+energySimplified, this can be represented as: C6H12O6→2C2H5OH+2CO2C6H12O6→2C2H5OH+2CO2This process yields a net gain of two ATP molecules for each glucose molecule metabolized.Lactic Acid Fermentation: Lactic acid fermentation is a process where glucose is converted into lactic acid. This type of fermentation is commonly observed in muscle cells under anaerobic conditions and in certain bacteria like lactobacilli. The chemical equation for homolactic fermentation is:C6H12O6(glucose)→2CH3CHOHCOO−(lactate)+energyC6H12O6(glucose)→2CH3CHOHCOO−(lactate)+energyIn its simplified form:C6H12O6→2C3H6O3C6H12O6→2C3H6O3Some bacteria, such as Leuconostoc mesenteroides, can further metabolize lactate, leading to the production of not just lactate but also alcohol and carbon dioxide. This heterolactic fermentation can be represented as:C6H12O6(glucose)→CH3CHOHCOO−(lactate)+C2H5OH(alcohol)+CO2(carbon dioxide)+energyC6H12O6(glucose)→CH3CHOHCOO−(lactate)+C2H5OH(alcohol)+CO2(carbon dioxide)+energyIn conclusion, the specific equation for fermentation is contingent on the type of fermentation and the organisms involved. These equations provide a snapshot of the chemical transformations that occur during the fermentation process, highlighting the versatility and adaptability of various organisms in energy production.Types of fermentationFermentation is a metabolic process that facilitates the conversion of carbohydrates into simpler compounds, primarily in anaerobic conditions. Various types of fermentation have been identified, each characterized by specific substrates, microorganisms, and end products. Here, we delve into the primary types of fermentation:Lactic Acid Homofermentation:Reaction: Glucose → Lactic acidMicroorganisms: Genera such as Lactococcus, Enterococcus, Streptococcus, Pediococcus, and specific Lactobacillus species.Characteristic: Homolactic bacteria convert glucose exclusively into lactic acid. Lactococcus spp., for instance, is integral to dairy starter cultures.Lactic Acid Heterofermentation:Reaction: Glucose → Lactic acid + Acetic acid + Ethyl alcohol + 2CO2 + H2OMicroorganisms: Genera like Leuconostoc, Oenococcus, and Weissella, along with heterofermentative lactobacilli.Characteristic: Heterofermentative LAB produce a mix of lactic acid, ethanol/acetic acid, and carbon dioxide.Propionic Acid Fermentation:Reaction: Glucose → Lactic acid + Propionic acid + Acetic acid + CO2 + H2OMicroorganisms: Genus Propionibacterium and species Clostridium propionicum.Characteristic: These bacteria can utilize both sugar and lactate, producing propionate through a series of intermediate reactions.Diacetyl and 2,3-Butylene Glycol Fermentation:Microorganisms: Genera such as Enterobacter, Erwinia, Hafnia, Klebsiella, and Serratia.Characteristic: The production of 2,3-butanediol involves a unique double decarboxylation step.Alcoholic Fermentation:Reaction: Glucose → Ethyl alcoholMicroorganisms: Yeasts, certain fungi, and bacteria.Characteristic: Pyruvate, formed via the EMP or ED pathways, is reduced to ethanol, ensuring redox balance by regenerating NAD+.Butyric Acid Fermentation:Reaction: Glucose → Acetic acid + Butyric acidMicroorganisms: Predominantly the genus Clostridium.Characteristic: Acetyl-CoA is oxidized to produce butyric acid, with certain species like Clostridium acetobutylicum undergoing acetone butanol fermentation.In summary, fermentation processes are diverse, each tailored to specific substrates and yielding distinct products. The choice of microorganisms and the metabolic pathways they employ dictate the type and efficiency of the fermentation process.Types of fermentationProducts of fermentationFermentation, a metabolic process, results in the production of various compounds depending on the specific enzymes and microorganisms involved. This process has been harnessed for various industrial, food, and medical applications. Here, we elucidate the primary products and their significance.Ethanol fermentationSchematic diagram of lactic acid fermentation.Ethanol:Formation: Ethanol is produced when pyruvate, derived from glucose, is acted upon by enzymes such as pyruvate carboxylase and alcohol dehydrogenase. The overall reaction converts one glucose molecule into two ethanol and two carbon dioxide molecules.Applications: Ethanol fermentation is pivotal in the production of alcoholic beverages like wine and beer. Additionally, it plays a role in bread-making, where the released carbon dioxide aids in dough rising. Ethanol also serves as a biofuel, supplementing or replacing gasoline.Lactic Acid:Formation: Homolactic fermentation results in the conversion of glucose into two molecules of lactic acid. This process is facilitated by the enzyme lactate dehydrogenase.Applications: Lactic acid fermentation is crucial in the dairy industry, producing yogurt and certain cheeses. The sour taste of yogurt is attributed to lactic acid. Some bacteria can further metabolize lactate, producing ethanol, carbon dioxide, and other compounds.Acetic Acid:Formation: Acetic acid bacteria oxidize sugars or ethanol to yield acetic acid. The reaction involves the conversion of ethanol in the presence of oxygen to acetic acid and water.Applications: The commercial production of vinegar is a notable application of acetic acid fermentation.Hydrogen Gas:Formation: Certain fermentation processes result in the production of hydrogen gas, serving as a mechanism to regenerate NAD+ from NADH. The gas is produced as a byproduct in reactions involving specific bacteria.Applications: Hydrogen gas has potential as an energy source, and its production through fermentation is an area of active research.Other Products:Butanediol, Butyrate, Caproate, Acetone: These are products of various specialized fermentation processes. Their production and significance vary based on the microbial species and conditions.Alternative Protein Sources:Formation: Modern fermentation techniques enable the production of recombinant proteins, serving as meat analogues, milk substitutes, and egg substitutes.Applications: These proteins, such as recombinant myoglobin and leghemoglobin, are used in the production of meat alternatives, offering texture, flavor, and aroma akin to real meat.Enzymes:Formation: Industrial fermentation facilitates enzyme production, where microorganisms produce and secrete proteins with catalytic activity.Applications: Enzymes find applications across various industries, including food, beverage, baking, detergents, textiles, and pulp and paper industries.In conclusion, the products of fermentation are diverse and have been harnessed for a multitude of applications, from food and beverages to industrial processes and medical applications. The versatility of fermentation and its products underscores its significance in biotechnology and industry.Different Stages of the Fermentation ProcessFermentation, a complex metabolic process, undergoes distinct stages, each characterized by specific biochemical transformations and activities. These stages ensure the efficient conversion of substrates into desired products, often accompanied by the release of gases and other secondary metabolites. Here, we delineate the three primary stages of the fermentation process:Primary Fermentation:Initiation: This stage commences when yeast is introduced into aerated, cooled wort. The yeast swiftly utilizes the available oxygen to synthesize sterols, which are vital for yeast cell proliferation.Anaerobic Transition: Once the oxygen is exhausted, the yeast transitions to an anaerobic mode. In this phase, the majority of wort carbohydrates are metabolized into ethanol and carbon dioxide.Yeast Growth and Metabolite Synthesis: Concurrently, there is a proliferation of yeast cells. The synthesis of aroma and flavor compounds is directly linked to the magnitude and velocity of yeast growth during this stage.Secondary Fermentation:Metabolite Conversion: This stage is initiated when the bulk of the wort sugars have been metabolized, and the fermentation rate has substantially decelerated. Residual sugars are consumed during this phase, and the yeast begins to metabolize certain secondary metabolites.Yeast Flocculation: As the alcohol concentration increases and the availability of sugars and nutrients diminishes, yeast cells start to flocculate, forming clumps, and commence settling.Conditioning Stage:Initiation: This stage is triggered when the fermentation reaches its terminal gravity, and the fermentation vessel is cooled to specific chilling temperatures, typically between 31-38 °F (0-3 °C).Yeast Settling: The yeast continues to flocculate and settle during this period, clarifying the brew.Flavor Refinement: The yeast plays a pivotal role in refining the beer’s flavor by eliminating various undesirable compounds. It’s worth noting that ales, unlike lagers, benefit less from prolonged conditioning. The quintessential flavors in ales tend to diminish over time, making it prudent to minimize the conditioning duration before packaging.Oxygen Sensitivity: At this juncture, the beer becomes particularly susceptible to oxygen exposure, which can detrimentally affect its quality.In summation, the fermentation process, through its distinct stages, ensures the systematic transformation of wort into beer, with each stage contributing to the flavor, aroma, clarity, and quality of the final product.Important Factors before starting fermentationYou may want to make pickles with your vegetables or to begin the process of making your own beer, these guidelines can help you get started making.Establish your “starter” cultures: Microbes are present naturally in the air we breathe, but to get started with fermentation, you’ll usually need a “starter” set of cultures like the whey (from yogurt) or an Symbiotic Colony comprised of Bacteria and Yeast, or SCOBY (for Kombucha) or even liquid from an earlier ferment. These starter cultures are already filled in beneficial microorganisms. If you incorporate them into your beverage or food product They’ll grow rapidly and help kickstart the fermentation process.Keep your equipment clean: To stop bad bacteria from getting into your ferment it is vital to clean and disinfect your kitchen equipment and surfaces you use for your work.Avoid exposure: The exposure of your ferment to the air can stop the proper fermentation process from happening and increase the chance of food poisoning and spoilage. There are a variety of ways to prevent that.To stop fermenting food from coming in the air around it, place the food in an acid solution (brine). If you are fermenting large chunks of food, such as chops of vegetables, this technique works effectively. You can alter the pH of the process which determines the amount of oxygen will be present using vinegar in your mix.Storage: To prevent contamination by air, place your fermenting food in a container that is sealable. A lot of home fermenters utilize an ordinary mason jar that has lids to seal out air, however there are other options. Storage containers typically have the ability to release carbon dioxide gas that is released in the course of fermentation. If you’re determined to monitor the quality of your ferment to ensure that it doesn’t get spoiled and spoil, you can open the sealed containers manually and release carbon dioxide. (If you’re making wine, kombucha, or any other final product which benefit from carbonation, you may opt-out of carbon dioxide venting.)Fermentation management: By regulating the temperature of your environment and the temperature of the air, you can alter the result from your ferment. In general, microbes perform well in warm or room temperature however, the optimal temperature will depend on the kind of microbes that you’re using and the type of fermentation you’re doing. The temperature you choose to change can affect your process in a significant way. Moving your product into an environment that is cooler like an air-conditioned basement or refrigerator, can slow down the rate of fermentation , and sometimes stop it completely. The heating of a ferment in the opposite way could kill your vital microbes.Modes of industrial operationIndustrial fermentation processes are pivotal in producing a myriad of products, from pharmaceuticals to food and beverages. The mode of operation chosen for a particular fermentation process can significantly influence its efficiency, cost, and product yield. Here, we elucidate the primary modes of industrial operation in fermentation.Batch Fermentation:Description: In batch fermentation, all ingredients are combined at the outset, and the fermentation proceeds without further additions. It is a traditional method used for millennia in bread-making and alcoholic beverage production.Characteristics: The process undergoes various phases, including a lag phase (cell adjustment), exponential growth phase, stationary phase (nutrient depletion), and a cell death phase. The fermentor requires sterilization between batches, which can be cost-intensive.Fed-batch Fermentation:Description: A variation of batch fermentation, fed-batch involves the incremental addition of ingredients during the fermentation process.Characteristics: This mode offers enhanced control over fermentation stages. By adding limited nutrients during the non-exponential growth phase, the production of secondary metabolites can be optimized. It often integrates elements of both batch and continuous operations.Open Fermentation:Description: This approach avoids the high costs associated with fermentor sterilization by employing methods resistant to contamination.Characteristics: Open fermentation can utilize mixed cultures, which are particularly beneficial in wastewater treatment due to their adaptability. Other strategies include employing thermophilic bacteria for lactic acid production at elevated temperatures to deter microbial contamination or using halophilic bacteria in hypersaline conditions. Solid-state fermentation, another variant, involves minimal water addition to a solid substrate.Continuous Fermentation:Description: Continuous fermentation involves the uninterrupted addition of substrates and removal of products.Characteristics: There are several types of continuous fermentation:Chemostats: Maintain constant nutrient levels.Turbidostats: Regulate to keep cell mass constant.Plug Flow Reactors: Feature a steady flow of culture medium through a tube, with cells recycled from the outlet back to the inlet.Advantages: If maintained effectively, continuous fermentation can offer a steady flow of feed and effluent, reducing batch setup costs. It can also extend the exponential growth phase and continuously remove inhibitory byproducts. However, maintaining a steady state can be challenging, and the design is often intricate.In conclusion, the choice of fermentation mode is contingent upon the specific requirements of the industrial process, the nature of the product, and economic considerations. Each mode has its advantages and challenges, and the selection often involves a trade-off between operational simplicity, cost-efficiency, and product yield.How Does Fermentation Work?To master the art of fermentation it is necessary to know the scientific process behind it.Microorganisms can survive by consuming carbohydrates (sugars such as glucose) to generate energy and for fuel.Organic compounds such as adenosine Triphosphate (ATP) provide energy to all the cells in cells when it is needed.Microbes generate ATP using respiration. Aerobic respirationthat needs oxygen is the most effective method to accomplish this. Aerobic respiration starts with glycolysis, in which glucose is converted to the acid pyruvic. If oxygen is present aerobic respiration takes place.The process of fermentation is similar to that of anaerobic respiratory respiration, the type that occurs in the absence of oxygen available. But, it also triggers the creation of various organic molecules such as lactic acid. It produces ATP in contrast to respiration which relies on pyruvic acid.Based on the environmental conditions, the microbes and cells have the capability to switch between two different energy sources.Organisms usually obtain energy through fermentation, however, certain systems make use of sulfate to be one of the last electrons to be accepted by the electron transportation chain.What Happens During the Fermentation Process?Fermentation takes place when oxygen is not present (anaerobic conditions) and when there are beneficial microorganisms (yeasts and molds as well as bacteria) that get their energy via fermentation. If there is enough sugar available certain yeast cells such as Saccharomyces cerevisiae, will prefer fermentation to aerobic respiration, even when oxygen is plentiful.Through the process of fermentation beneficial microbes break down sugars and starches to alcohols and acids and make food more nutritious and also preserving it, allowing people to keep it for longer durations of time without it deteriorating.Fermentation products supply enzymes needed to digest food. This is vital because we have a limited amount of enzymes and they diminish with the aging process. Fermented foods contain enzymes that breakdown them.Fermentation can also help in the process of pre-digestion. In the process of fermentation the microbes consume sugars and starches and break down food before it’s eaten it.Applications of fermentationFermentation, a metabolic process primarily characterized by the conversion of carbohydrates in anaerobic conditions, has been harnessed for various applications across diverse sectors. The versatility of fermentation is evident in its widespread use, from medicine to waste management. Here, we elucidate the primary applications of fermentation:Medical Applications:Antibiotics Production: Fermentation is pivotal in producing several antibiotics, which are compounds that inhibit or kill pathogenic microorganisms.Insulin Production: Through recombinant DNA technology, specific bacteria are engineered to produce human insulin via fermentation.Growth Hormones: Fermentation aids in the synthesis of certain growth hormones, essential for therapeutic purposes.Vaccines: Some vaccines are produced using fermentation processes, harnessing specific microorganisms or their components.Interferon Production: Interferons, proteins vital for immune responses, are produced using microbial fermentation.Food Industry Applications:Fermented Foods: Traditional foods like cheese, wine, beer, and bread owe their production and unique characteristics to fermentation.Bio-preservatives: Fermentation aids in producing food-grade preservatives that extend shelf life and maintain food quality.Functional Foods and Neutraceuticals: These are foods fortified with health-enhancing components, often produced through fermentation.Single-cell Protein Production: Fermentation is employed to produce protein-rich microbial biomass, serving as an alternative protein source.Environmental and Industrial Applications:Biofuels Production: Fermentation is instrumental in producing biofuels like biodiesel, bioethanol, butanol, and biohydrogen, offering sustainable energy alternatives.Bio-surfactant and Polymers Production: Certain microbial fermentations result in bio-surfactants and polymers like bacterial cellulose, which have industrial applications.Bioremediation: Fermentation plays a role in developing bioremediation processes, where microbes or their enzymes are used to treat contaminated soils and wastewater, restoring environmental balance.In essence, fermentation, with its multifaceted applications, stands as a testament to the symbiotic relationship between humans and microorganisms. Its diverse applications underscore its significance in advancing medical, food, and environmental sectors.Limitations of fermentationFermentation, while a versatile and widely employed process, is not without its challenges. The intricacies of microbial metabolism and the complexities of scaling up the process present several limitations. Here, we elucidate the primary constraints associated with fermentation:Economic and Energetic Concerns:Low-Scale Production: Fermentation, especially when tailored for specific high-value products, often operates on a smaller scale, which may not be economically viable for large-scale industrial applications.High Costs and Energy Consumption: The specialized equipment, stringent conditions, and energy-intensive operations can escalate the costs associated with fermentation processes.Microbial and Product Challenges:Contamination Risks: The introduction of undesired microorganisms can compromise the fermentation process, leading to reduced yields or product contamination.Natural Variations: Microbial cultures can exhibit natural variations over time, potentially affecting the consistency and quality of the end product.Impurity of Products: The products derived from fermentation often contain impurities or by-products, necessitating further purification steps, which can be time-consuming and costly.Unexpected End Products: Due to the multifaceted nature of microbial metabolism, sometimes the end products may deviate from the expected outcome, impacting the product’s quality and utility.Microbial Viability and Competition:Growth of Undesirable Microbes: In some fermentation setups, undesirable or contaminant microorganisms might outcompete the desired microbes, leading to reduced product yields or altered product profiles.Loss of Desired Microbes: The desired microorganisms, especially if they are sensitive to specific environmental conditions, might lose viability during the fermentation process, affecting the overall efficiency.In summary, while fermentation offers a plethora of benefits across various sectors, it is imperative to recognize and address its limitations to optimize its applications and ensure consistent, high-quality outcomes.Advantages of FermentationAdvantages of FermentationFermentation, a time-honored metabolic process, offers a myriad of advantages, particularly in the realm of food and health. The transformation of raw materials by microorganisms not only enhances the nutritional profile of the products but also introduces beneficial compounds that can positively impact human health. Here, we delve into the primary advantages of fermentation:Enhancement of Gut Health:Probiotic Enrichment: Fermented foods are replete with probiotics, which are beneficial microorganisms that promote a healthy gut environment. A robust gut microbiota is essential for optimal nutrient absorption and overall digestive health.Immune System Augmentation:Antimicrobial Production: The gut, aided by the probiotics from fermented foods, synthesizes various antimicrobial compounds, including antibiotics, antiviral, antifungal, and anti-tumor agents. These compounds bolster the immune system, offering protection against potential pathogens.Creation of Unfavorable Environment for Pathogens: The acidic milieu resulting from fermentation impedes the proliferation of many harmful pathogens, ensuring gut health.Neutralization of Anti-Nutritional Factors:Phytic Acid Reduction: Fermentation can significantly reduce the levels of phytic acid, an anti-nutritional factor found in nuts, seeds, grains, and legumes. Phytic acid can bind essential minerals, rendering them unavailable for absorption, and potentially leading to mineral deficiencies. By neutralizing phytic acid, fermentation enhances the bioavailability of these minerals.Improved Digestibility: The reduction of phytates also enhances the digestibility of starches, fats, and proteins present in the food.Augmentation of Nutritional Content:Vitamin Enhancement: Fermentation can elevate the levels of certain vitamins, particularly those of the B-complex group, such as folic acid, riboflavin, thiamin, niacin, and biotin. Additionally, some fermented foods may also witness an increase in vitamin C content.Enhanced Mineral Absorption: The presence of probiotics, enzymes, and lactic acid in fermented foods facilitates the absorption and utilization of essential minerals, ensuring that the body derives maximum nutritional benefit.In essence, fermentation not only amplifies the nutritional value of foods but also introduces compounds that can profoundly influence human health. The myriad benefits underscore the significance of incorporating fermented foods into a balanced diet.Fermentation FactsFermentation, a metabolic process, has intrigued scientists and researchers for its unique characteristics and widespread occurrence in nature. Here, we present a compilation of salient facts about fermentation:Anaerobic Nature: Fermentation is inherently an anaerobic process, implying that it transpires in the absence of oxygen. This characteristic distinguishes it from aerobic respiration, which necessitates oxygen for energy production.Yeast’s Preference: Interestingly, even in oxygen-rich environments, yeast cells exhibit a predilection for fermentation over aerobic respiration, provided there is an ample supply of sugar. This showcases the adaptability and versatility of these unicellular organisms in energy production.Human Digestive System: Fermentation is not exclusive to microorganisms. It also transpires within the human digestive system, aiding in the breakdown of complex molecules.Gut Fermentation Syndrome: A rare yet intriguing medical condition known as gut fermentation syndrome or auto-brewery syndrome manifests when fermentation within the human digestive tract culminates in the production of ethanol. This endogenous ethanol production can lead to symptoms of intoxication in the affected individual.Muscle Cell Fermentation: Human muscle cells, under strenuous conditions, can resort to fermentation for energy production. When muscles are exerted beyond the oxygen supply rate, they derive ATP through glycolysis, an anaerobic process, ensuring continuous energy supply even in oxygen-deprived conditions.Beyond Fermentation: While fermentation is a prevalent anaerobic pathway, it’s worth noting that it’s not the sole anaerobic mechanism for energy derivation. Certain biological systems employ sulfate as the terminal electron acceptor in their electron transport chains, showcasing the diversity of anaerobic energy production mechanisms.In summation, fermentation is a multifaceted process with a myriad of applications and manifestations across different organisms. Its ability to produce energy anaerobically underscores its evolutionary significance and its pivotal role in the survival and functioning of various organisms.Comparison of Fermentation, Anaerobic Respiration, and Aerobic RespirationThe processes of fermentation, anaerobic respiration, and aerobic respiration are vital metabolic pathways that cells employ to generate energy. While they share certain similarities, they also exhibit distinct differences in terms of mechanisms, electron transport, ATP yield, and end products. Here, we present a comprehensive comparison of these three processes:Nature of the Process:Fermentation: An anaerobic process that does not utilize the electron transport chain.Anaerobic Respiration: An anaerobic process that employs the electron transport chain to transfer electrons to the final electron acceptor.Aerobic Respiration: An aerobic process that uses the electron transport chain, with oxygen serving as the final electron acceptor.ATP Production:Fermentation: Yields 2 ATP molecules per glucose molecule, exclusively through substrate-level phosphorylation.Anaerobic Respiration: The ATP yield varies depending on the specific pathway and organism.Aerobic Respiration: Produces approximately 38 ATP molecules per glucose molecule, through both substrate-level phosphorylation and oxidative phosphorylation.Final Electron Acceptor:Fermentation: Organic molecules, such as pyruvate in lactic acid fermentation or acetaldehyde in alcohol fermentation.Anaerobic Respiration: Inorganic compounds like sulfate ion (SO_4^{2-}), nitrate (NO_3^-), and ferric ion (Fe^{3+}) or certain organic compounds like dimethyl sulfoxide and fumarate.Aerobic Respiration: Oxygen (O_2) acts as the final electron acceptor.End Products:Fermentation: Products include lactic acid, alcohol, hydrogen gas, and CO_2.Anaerobic Respiration: The end products vary. For instance, denitrification produces N_2, sulfate respiration yields HS^-, and methanogenesis results in methane.Aerobic Respiration: The primary end products are water (H_2O) and carbon dioxide (CO_2).Examples:Fermentation: Processes include lactic acid fermentation, alcohol fermentation, and various other fermentative pathways.Anaerobic Respiration: Examples encompass denitrification, fumarate respiration, sulfate respiration, and methanogenesis, among others.Aerobic Respiration: Encompasses pathways like glycolysis followed by acetyl-CoA metabolism and fatty acid catabolism (beta-oxidation) coupled with acetyl-CoA metabolism.In summary, while fermentation, anaerobic respiration, and aerobic respiration are all mechanisms to harness energy, they differ in their electron transport systems, ATP yields, electron acceptors, and resultant products. Understanding these differences is crucial for comprehending the diverse metabolic strategies organisms employ to thrive in various environments.CriteriaFermentationAnaerobic RespirationAerobic RespirationNature of the ProcessAnaerobic (without electron transport chain)Anaerobic (with electron transport chain)Aerobic (with electron transport chain)ATP Production2 ATP per glucose (substrate-level phosphorylation)Varies~38 ATP per glucose (substrate-level and oxidative phosphorylation)Final Electron AcceptorOrganic molecules (e.g., pyruvate, acetaldehyde)Inorganic compounds (e.g., SO_4^{2-}, NO_3^-, Fe^{3+}) or certain organic compoundsOxygen (O_2)End ProductsLactic acid, alcohol, hydrogen gas, CO_2Varies (e.g., N_2 in denitrification, HS^- in sulfate respiration, methane in methanogenesis)Water (H_2O) and carbon dioxide (CO_2)ExamplesLactic acid fermentation, alcohol fermentation, etc.Denitrification, fumarate respiration, sulfate respiration, methanogenesis, etc.Glycolysis + acetyl-CoA metabolism, fatty acid catabolism (beta-oxidation) + acetyl-CoA metabolism, etc.This table provides a concise comparison of the three metabolic processes: fermentation, anaerobic respiration, and aerobic respiration.Examples of FermentationFermentation is a metabolic process that converts sugar to acids, gases, or alcohol. It occurs in yeast and bacteria, and also in oxygen-starved muscle cells, as in the case of lactic acid fermentation. Here are some common examples of fermentation:Alcoholic Fermentation:Beer: Yeast ferments the sugars present in malted grains to produce alcohol and carbon dioxide.Wine: Yeast ferments the sugars in grapes.Sake: Fermentation of rice by fungi and yeast.Lactic Acid Fermentation:Yogurt: Specific strains of bacteria convert lactose in milk to lactic acid.Cheese: Various bacteria ferment milk to produce different types of cheeses.Sauerkraut: Fermentation of cabbage by lactic acid bacteria.Kimchi: Fermented vegetables, primarily napa cabbage and Korean radishes, with chili pepper, garlic, ginger, and jeotgal (salted seafood).Pickles: Cucumbers fermented in a solution of salt and water.Acetic Acid Fermentation:Vinegar: Acetic acid bacteria ferment alcoholic beverages to produce vinegar.Mixed Acid Fermentation:Kombucha: A fermented tea drink produced by fermenting sweetened tea with a symbiotic culture of bacteria and yeast (SCOBY).Butyric Acid Fermentation:Certain cheeses and butter have a characteristic flavor due to butyric acid produced by fermentation.Propionic Acid Fermentation:Used in the production of Swiss cheese, giving it its characteristic holes and flavor.Fermentative Hydrogen Production:Some bacteria produce hydrogen gas as a byproduct of fermentation.Bread Making:Yeast ferments the sugars in dough, producing carbon dioxide, which makes the bread rise.Traditional African Beverages:Drinks like “ogi” and “ukodo” are produced by fermenting cereals.Asian Fermented Foods:Miso: A Japanese seasoning produced by fermenting soybeans with salt and koji (the fungus Aspergillus oryzae).Tempeh: An Indonesian product made from fermented soybeans.Nattō: Japanese fermented soybeans known for their strong smell and sticky texture.These are just a few examples, and many cultures around the world have their unique fermented foods and beverages that have been integral to their culinary traditions for centuries.QuizWhat is the primary product of fermentation in yeast?a) Lactic acidb) Ethanolc) Methaned) Acetic acidWhich of the following is NOT a product of fermentation?a) Oxygenb) Carbon dioxidec) Ethanold) Lactic acidIn which food is lactic acid fermentation primarily used?a) Breadb) Winec) Yogurtd) BeerWhat is the main purpose of fermentation in bread making?a) To add flavorb) To produce alcoholc) To make the bread rised) To preserve the bread c) To make the bread riseWhich organism is primarily responsible for alcoholic fermentation?a) Lactobacillusb) E. colic) Saccharomyces cerevisiaed) Acetobacter c) Saccharomyces cerevisiaeWhich of the following is a product of lactic acid fermentation in muscles?a) Ethanolb) Methanec) Lactic acidd) Hydrogen gasWhat is the primary role of yeast in wine production?a) Flavoringb) Preservationc) Fermentationd) ColoringWhich of the following is NOT a benefit of fermented foods?a) Enhanced nutrient absorptionb) Longer shelf lifec) Increased sugar contentd) Probiotic enrichment c) Increased sugar contentIn which process is acetic acid primarily produced?a) Alcoholic fermentationb) Lactic acid fermentationc) Acetic acid fermentationd) Butyric acid fermentation c) Acetic acid fermentationWhich of the following beverages is made by fermenting tea using a symbiotic culture of bacteria and yeast?a) Beerb) Winec) Kombuchad) CiderFAQFermentation is a metabolic process that converts carbohydrates, such as sugars and starches, into chemical compounds like alcohol and organic acids using microorganisms like yeast and bacteria.The main products of fermentation include ethanol (alcohol), lactic acid, carbon dioxide, and various organic compounds, depending on the type of fermentation and microorganisms involved.Fermentation is essential in various industries, including food and beverage production, pharmaceuticals, and biofuel manufacturing. It is used to produce a wide range of products, from bread and yogurt to bioethanol and antibiotics.Aerobic fermentation occurs in the presence of oxygen, while anaerobic fermentation occurs in the absence of oxygen. In aerobic fermentation, oxygen is the final electron acceptor, while in anaerobic fermentation, other molecules serve as electron acceptors.Fermentation helps preserve food by creating an acidic or alcoholic environment that inhibits the growth of harmful microorganisms. This extended shelf life is a result of the production of organic acids, alcohol, and other antimicrobial compounds during fermentation.Yes, humans can undergo fermentation in their muscles during strenuous exercise when oxygen supply becomes limited. This process produces lactic acid, causing muscle fatigue and soreness.Probiotics are beneficial live microorganisms that can improve gut health. Many fermented foods, like yogurt and kimchi, contain probiotics naturally, making them popular choices for maintaining a healthy gut microbiome.Yeast is a microorganism commonly used in alcoholic fermentation. It consumes sugars and produces ethanol and carbon dioxide as byproducts. This process is utilized in brewing and winemaking.Yes, fermented foods can have health benefits. They can improve digestion, enhance nutrient absorption, and contribute to a balanced gut microbiota, which is linked to overall health and well-being.Examples of fermented foods and beverages include yogurt, sauerkraut, sourdough bread, kefir, cheese, wine, beer, and kombucha. These products undergo fermentation to develop their distinctive flavors and properties.Our AI will generate interactive flashcards and quizzes from this article to help you practice. You can also ask any question to deepen your understanding!BNO Team. (2024, May 22). Fermentation – Definition, Types, Principle, Products, Stages, Limitations. Biology Notes Online. Retrieved from Team. "Fermentation – Definition, Types, Principle, Products, Stages, Limitations." Biology Notes Online, 22 May 2024, biologynotesonline.com/fermentation/.BNO Team. "Fermentation – Definition, Types, Principle, Products, Stages, Limitations." Biology Notes Online (blog). May 22, 2024. . Fermentation is a biochemical process in organisms that obtains energy from carbohydrates without requiring oxygen.In chemistry and biology, fermentation is a biochemical process that obtains energy from carbohydrates without using oxygen. Many foods come from fermentation, plus the process has industrial applications. Here is the definition of fermentation, examples of fermented products, and a look at how fermentation works.Fermentation is a metabolic process in organisms that converts carbohydrates into chemical energy, without requiring oxygen. In other words, it is an anaerobic process. In contrast, cellular respiration produces energy, but it is an aerobic process (requires oxygen). In addition to energy molecules (such as ATP), fermentation produces a variety of molecules, including ethanol, carbon dioxide, lactic acid, methanol, hydrogen, methane, butyric acid, acetone, and acetic acid. Examples of organisms that carry out fermentation include fungi (yeast), animals (humans, cattle), and bacteria (Clostridium).The word fermentation comes from the Latin word fervere, which means “to boil.”While organisms use fermentation mainly for energy, people apply the process for making many products. You may know that beer, wine, and cheese come from fermentation, but some other examples may surprise you.BeerWineMeadLiquorCheeseYogurtSour food containing lactic acid, such as kimchi, sauerkraut, pickles, and pepperoniLeavened breadIndustrial alcohol, as for biofuelsSewage treatment involves fermentation.Human muscles initially use aerobic respiration, but switch to fermentation and produce lactic acid as an anaerobic energy supply.Bacteria in the human digestive tract perform fermentation, producing hydrogen gas and sometimes methane as flatus (farts). Herbivores, like cattle, release more methane.The classic fermentation example is yeast fermentation of sucrose (a sugar) into ethanol and carbon dioxide. Each sucrose molecule consists of a glucose subunit and a fructose subunit. For every mole of glucose, fermentation produces two moles of ethanol, two moles of carbon dioxide, and two moles of adenosine triphosphate or ATP. The overall chemical reaction is as follows:C6H12O6 → 2 C2H5OH + 2 CO2But, fermentation is a process and not a single chemical reaction. It occurs in multiple steps.(1) In the first step, the enzyme invertase breaks the glycosidic linkage between the glucose and fructose residues of sucrose.C12H22O11 + H2O + invertase → 2 C6H12O6(2) Next, glycolysis occurs. This is where each glucose molecule breaks into two pyruvate molecules. Glycolysis takes several steps, but here is the overall chemical equation:glucose + 2 ADP + 2 inorganic phosphate → 2 pyruvate + 2 ATP + 2 NAD + 2 water + 2 protonsC6H12O6 + 2 ADP + 2 Pi + 2 NAD+ → 2 CH3COCOO− + 2 ATP + 2 NADH + 2 H2O + 2 H+(3) Finally, pyruvate reacts and forms ethanol and carbon dioxide. This occurs in two steps and regenerates the oxidized NAD+ for glycolysis:CH3COCOO− + H+ → CH3CHO + CO2 (catalyzed by pyruvate decarboxylase)CH3CHO + NADH + H+ → C2H5OH + NAD+ (catalyzed by alcohol dehydrogenase)These reactions convert two moles each of NAD+ and ADP into two moles each of NADH, ATP, and water.Fermentation is not as efficient at energy production as cellular respiration, so organisms capable of both processes typically utilize respiration when oxygen is available. However, the presence of oxygen does not necessarily prevent fermentation from occurring. For example, yeast prefer fermentation over cellular respiration as long there is a sufficient sugar supply.People have been using fermentation since at least the Neolithic (7000 to 6600 BCE), primarily for fermenting beverages and making cheese. However, it wasn’t until the nineteenth century that scientists started understanding the process. In 1837, Theodor Schwann observed yeast budding using a microscope and found that boiling grape juice prevented fermentation until new yeast was added. But, many chemists still believed fermentation was a simple chemical reaction that could occur without a living organism. In the 1850s and 1860s, Louis Pasteur repeated Schwann’s experiments and demonstrated fermentation came from living cells. However, he could not extract the enzyme responsible for the process. In 1897, German chemist Eduard Buechner ground up yeast, extracted fluid, and discovered this fluid fermented a sugar solution. His experiment earned him the 1907 Nobel Prize in Chemistry.Studying fermentation for practical applications is called zymurgy. The name comes from a Greek word that literally means “the workings of fermentation.” The science of studying fermentation is zymology. A person who practices fermentation is a zymurgist, while a scientist specializing in fermentation is a zymologist.Yeast fermentation produces carbon dioxide gas bubbles that expand during cooking and make baked goods rise. But, yeast also produces alcohol (ethanol). Less than 2% of this alcohol remains after baking.Overgrowth of yeast in the gut can cause auto-intoxication. This is where yeast produces ethanol that gets in the blood stream and causes intoxication even when a person has not been drinking.Yeast converts sugar into ethanol, which is safe for human consumption. But, if high levels of pectin are present, one fermentation product is toxic methanol.Akhavan, Bobak; Luis Ostrosky-Zeichner; Thomas, Eric (2019). “Drunk Without Drinking: A Case of Auto-Brewery Syndrome.” ACG Case Reports Journal. 6(9): e00208. doi:10.14309/crj.0000000000000208Hui, Y. H. (2004). Handbook of Vegetable Preservation and Processing. New York: M. Dekker. ISBN 0-8247-4301-6.Klein, Donald W.; Lansing M.; Harley, John (2006). Microbiology (6th ed.). New York: McGraw-Hill. ISBN 978-0-07-255678-0.Purves, William K.; Sadava, David E.; Orians, Gordon H.; Heller, H. Craig (2003). Life, the Science of Biology (7th ed.). Sunderland, Mass.: Sinauer Associates. ISBN 978-0-7167-9856-9.Steinkraus, Keith (2018). Handbook of Indigenous Fermented Foods (2nd ed.). CRC Press. ISBN 9781351442510.Tortora, Gerard J.; Funke, Berdell R.; Case, Christine L. (2010). Microbiology: An Introduction (10th ed.). San Francisco, CA: Pearson Benjamin Cummings. ISBN 978-0-321-58202-7.Related Posts Fermentation is a process where tiny organisms like bacteria and yeast cause chemical changes in food and other materials. It's how we get yogurt and wine, but it's used for much more than just food. Fermentation plays a role in everything from making energy to creating new medical materials. Different types of fermentation produce different things, making them useful for various purposes.In the following article by thedailyECO we explore the different types of fermentation and its different uses. From preserving food to developing sustainable materials, fermentation has a lot to offer. Contents See more >> Fermentation is a metabolic process where organisms break down carbohydrates to produce energy (ATP) without using oxygen. While commonly associated with microorganisms like yeast and bacteria, many organisms can perform fermentation.Fermentation enables organisms to extract energy from a variety of carbohydrates, such as:Simple sugars (e.g., glucose, fructose)Disaccharides (e.g., sucrose, maltose, lactose)Complex carbohydrates (which must first be broken down into simpler sugars)Where does fermentation occur in nature?Fermentation is a widespread natural process, occurring in environments ranging from soil to the human body. In human muscle cells, lactic acid fermentation provides crucial energy during intense exercise when oxygen becomes limited. This same process occurs in many other organisms when oxygen is scarce. In the natural world, soil microorganisms use fermentation to break down organic matter, contributing to nutrient cycling and soil health. Various species of wild yeasts ferment fallen fruits, while beneficial bacteria ferment plant materials in the digestive systems of many animals.Fermentation's versatility makes it invaluable. It's crucial in traditional food production (bread, wine, beer, yogurt, pickles, miso), modern biotechnology (antibiotics, enzymes, vitamins), and sustainable solutions (bioethanol, waste treatment, biodegradable materials). Its industrial uses, like producing organic acids and solvents, are constantly expanding Imagine your body needing energy, like when you're exercising. Your cells primarily use a process called cellular respiration to get this energy from sugars, much like burning wood to get heat. Cellular respiration is very efficient, but it needs oxygen to work properly.Now, imagine you're running a sprint. Your muscles need energy fast, and sometimes, they can't get enough oxygen quickly enough. That's where fermentation comes in. It's like a backup energy system that can kick in when oxygen is limited.The key difference between fermentation and cellular respiration is how they keep the energy-producing process going. Cellular respiration uses oxygen to recycle a crucial molecule called NAD+, which is needed for the first step of energy extraction (called glycolysis). Think of NAD+ as a reusable battery. When it's "charged" (NAD+), it can pick up electrons and become "discharged" (NADH). Cellular respiration uses oxygen to recharge NADH back to NAD+.Fermentation, on the other hand, doesn't use oxygen. Instead, it uses other organic molecules (like the products of the partial breakdown of sugar) to recycle NADH back to NAD+. It's less efficient than cellular respiration, producing much less energy, but it's a vital survival mechanism when oxygen is scarce.This is why your muscles might feel tired and sore after a sprint, they've likely switched to fermentation to keep going when oxygen supply couldn't keep up with the energy demand. The "burn" you feel is often due to byproducts of fermentation, like lactic acid. While all fermentation shares the core idea of energy production without oxygen, the process itself can take many different routes. Each path leads to unique end products and serves specific biological purposes.Alcoholic (Ethanol) fermentation: used in bread making and the production of beer, wine, and other alcoholic beverages.Lactic acid fermentation: common in muscle cells during intense exercise and in the production of yogurt, sauerkraut, and pickles.Acetic acid fermentation: creates vinegar and other acidic products used in food preservation.Butyric acid fermentation: occurs in butter aging and certain cheese production processes.Propionic acid fermentation: essential in Swiss cheese production, creating its distinctive holes and flavor.Mixed acid fermentation: produces multiple organic acids, common in enterobacteria.Butanediol fermentation: results in 2,3-butanediol production, important in industrial processes.Each type of fermentation has evolved to help organisms thrive in specific environments, from our guts to the soil beneath our feet.In the following sections, we'll dive deeper into each type of fermentation, exploring their unique characteristics, products, and how we use them. Alcoholic fermentation, primarily carried out by yeasts like Saccharomyces cerevisiae, converts glucose into ethanol and carbon dioxide. Sugar gets partially broken down into pyruvate. Then, because there's no oxygen, the pyruvate gets changed into acetaldehyde, and the acetaldehyde is finally converted into the alcohol, ethanol. It's a simple but clever way for yeast to get energy when oxygen isn't around.What is alcoholic fermentation used for?Beer production using different strains of

Saccharomyces cerevisiae, each creating unique flavor profiles.Wine making where yeast strains interact with grape varieties to produce distinct characteristics.Bread leavening through CO2 production while developing flavors through secondary metabolites.Industrial bioethanol production from various feedstocks (corn, sugarcane, cellulosic materials).Research applications in biotechnology and molecular biology studies. Lactic acid fermentation occurs in two distinct pathways: homofermentative and heterofermentative.In homofermentative fermentation, glucose is converted solely to lactic acid. This process is exemplified by organisms such as Lactobacillus casei and Streptococcus thermophilus, which are crucial in the production of yogurt. These bacteria convert lactose in milk entirely to lactic acid, contributing to the characteristic tang of the final product.Heterofermentative fermentation differs from homofermentative fermentation in its products. While homofermentative fermentation produces only lactic acid, heterofermentative pathways, used by a variety of bacteria, generate a wider range of compounds. These include lactic acid, but also other products like ethanol, acetic acid, and carbon dioxide. This diversity of end products contributes to the varied flavors found in different fermented foods.What is lactic fermentation used for?Dairy fermentation creating yogurt, transforming milk proteins and creating beneficial compounds.Traditional lacto-fermented vegetables: kimchi (using Lactobacillus kimchii), sauerkraut, etc.Energy production in muscle cells during intense exercise when oxygen is limited, converting glucose to lactate.Sourdough cultures where wild yeasts and Lactobacillus work together to develop complex flavors.Biodegradable medical materials like PLA (polylactic acid) sutures that naturally dissolveDevelopment of lactic acid for natural skin exfoliation in cosmetics.Curious about extreme microbial life? Dive into our article about bacteria that thrive in environments too salty for most life forms. Acetic acid fermentation is a two-stage process. It begins with alcoholic fermentation, typically carried out by yeasts, which produces ethanol. In the second stage, Acetobacter bacteria convert this ethanol to acetic acid.Uniquely among common fermentation types, this process requires oxygen. The resulting product, vinegar, has a characteristic sour taste and preservative properties.What is acetic acid fermentation used for?Food preservation: various vinegars (balsamic, apple cider, rice), pickled products, and natural preservatives.Agricultural uses: natural herbicides, plant growth stimulants, and soil amendments.Industrial applications: textile processing, cleaning products, and chemical manufacturing.Healthcare products: therapeutic vinegars, natural remedies, and pharmaceutical ingredients.Did you know that fermented products like vinegar can help your garden thrive? Learn about this eco-friendly gardening solution in our other article. Butyric acid fermentation, carried out by bacteria like Clostridium butyricum and related species, produces butyric acid, carbon dioxide, and hydrogen gas. While often associated with food spoilage, this process also plays a vital role in the production of certain cheeses, traditional fermented foods, and the industrial production of various chemicals.What is butyric fermentation used for?Cheese development, contributing to the complex flavors in aged cheeses.Food industry applications for creating butter-like flavors.Medical research studying gut health and potential cancer treatments.Industrial production of plastics and fibers.Fragrance industry for specific scent compounds.Animal feed supplements to improve digestive health.Want to expand your knowledge of microorganisms beyond fermentation? Check out our detailed comparison of two fundamental types of microbes. Propionic acid fermentation, performed by Propionibacterium freudenreichii and related species, converts lactate into propionic acid, acetic acid, and carbon dioxide. The carbon dioxide production is responsible for the characteristic holes in Swiss cheese, while the propionic acid itself contributes to its distinctive flavor.What is propionic acid fermentation used for?Cheese production, particularly creating the characteristic holes and flavor in Swiss-type cheeses.Natural food preservation in baked goods and dairy products.Animal feed preservation to prevent mold growth in stored grains.Vitamin production, particularly vitamin B12 for supplements.Flavor development in food products, especially dairy-based foods.Industrial chemicals production for various manufacturing processes. Mixed acid fermentation, common in enterobacteria such as Escherichia coli, produces a variety of acids, including lactic, acetic, succinic, and formic acid, as well as gases like hydrogen and carbon dioxide.What is mixed acid fermentation used for?Waste treatment in environmental management systems.Biogas production from organic waste materials.Food preservation through multiple acid production.Industrial chemical production for various applications.Bioplastic manufacturing from fermentation products.Water treatment processes in environmental management.Did you know that some types of fermentation are key to producing renewable energy? Learn how microorganisms help create sustainable fuels in our guide to biomass energy. Butanediol fermentation, found in organisms such as Klebsiella and Enterobacter, produces 2,3-butanediol, ethanol, and various organic acids. This pathway has industrial applications in the production of chemical precursors, solvent manufacturing, and potentially, biofuel production.What is butanediol fermentation used for?Synthetic rubber production for industrial applications.Plastic manufacturing as a key chemical component.Antifreeze production for industrial and consumer use.Solvent production for industrial processes.Sustainable materials development for eco-friendly products.Chemical manufacturing for various industrial applications. If you want to read similar articles to What Are the Types of Fermentation?, we recommend you visit our Biology category. Bibliography Álvarez, Y. (2010). Lactic fermentation. A., & Fernández, B. (2006). Butyric contamination of milk: Causes and effects on cheeses. J. (n.d.). Chapter 12: Other carbohydrate metabolic pathways. Retrieved from S., Ramírez, R., & Quispe, J. (2018). Citrus fermentation. Polytechnic School of Chimborazo.Simon Bolivar Institute. (2018). Reproduction of Bulgarians «Lactobacillus bulgaricus». ˈfɜ·mentеɪʃən An anaerobic cellular process in which an organic food is converted into simpler compounds, and chemical energy (ATP) is produced What is fermentation? Fermentation is the breaking down of sugar molecules into simpler compounds to produce substances that can be used in making chemical energy. Chemical energy, typically in the form of ATP, is important as it drives various biological processes. Fermentation does not use oxygen; thus, it is "anaerobic". Apart from fermentation, living things produce chemical energy by degrading sugar molecules (e.g. glucose) through aerobic respiration and anaerobic respiration. Aerobic respiration uses oxygen, hence, the term "aerobic". It has three major steps. First, it begins with glycolysis wherein the 6-carbon sugar molecule is lysed into two 3-carbon pyruvate molecules. Next, each pyruvate is converted into acetyl coenzyme A to be broken down to CO2 through the citric acid cycle. Along with this, the hydrogen atoms and electrons from the carbon molecules are transferred to the electron-carrier molecules, NADH, and FADH2. Then, these electron carriers shuttle the high-energy electrons to the electron transport chain to harness the energy and synthesize ATP. The final electron acceptor in the chain is oxygen. As for anaerobic respiration, this form of respiration does not require oxygen. However, it is similar to aerobic respiration in a way that the electrons are passed along the electron transport chain to the final electron acceptor. In anaerobic respiration, the bottom of the chain is not oxygen but other molecules, for example, sulfate ion (SO4–2) or nitrate ion (NO3–). Some people consider fermentation as an example or part of anaerobic respiration as both of them do not use oxygen, and therefore, are anaerobic. However, anaerobic respiration and fermentation are two different processes. Fermentation skips the electron transport chain system. After glycolysis, pyruvate (in lactic acid fermentation) or acetaldehyde (in alcohol fermentation) serves as the final electron acceptor. The type of fermentation depends on its byproducts. For example, lactic acid fermentation is a type of fermentation that produces lactic acid. Alcohol fermentation produces alcohol, such as ethanol, aside from CO2. Fermentation occurs in prokaryotes and eukaryotes, including humans. Our body resorts to fermentation when there is a high energy demand while the oxygen supply becomes limited. An example of this is when we do strenuous exercise. The muscle cells generate ATP to supply energy via aerobic respiration. But when the ATP demand in the muscle cells outruns the blood supply of oxygen, the muscle cells resort to lactic acid fermentation so that they can continue providing energy while the supply of oxygen is limited. When the oxygen level returns to normal, they go back to aerobic respiration. While fermentation is only an alternative pathway in generating ATP, some organisms, such as obligate anaerobes, rely on fermentation to biosynthesize ATP. The genus Neocallimastix is an example of obligate anaerobes. The fungi in this genus are found in the rumen of herbivorous animals. As symbionts, they help digest cellulose through fermentation. (Ref. 1) Another example of obligate anaerobe is the genus Bacteroides. This genus consists of obligate anaerobes that are part of human colonic flora. (Ref. 2) They degrade sugar derivatives from plant materials and generate energy through fermentation. Then, there are certain facultative anaerobes that will favor fermentation over aerobic respiration even in the presence of oxygen, especially when pyruvate is building up faster than it is metabolized. Baker's yeast (Saccharomyces cerevisiae) and fission yeast (Schizosaccharomyces pombe) are examples of organisms that will ferment rather than respire even in the presence of oxygen. In contrast, Kluyveromyces lactis is an example of a yeast species that will ferment only in a completely anaerobic environment and will favor respiration over fermentation if oxygen becomes available. Microbial fermentation is used commercially by certain industries. Lactic acid fermentation by certain fungi and bacteria, for instance, is used by the dairy industry to make yogurt and cheese. Alcohol fermentation by yeasts is used in making wine and liquor. Biology definition: Fermentation is an anaerobic process performed by a cell to generate chemical energy (e.g. ATP) from pyruvate (a product of glycolysis) but without going through the citric acid cycle and the electron transport chain system as cellular respiration does. Etymology: from Latin fermentātiō, fermentātiōnem, fermentum, meaning "that which causes fermentation, yeast") Table 1: Comparison of Fermentation, Anaerobic Respiration, and Aerobic Respiration Fermentation Anaerobic Respiration Aerobic Respiration Anaerobic process Anaerobic process Aerobic process Does not use the electron transport chain system to pass the electrons to the final electron acceptor Uses the electron transport chain system to pass the electrons to the final electron acceptor Uses the electron transport chain system to pass the electrons to the final electron acceptor Number of ATP gained: 2 per glucose molecule (by substrate-level phosphorylation) Number of ATP gained: varies Number of ATP gained: ~38 per glucose molecule (by substrate-level phosphorylation and oxidative phosphorylation) Final electron acceptor: organic molecule, e.g. pyruvate (lactic acid fermentation) or acetaldehyde (alcohol fermentation) Final electron acceptor: inorganic compounds, e.g. sulfate ion (SO4–2), nitrate (NO3–)and ferric ion (Fe3+) or organic compounds, e.g. dimethyl sulfoxide, fumarate, and trimethylamine N-oxide (Ref. 3) Final electron acceptor: oxygen Examples: lactic acid fermentation, alcohol fermentation, fermentative hydrogen production, mixed acid fermentation, butanediol fermentation, butyrate fermentation Examples: denitrification, fumarate respiration, sulfate respiration, methanogenesis, sulfur reduction, acetogenesis, dehalorespiration, iron reduction, cobalt reduction Examples: glycolysis + acetyl-CoA metabolism, fatty acid catabolism (beta oxidation) + acetyl-CoA metabolism Final product: lactic acid, alcohol, hydrogen gas, CO2 Final product: varies, for example, N2 (in denitrification), succinate (in fumarate respiration), HS− (in sulfate respiration and sulfur reduction), methane (in methanogenesis), acetate (in acetogenesis), halide ions, and dehalogenated compound (in dehalorespiration), Fe(II) in iron reduction, Co(II) in cobalt reduction Final product: water, CO2 Function of Fermentation What is the function of fermentation? Fermentation enables cells to produce chemical energy from the breakdown of sugar, e.g. glucose, without the help of oxygen. That gives anaerobic (obligate, facultative, or aerotolerant) organisms the advantage of thriving in anoxic (without oxygen) environments that would rather be harsh for aerobic organisms. Examples of anoxic environments are mud, soil, and hydrothermal vents deep under the sea. The anaerobic bacteria that can thrive in these environments are essential for their ecological niche. They ferment molecules to derive energy and, in return, they produce byproducts released into the environment. Their byproducts may be used by other organisms or may be returned to the environment as a form of nutrient cycling. Thus, having them in these environments could be essential for their distinctive ecological niche. Figure 1: Fermentation reactions. Image Source: Maria Victoria Gonzaga of Biology Online. Apart from these habitats, there are also microbes that inhabit living organisms, such as the gastrointestinal tract of mammals. Ruminants, such as cattle, harbor normal gut flora that can ferment dietary food that the animals cannot digest by themselves. That is because the microbes living in their gut can synthesize enzymes needed in digesting celluloses and residual starch. Humans also have normal flora in the gut for a similar purpose. They help degrade undigested sugars in the large intestine. Too much fructose, for instance, may cause fructose to reach the large intestine. When it does, it is used in fermentation by the colonic flora. Byproducts, such as lactic acid, methane, hydrogen, and carbon dioxide, are produced. (Ref. 4) Fermentation is the major source of intestinal gas, which can cause flatulence, bloating, gastrointestinal pain, or diarrhea. Some bacteria, though, are pathogenic (disease-causing) if they infect a human body. An example is Clostridium perfingens. This bacterial species can cause gas gangrene in humans. Our body also carries out fermentation. When we are doing an energy-demanding activity, our body will keep on sustaining energy (ATP). If aerobic respiration is no longer able to meet up the energy demand, the body has lactic acid fermentation as an alternative. The cells will resort to it as a quick way to generate ATP. Truly, aerobic respiration is better at producing more ATP than fermentation as there are ~38 ATPs released per glucose molecule through aerobic respiration as opposed to only 2 ATP via fermentation. However, aerobic respiration is a longer process. Fermentation lets our cells, such as skeletal muscle cells, to quickly obtain the power they need to carry out a task. The purpose of lactic acid fermentation, in this regard, is chiefly to regenerate NAD+, which is essential for glycolysis to proceed again. NAD+ is regenerated when pyruvate (the end product of glycolysis) accepts electrons from NADH. (Ref. 5) Fermentation is also the pathway used by certain cells in our body lacking in mitochondria. Our red blood cells, in particular, no longer possess mitochondria at maturity. Mitochondria are the organelles where the citric acid cycle and electron transport chain redox reactions occur. Fermentation entails glycolysis and the transferring of electrons from NADH to pyruvate or its derivatives (to regenerate NAD+). These processes occur in the cytosol. Therefore, mature red blood cells circulating in our blood generate chemical energy through lactic acid fermentation. This ensures that the red blood cells will not use any of the oxygen they transport. (Ref. 5) In the food industry, fermentation is an important process in making bread, wine, cheese, soy sauce, and other foods and beverages. In particular, the yeasts ferment the sugars in the dough, releasing CO2 in the process. The CO2 helps the bread to rise. As for wines and other liquors, yeasts are added to the fruit juice (e.g. grape juice). The yeasts ferment the sugar in the juice into alcohol. Cheese is a product of bacteria fermenting milk or cream. Fermentation Process What is the process of fermentation? Does fermentation require oxygen? Fermentation is an anaerobic process. It does not use oxygen. The fermentation reaction entails two major steps: (1) glycolysis and (2) electron transfer from NADH to pyruvate or its derivatives. The first step — glycolysis — is similarly the first step in cellular respiration. Glycolysis means "splitting of sugar". That's because, glucose, a 6-carbon sugar molecule is split into two pyruvates (a 3-carbon compound) after glycolysis. In glycolysis, glucose is oxidized to pyruvate to harvest chemical energy. The first phase is called an energy-investment phase because the process uses ATP molecules. The next phase is an energy-payoff phase. That's because ATP is now produced via substrate-level phosphorylation. Aside from ATP, NADH, another high-energy molecule, is produced. NADH is produced when glyceraldehyde phosphate (product of the energy-investment phase) is oxidized and then the H+ and the electrons are transferred to NAD+. The end product of the energy-payoff phase is pyruvate. Pyruvate is, then, used in the next step of fermentation, which is the electron transfer from NADH to pyruvate or its derivatives. This step regenerates NAD+, which is important because it is used in glycolysis during the energy-payoff phase, as mentioned above. How much ATP does fermentation produce? Because fermentation skips the citric acid cycle after glycolysis, the energy gain is two ATP molecules per glucose molecule. But what about the NADH produced in glycolysis? As described above, NADH is consumed in the second step when the electron from NADH is transferred to pyruvate or its derivatives, e.g. acetaldehyde. Thus, there is no net NADH production during fermentation. This is also why there is no ATP production through oxidative phosphorylation but only substrate-level. In cellular respiration, NADH enters the electron transport chain to transfer the electron along the chain and produce ATP through oxidative phosphorylation. Where does fermentation occur? Glycolysis and the electron transfer from NADH to pyruvate or its derivatives occur in the cytoplasm (particularly, the cytosol). What causes fermentation? The presence of pyruvate coming from glycolysis incites fermentation. Some cells that respire aerobically (e.g. muscle cells) may resort to fermentation when oxygen is scarce and yet there is high energy demand. The muscle cells seem to "buy time" by using fermentation to generate energy quickly until such time that the muscle cell can respire again when the oxygen supply is no longer limited. (Ref. 5) Types of Fermentation What are the 3 types of fermentation? There are many types of fermentation. But the three types of fermentation that are commonly used in the industry are lactate fermentation, ethanol fermentation, and acetic acid fermentation. In brief, lactate fermentation produces lactate, ethanol fermentation produces ethanol, and acetic acid fermentation produces acetic acid. The first two types of fermentation are further described in the preceding sections. Fermentation activity occurs in both prokaryotes and eukaryotes. Nevertheless, bacterial fermentation and yeast fermentation are the most commercially valuable. They are used in the food industry. Below are examples of some of the commercial applications of fermentation. Definition: Alcoholic fermentation is a type of fermentation wherein the end product is alcohol, e.g. ethanol. The yeasts, for instance, are used to ferment sugars in fruit juice (e.g. grapes) to produce alcohol. Definition: Lactate fermentation is a type of fermentation wherein the end product is lactate. This is used to produce cheese. Certain bacteria, e.g. Lactococcus or Lactobacillus spp. are used to convert lactose in milk to lactic acid. Definition: Acetic acid fermentation is a type of fermentation wherein the end product is acetic acid. Ethanol fermentation is a type of fermentation wherein the end product is ethanol (or ethyl alcohol). It is a three-step process. First, glucose is oxidized by glycolysis, producing two pyruvate molecules. Second, each pyruvate releases carbon dioxide to produce acetaldehyde. Third, acetaldehyde takes the hydrogen ions from NADH, consequently producing ethanol and converting NADH back to NAD+. The enzymes that catalyze the second and third steps are pyruvate carboxylase and alcohol dehydrogenase, respectively. Figure 2: Schematic diagram of ethanol fermentation. Credit: Davidcarmack, CC BY-SA 3.0 Yeasts (e.g. Saccharomyces cerevisiae, Schizosaccharomyces) and certain anaerobic bacteria (e.g. Zymomonas mobilis) are capable of ethanol fermentation. These microscopic organisms are used by the food industry in making alcoholic beverages and causing bread dough to rise. Certain fish groups (e.g. goldfish and crucian carp) can also ferment and produce ethanol especially when their environment becomes anoxic (oxygen-deficient). These fish species of the Cyprinid family form ethanol in their myotomal muscles. Apart from ethanol fermentation, they are also capable of lactic acid fermentation. (Ref. 6) Lactic Acid Fermentation Lactic acid fermentation is a biological process wherein sugars are converted into lactate to yield energy. Where does lactic acid fermentation occur? Similar to ethanol fermentation, lactic acid fermentation occurs in the cytosol of the cell. There are two forms of lactic acid fermentation: (1) homolactic fermentation and (2) heterolactic fermentation. Homolactic fermentation is when the endproduct is only lactate. When there are other endproducts apart from lactate, for example, ethanol and carbon dioxide, it is a heterolactic type. Nevertheless, both of them begin in glycolysis and ultimately produce two pyruvates with each glucose molecule. In homolactic fermentation, no carbon dioxide is released. Also, the pyruvate is reduced directly by NADH. This results in lactate (an ionized form of lactic acid) formation and NAD+ regeneration. The enzyme responsible for this reaction is lactate dehydrogenase. Figure 3: Schematic diagram of lactic acid fermentation. Credit: Sjantoni, CC BY-SA 3.0 Unported. Lactic acid fermentation is the type of fermentation used in making cheese, yogurt, acetone, and methyl alcohol. This is the type of fermentation that occurs in the muscle cells during vigorous physical activity. Lactate is a waste product released by the muscle cell into the bloodstream to be carried by the blood to the liver. The liver cell takes up lactate from the blood to convert it back into pyruvate via the enzyme, lactate dehydrogenase — a process called the Cori cycle (Ref. 7) This means that the reaction can proceed in either direction. Fermentation Equation The chemical equation of fermentation varies depending on the reactants and products involved. Let's take a look at the following examples below. Ethanol Equation The overall chemical formula for ethanol fermentation is: C6H12O6 (glucose) → 2 C2H5OH (ethanol) + 2 CO2 (carbon dioxide) + energy Because there are two pyruvates produced per one glucose molecule, there are two ethanol molecules and two carbon dioxide molecules produced after fermentation. The total ATP gain is two. Lactic acid fermentation equation The general chemical formula for lactic acid (homolactic) fermentation is as follows: C6H12O6 (glucose) → 2 CH3CHOHCOO- (lactate) + energy Because there are two pyruvates produced per one glucose molecule, there are two lactate molecules produced after fermentation. The total ATP gain is two. Certain fermentative bacteria (e.g. Leuconostoc mesenteroides) are capable of further metabolizing lactate. As a result, the products of the fermentation are not just lactate but other metabolic products, such as alcohol and carbon dioxide. In this case, the formula is: C6H12O6 (glucose) → CH3CHOHCOO- (lactate) + C2H5OH (alcohol) + CO2 (carbon dioxide) + energy This is a sample of a heterolactic type of lactic acid fermentation. The total ATP gain in this example is 1 ATP. Fermentation Products The products of fermentation will depend on the enzymes involved. For instance, producing ethanol from pyruvate will require enzymes, pyruvate carboxylase, and alcohol dehydrogenase. Conversely, to produce lactate from pyruvate, the enzyme, lactate dehydrogenase is required. Apart from lactate (or lactic acid) and ethanol, other byproducts of fermentation are acetates, carbon dioxide, and hydrogen gas. Acetic acid bacteria are a group of bacteria that will oxidize sugars or ethanol to produce acetic acid. One such important commercial application is vinegar making. Vinegar is produced by allowing the acetic acid bacteria to act on sugars or ethanol. The formula is as follows: CH3CH2OH (ethanol) + O2 (oxygen)→ CH3COOH (acetic acid)+ H2O (water). In this reaction, oxygen is utilized and made to react with ethanol to produce acetic acid and water. Thus, the production of vinegar is a combined process of fermentation and oxidation. Fermentative hydrogen production, in turn, is a form of fermentation wherein an organic compound is converted into hydrogen gas (H2). Certain types of bacteria and protozoa have enzymes that enable this process. When light is not required, the process is referred to as dark fermentation. If light energy is required, the process is called photofermentation. History of the Use of Fermentation The practice of fermentation has existed in ancient history. People have been applying the basic steps of fermentation in their food and beverages. They were making beer from malted barley, wine from grapes, chicha from maize, and octli (now known as "pulque") from agave, a type of cactus. (Ref. 8) People were able to produce these beverages by placing them inside the tightly covered containers and then leaving them for over a certain period of time but no one knew how this practice worked. It was only in the 17th century that people began to understand the biology of it when microscopes and lenses were invented. Antoni van Leeuwenhoek, for instance, was able to see for the first time various microorganisms, including yeasts. As more powerful microscopes were contrived, scientists were able to learn more about multifarious microorganisms. Charles Cagniard de la Tour found out that yeasts are microorganisms and might have been associated with the fermentation process. He observed them multiplying by budding during alcoholic fermentation. However, our modern understanding of the biology and chemistry of fermentation comes from the work of Louis Pasteur, a French chemist and microbiologist. In the 1850s and 1860s, he was the first to demonstrate through experiments that living yeasts were the ones responsible for transforming glucose into ethanol in fermented beverages. And these yeasts were able to do so in the absence of oxygen. He described the process as "respiration without air". (Ref. 8) Pasteur also identified two types of fermentation: alcoholic fermentation which he attributed to the multiplying yeasts and lactic acid fermentation by the growing bacteria. (Ref. 8) This was based on his observations where he found out that sugars were converted into alcohol in the presence of live yeast and that the "souring" of the beet juice was due to the presence of live bacterial species, which led to the conversion of ethanol into acetic acid. (Ref. 9) Pasteur, however, did not know exactly how these organisms caused fermentation. By the end of the 19th century, Eduard Buchner (German chemist) found that by pulverizing the yeasts cells and extracting "press juice" from the yeasts he was able to incite the conversion of sucrose to alcohol and carbon dioxide. He coined the term "zymase" to refer to the compound extracted from yeast that catalyzed the conversion in alcoholic fermentation. (Ref. 9) Since then, more organisms have been identified to carry out fermentation, including the cells of human muscles. (Ref. 10) Try to answer the quiz below to check what you have learned so far about fermentation. References 1. Neocallimastix – microbewiki. (2010). Kenyon.Edu. 2. Wexler, H. M. (2007). Bacteroides: the Good, the Bad, and the Nitty-Gritty. Clinical Microbiology Reviews, 20(4), 593–621. 3. 5.9A: Electron Donors and Acceptors in Anaerobic Respiration. (2017, May 9). Biology LibreTexts. 3A_Microbiology_(Boundless)/5%3A_Microbial_Metabolism/5.09%3A_Anaerobic_Respiration/5.9A%3A_Electron_Donors_and_Acceptors_in_Anaerobic_Respiration 4. Microbial Fermentation. (2020). Colostate.Edu. ~:text=Several%20species%20of%20bacteria%20in,major%20source%20of%20intestinal%20gas. 5. Berg, J. M., Tymoczko, J. L., & Lubert Stryer. (2020). Gluconeogenesis and Glycolysis Are Reciprocally Regulated. Nih.Gov; W H Freeman. 6. Aren van Waarde, Van, & Verhagen, M. (2020). Ethanol Formation and pH-Regulation in Fish. Www.Rug.Nl, 157–170. //hdl.handle.net/11370/3196a88e-a978-4293-8f6f-cd6876d8c428 7. Gray, L. R., Tompkins, S. C., & Taylor, E. B. (2013). Regulation of pyruvate metabolism and human disease. Cellular and Molecular Life Sciences, 71(14), 2577–2604. Yeast, Fermentation, Beer, Wine | Learn Science at Scitable. (2010). Nature.Com. History and Biochemistry of Fermented Foods – RockEDU. (2011). RockEDU. fermentation | Definition, Process, & Facts | Britannica. (2020). In Encyclopædia Britannica. By Dr. Bryan Rithesh MirandaFermentation is a natural process where microorganisms like bacteria, yeast, or fungi convert sugars into other compounds such as alcohol, gases, or acids. It is a chemical reaction that has been used for thousands of years in food preparation, preservation, and industrial applications.This blog explains the types of fermentation, its benefits, disadvantages, and common uses in everyday life.Fermentation occurs in the absence of oxygen (anaerobic conditions). Microbes break down sugars (carbohydrates) and produce by-products like alcohol, carbon dioxide, or lactic acid. This process not only preserves food but also enhances flavour, texture, and nutritional value.There are several types of fermentation, including:What it is: Yeast converts sugars into alcohol and carbon dioxide.Uses: Brewing beer, winemaking, and producing biofuels.What it is: Bacteria such as Lactobacillus convert sugars into lactic acid.Uses: Making yogurt, cheese, sauerkraut, kimchi, and pickles.What it is: Sugars or ethanol are converted into acetic acid by bacteria.Uses: Producing vinegar and kombucha.4. Butyric Acid FermentationWhat it is: Anaerobic bacteria produce butyric acid, carbon dioxide, and hydrogen.Uses: Sometimes involved in dairy production or creating biofuels.Food and Beverage ProductionFermentation is essential for making bread, beer, wine, cheese, yogurt, and fermented vegetables. It improves taste and increases shelf life.Used to produce biofuels, pharmaceuticals (e.g., antibiotics), and chemicals like ethanol or lactic acid.Fermented foods are rich in probiotics, which promote gut health and improve digestion.Fermentation breaks down organic waste into usable products like biogas or compost.• Improves Digestive Health: Probiotics in fermented foods support gut bacteria.• Enhances nutritional value: Increases availability of vitamins and minerals.• Food preservation: Extends shelf life without harmful chemicals.• Eco-Friendly Production: Used in sustainable practices like biofuel creation.Disadvantages of Fermentation• Health risks: Contamination during fermentation can lead to harmful bacteria or toxins.• Allergies or Intolerance: Fermented foods may trigger allergies or histamine sensitivity in some individuals.• Time-consuming: Fermentation often takes days or weeks to complete.• Quality control issues: Improper methods can lead to inconsistent results.Fermentation is a cornerstone of food production, industrial processes, and health innovation. While its benefits are significant, understanding the process and risks is essential to ensure its safe and effective use. CBSE Class 11 Biology Notes Diversity In The Living World Binomial Nomenclature - Definition, Rules, Classification and Examples Taxonomic Hierarchy In Biological Classification Genus and Family Difference Between Phylum and Class Taxonomical Aids Botanical Gardens The Living World - Introduction, Classification, Characteristics, FAQs Biological Classification Kingdom Monera - Definition, Classification, Characteristics, Examples Archaebacteria Eubacteria - Structure, Characteristics, Classification, and Types Kingdom Protista Chrysophytes Dinoflagellates Euglenoid Slime Moulds Protozoans - Structure, Classification, Characteristics, Examples Kingdom Fungi Phycomycetes Ascomycetes - Introduction, Characteristics, Reproduction, Importance Deuteromycetes Kingdom Plantae - Class 11 Biology What is Plant Kingdom? Algae - Definition, Characteristics, Types and Examples Chlorophyceae Phaeophyceae - Overview, Characteristics, Importance, Examples Rhodophyceae Bryophytes | Class 11 Biology Liverworts Mosses Pteridophytes Gymnosperms - Definition, Characteristics, Uses and Examples Angiosperms Difference between Angiosperms and Gymnosperms Animal Kingdom Classification of Animal Kingdom Levels of Organization in Animals Symmetry in Animals - Definition, Types and Importance Diploblastic And Triploblastic Organization Classification of Animals Phylum Porifera Phylum Coelenterata | Class 11 Biology Phylum Ctenophora Platyhelminthes Phylum Aschelminthes Phylum Annelida Phylum Arthropoda Phylum Mollusca Phylum Echinodermata Phylum Hemichordata Phylum Chordata Morphology of Flowering Plants Root System in Plants - Types and Functions of Root Stem - Characteristics and Functions Inflorescence Morphology of Flower - Definition, Structure, Parts, Examples Parts of a Flower and Their Functions Androecium - Definition, Components, Structure, Functions Gynoecium - Definition, Concept, Parts, Functions What is a Fruit? Structure Of A Dicotyledonous Seed Structure Of Monocotyledonous Seed Semi Technical Description of a Flowering Plant - Class 11 Biology Fabaceae - Overview, Characteristics, Classification, Importance Solanaceae - Characteristics, Importance, Examples Liliaceae Meristematic Tissues | Class 11 Biology Permanent Tissues Why are Xylem and Phloem called Complex Tissues? Epidermal Tissue System: Its Functions and Tissue in Plant Difference between Dicot and Monocot Root Monocot and Dicot Stems - Definition, Structure, Characteristics, Examples Describe the Internal Structure of a Dorsiventral Leaf Isobilateral (Monocotyledonous) Leaf - Definition, Features, Structure, Examples Secondary Growth Cork Cambium NCERT Notes of Class 11 Biology Chapter 7 Structural Organisation in Animals Structural Organization in Animals Epithelial Tissue - Introduction, Characteristics, Types, Importance Connective Tissue - Definition, Functions, Types, Examples Organ System Morphology of Earthworm Earthworm Anatomy Morphology of Cockroach Anatomy of Cockroach Morphology and Anatomy of Frogs Cell the Unit of Life Class 11 Notes CBSE Biology Chapter 8 Prokaryotic Cells Cell Envelope - Definition, Classification, Types, Functions Ribosomes and Inclusion Bodies Eukaryotic Cells Cell Membrane Endomembrane System - Overview, Structure, and Functions Mitochondria Golgi Apparatus Plastids - Definition, Classification, Structure, Functions Ribosomes Cytoskeleton - Definition, Structure, Components, Functions Cilia And Flagella - Definition, Structure, Functions and FAQs What is Nucleus? | Class 11 Biology Biomolecules - Definition, Structure, Classification, Examples How To Analyze Chemical Composition? What are Metabolites - Primary and Secondary Metabolites Biomacromolecules - Definition, Types, Functions, Significance Proteins - Definition, Structure, Significance, Examples Polysaccharides Nucleic Acid - Definition, Function, Structure, and Types Protein Structure - Primary, Secondary, Tertiary, Quaternary Metabolic Basis For Living | CBSE Class 11 Biology Chapter 9 Enzymes - Definition, Structure, Classification, Examples Nature of Enzyme Action Mechanism of Enzymes Action Factors Affecting Enzyme Activity Cofactors Fermentation is a biochemical process in which carbohydrates like glucose or starch are converted to alcohol or acid without oxygen. Microorganisms like yeasts, anaerobic bacteria, and muscle cells in animals use fermentation as a means of producing ATP without the presence of oxygen. Thus, fermentation is a form of anaerobic respiration. It involves glycolysis but not the other two stages of aerobic respiration. Like glycolysis, fermentation occurs in the cytoplasm of both prokaryotic and eukaryotic cells. 'Ferment' comes from the Latin word fervere, meaning 'to boil'. The science of fermentation is called zymology. Some common fermented food beverages are wine, beer, cheese, yogurt, sauerkraut, kimchi, and pepperoni. Fermentation dates back to 10,000 BCE when early humans used to preserve milk from cattle, sheep, goats, and camels.The scientific investigation began in the 16th century. People used fermentation to make products such as wine, cheese, and beer long before the process was correctly understood.In the 1850s and 1860s, Louis Pasteur described how fermentation was caused in living cells. However, he could not extract the enzyme necessary for fermentation in yeasts.In 1897, German chemist Eduard Buechner extracted the fluid responsible for fermentation, which earned him Nobel Prize in 1907. Fermentation and cellular respiration begin the same way, using glycolysis. However, due to a lack of oxygen, pyruvate formed in glycolysis does not enter the Kreb's cycle and oxidative phosphorylation through the electron transport chain (ETC). The ETC being non-functional, the NADH made in glycolysis cannot transfer its electrons and revert to NAD+. However, the NADH must be oxidized to allow cells to continue making ATPs using glycolysis. In this condition, fermentation is necessary for the cell. How does Fermentation Allow Glycolysis to Continue In fermentation, pyruvate produced through glycolysis is reduced, and NADH is oxidized to NAD+. Regeneration and a steady supply of NAD+ allow glycolysis to continue, thus providing the cell with the energy necessary for all metabolic functions. How Many ATPs are produced in Fermentation Cells can make only 2 ATPs at most per fermentation as oxidative phosphorylation remains non-functional. Fermentation is a two-step reaction. The exact step depends on the type of fermentation under study. The two main types of fermentation found in living organisms are 1) lactic acid fermentation and 2) alcoholic fermentation. Fermentation The pyruvate produced through glycolysis is converted to lactate or lactic acid by the fungus Aspergillus. The enzyme that catalyzes this step is lactate dehydrogenase, lactic acid being the byproduct. Humans carry out lactic acid fermentation when the body needs much energy, such as during sprinting and workouts. Once the stored ATP in the cell is used up, our muscles start producing ATP through lactic acid fermentation. Lactic acid fermentation also occurs in the bacteria Lactobacillus,which is used in making cheese and yogurt. Equation Glucose → 2 Pyruvate + 2 NADH → 2 Lactic Acid + 2 NAD+ When yeasts such as Saccharomyces are kept without oxygen, they switch to alcoholic fermentation to generate usable energy from food. Similar to lactic acid and ethyl alcohol, the product of alcoholic fermentation is also a byproduct. It is a two-step process. Step 1: A carboxyl group is removed from pyruvate and released as carbon dioxide, producing a two-carbon molecule called acetaldehyde. Step 2: NADH passes its electrons to acetaldehyde, regenerating NAD+ and ethyl alcohol. It is the process that causes bread dough to rise. When yeast cells in the dough run out of oxygen, the dough begins to ferment, producing tiny bubbles of carbon dioxide as their waste products. These bubbles are the air spaces we see in a slice of bread. Alcoholic fermentation is also used in wine production. Equation Glucose → 2 Pyruvate + 2 NADH →2 Ethanol + 2 NAD++ 2CO2 To regenerate NAD+ by oxidizing NADH, the electron carriers in glycolysis. Thus, fermentation ensures an uninterrupted supply of ATP to the cell. Fermentation also has high commercial importance. To produce fermented food and beverages. For example, wine, beer, cheese, yogurt, sauerkraut, kimchi, and pepperoni are high in nutritional value and can act as probiotics.To produce methane and hydrogen gasTo neutralize anti-nutrients like phytic acid in grains, nuts, seeds, and legumes, thus increasing their nutritional value Some bacteria and archaea (methanogens) found in the soil and the digestive tracts of cows and sheep do not perform fermentation. However, they use an alternative way to regenerate NAD+. They reduce carbon dioxide to methane to oxidize NADH. Likewise, sulfate-reducing bacteria and archaea reduce sulfate to hydrogen sulfide to regenerate NAD+ from NADH. Q.1. Why is fermentation less effective than aerobic respiration?
Ans. Fermentation is less effective than aerobic respiration because it cannot wholly break down glucose molecules. Unlike aerobic respiration, it can produce only two ATPs via glycolysis, compared to 36 ATPs in aerobic respiration. Q.2. Is fermentation an anabolic or catabolic reaction? Ans. Fermentation is a catabolic reaction. Q.3. What is the difference between glycolysis and fermentation? Ans. The main difference between glycolysis and fermentation is that glycolysis can occur in the presence or absence of oxygen. In contrast, fermentation strictly occurs in the absence of oxygen. Q.4. How are lactic acid and alcoholic fermentation similar? Ans. Lactic acid and alcoholic fermentation both occur in the absence of oxygen. Q.5. What is the electron acceptor in fermentation? Ans. The final electron acceptor in fermentation is an organic compound. Article was last reviewed on Tuesday, August 23, 2022 Home » Biotechnology Fermentation is one of the ancient food processing technologies. Fermentation is defined as a process in which chemical changes occur in an organic substrate through the action of enzymes produced by microorganisms. For example, yeast enzymes convert sugars and starches into alcohol, while proteins are converted to peptides/amino acids. Fermentation takes place in the lack of oxygen that produces ATP (energy). It turns NADH and pyruvate produced in the glycolysis step into NAD+ and various small molecules depending on the type of fermentation. The fermenting microorganisms mainly involve L.A.B. like Enterococcus, Streptococcus, Leuconostoc, Lactobacillus, and Pediococcus and yeasts and molds like Debaryomyces, Kluyveromyces, Saccharomyces, Geotrichium, Mucor, Penicillium, and Rhizopus species. Principle of fermentation The main principle of fermentation is to derive energy from carbohydrates in the absence of oxygen. Glucose is first partially oxidized to pyruvate by glycolysis. Then pyruvate is converted to alcohol or acid along with regeneration of NAD+ which can take part in glycolysis to produce more ATP. Fermentation yields only about 5% of the energy obtained by aerobic respiration. Flowchart: Generalized pathways for the production of some fermentation end products from glucose by various organisms. Fermentation is an anaerobic biochemical process that is used for the production of energy from the partial oxidation of glucose or other carbon sources. The oxidation of the substrate, which occurs through the Embden–Meyerhoff (EMP) or Entner–Doudoroff(ED) pathways, results in the production of pyruvate, ATP, and NAD (P) H. In the absence of external electron acceptors, the pyruvate undergoes reduction with the regeneration of NAD+(P). This step is essential for the fermentation process to progress and it leads to the production of products (ethanol and organic acids). ATP is the main product of fermentation, and it is generated by phosphorylation at the substrate level. NADH is then re-oxidized, reverting to NAD+ in the second phase of fermentation that reduces pyruvate to the fermentation product, such as ethanol and lactate. For example, in the fermentation of glucose by Streptococcus lactis, the pyruvate is converted to lactic acid to reform NAD+ coenzymes so two ATP molecules are produced In yeasts like Saccharomyces, when pyruvate is converted to ethyl alcohol (ethanol), NAD+ is reformed. Types of fermentation 1. Lactic acid homofermentation Glucose → Lactic acid Homolactic fermentation is carried out by bacteria belonging to the genera Lactococcus, Enterococcus, Streptococcus, and Pediococcus, and by some species of the genus Lactobacillus. Homofermentative LAB ferment glucose to lactic acid. Lactococcus spp. is used in the dairy starter culture. 2. Lactic acid heterofermentation Glucose → Lactic acid + Acetic acid + Ethyl alcohol + 2CO2 + H2O Heterolactic fermentation is carried out by bacteria of the genera Leuconostoc, Oenococcus, and Weissella, and by heterofermentative lactobacilli. Heterofermentative LAB ferment glucose with lactic acid, ethanol/acetic acid, and carbon dioxide (CO2) as by-products. 3. Propionic acid fermentation Glucose → Lactic acid + Propionic acid + Acetic acid + CO2 + H2O Propionic acid fermentation is carried out by several bacteria that belong to the genus Propionibacterium and the species Clostridium propionicum. During propionic acid fermentation, both sugar and lactate can be used as the initial substrate. When sugar is available, these bacteria use the EMP pathway to produce pyruvate; the pyruvate is carboxylated to oxaloacetate and then reduced to propionate via malate, fumarate, and succinate. The other end products of propionic fermentation are acetic acid and CO2. 4. Diacetyl and 2,3-butylene glycol fermentation Diacetyl ↑ Citric acid→ Pyruvic acid + Acetylmethylcarbon ↓ 2,3-Butylene glycol Butanediol fermentation is carried out by members of the genera Enterobacter, Erwinia, Hafnia, Klebsiella, and Serratia. The reactions that lead to the production of 2,3-butanediol involve a double decarboxylation step. 5. Alcoholic fermentation Glucose → Ethyl alcohol Alcoholic fermentation is the best known of the fermentation processes. It is carried out by yeasts and some other fungi and bacteria. The first step of the alcoholic fermentation pathway involves pyruvate, which is formed by yeast via the EMP pathway, while it is obtained through the ED pathway in the case of Zymomonas (bacteria). The redox balance of alcoholic fermentation is achieved by the regeneration of NAD+ during the reduction of acetaldehyde to ethanol. Figure: Alcohol Fermentation. Created with biorender.com. 6. Butyric acid fermentation Glucose → Acetic acid + Butyric acid Butyric acid fermentation is characteristic of several obligate anaerobic bacteria that mainly belong to the genus Clostridium. Pyruvate is in turn oxidized to acetyl-CoA, with the production of CO2 and H2. Part of the acetyl-CoA is converted into acetic acid, with ATP production. Some bacteria, such as Clostridium acetobutylicum, produce fewer acids and more neutral products, thus carrying out acetone butanol fermentation. Applications of fermentation Figure: Application of fermentation. Application in medicine Production of antibiotics Production of insulin Production of growth hormones Production of vaccines Production of interferon Application in the food industry Production of fermented foods as cheese, wine, beer, and bread to high-value products Food grade bio preservatives Functional foods/Neutraceuticals Production of single-cell protein Other Applications It is also used for waste management such as biofuels production (biodiesels, bioethanol, butanol, biohydrogen, etc). It is also used to produce bio-surfactant, polymers production such as bacterial cellulose production. Development of bioremediation processes (involving microbes or their isolated enzymes) for soils and wastewater treatments. Limitations of fermentation Low scale production that requires high cost and high energy Possibilities of contamination. Natural variations over time the product is impure which needs further treatment the undesirable and unexpected end product the undesirable microbes grow and multiply and desirable microbes died. References Admassie, M. (2018). A Review on Food Fermentation and the Biotechnology of Lactic Acid Bacteria. World Journal of Food Science and Technology, 2(1), 19. Ciani, M., Comitini, F., & Mannazzu, I. (2018). Fermentation. Encyclopedia of Ecology, June, 310–321. Ghosh, B., Bhattacharya, D., & Mukhopadhyay, M. (2018). Use of Fermentation Technology for Value-Added Industrial Research. Principles and Applications of Fermentation Technology, August, 141–161. Hind, H. L., & Day, F. E. (1930). Fermentation Industries. In Journal of the Institute of Brewing (Vol. 36, Issue 6, pp. 1–29). Landine, R., De Garie, C., & Cocci, A. (1997). Fermentation process. Biotechnology Advances, 15(3–4), 702. 97)87650-1 Martínez-Espinosa, R. M. (2020). Introductory Chapter: A Brief Overview on Fermentation and Challenges for the Next Future. New Advances on Fermentation Processes. Microbiology, F. (2016). Basic Principles of Food Fermentation. Food Microbiology: Principles into Practice, 228–252. Principles and Applications of Fermentation Technology. (2018). In Principles and Applications of Fermentation Technology. Principles of Fermentation Technology Second Edition. (n.d.). Sharma, R., Garg, P., Kumar, P., Bhatia, S. K., & Kulshrestha, S. (2020). Microbial fermentation and its role in quality improvement of fermented foods. Fermentation, 6(4), 1–20. . About Author