FERMENTATION TECHNOLOGY

Abstract

In the bioprocessing sector, fermentation technology has established itself as a pillar, enabling the manufacture in a multifariousness of important goods, including biofuels, drugs, food components, and biopolymers. This abstract offers a succinct summary regarding dominant ideas and most recent developments in fermentation technology, highlighting the technique's significant contribution to environmentally friendly production methods.

Fermentation is a metabolic process employed by microorganisms to convert substrates into desired products, utilizing the inherent enzymatic capabilities of the organisms. This ancient technique has undergone significant transformation in recent years, owing to the integration of modern biotechnology, genetic engineering, and process optimization. This synergy has resulted in more efficient, environmentally friendly, and economically viable fermentation processes.

This abstract highlights several pivotal advancements in fermentation technology:

Strain Improvement: New infectious tensities with improved metabolic pathways and product yields have been created thanks to genetic engineering and synthetic biology. These GMOs are currently significant participants in poll of bioprocesses.

Bioreactor Design: Innovative bioreactor designs and control strategies has been leading to improved fermentation efficiency, reduced energy consumption, and enhanced scalability. Miniaturized and automated systems have also facilitated high-throughput

Authors

Janavi R
Department of Biotechnology
Sapthagiri College of Engineering
Bangalore, Karnataka, India.

Darshan P
Department of Biotechnology
Sapthagiri College of Engineering
Bangalore, Karnataka, India.

Soumya C
Department of Biotechnology
Sapthagiri College of Engineering
Bangalore, Karnataka, India.

screening and process optimization.

Nutrient Optimization: Tailored nutrient management, including carbon and nitrogen sources, vitamins, and trace elements, has resulted in improved cell growth and product formation, reducing resource utilization and waste generation.

Process Monitoring and Control: Advances in sensors, analytics, and data science have enabled real- time monitoring of fermentation parameters, leading to better process control, reduced batch-to-batch variability, and enhanced product quality.

Downstream Processing: Integrated approaches that combine fermentation with downstream processing steps have streamlined product recovery, purification, and formulation, reducing the overall production cost.

Sustainability: The use of fermentation technology in environmentally friendly bioprocessing is growing in popularity. It provides environmentally favorable substitutes for conventional chemical synthesis and has the potential to lower waste production and greenhouse gas emissions.
In conclusion, fermentation technology is still developing as attempts are made to improve the economic, environmental, and industrial viability of bioprocessing. These developments have the potential to satisfy the rising demand for renewable and ecologically friendly goods, resulting in a more sustainable future for many different businesses.

Keywords: Fermentation technology, Bioprocessing, Genetic Engineering, Bioreactor, Sustainability, Downstream Processing, Metabolic Pathways, Microbial strains.

I. INTRODUCTION

Network of molecules are fragmented into simpler ones during the metabolic process of fermentation, which is frequently aided by venturing of microorganisms like bacteria, yeast, or fungus. Pharmaceuticals, biofuels, and invent of foods and beverages are just hardly any of the businesses that can employ this method. The fermentation process' final products, which might include organic acids, alcohols, enzymes, and other useful substances, can differ relying on the particular microorganisms utilized. The scale of fermentation can vary from small laboratory experiments to large-scale industrial production. [1] The purposes of adopting fermentation-based proceedings possess to swap over time as a result of societal and cultural concerns as well as advancements in engineering and technology. As a result, fermentation has been widely employed in all civilizations around the world to manufacture drinks or regional meals in which fermented sauces, vegetable meat, or fish expand the culinary options or to improve food storage for short intervals. This process, also known as "indigenous fermentation" or "classical fermentation," is used to make foods and drinks utilizing natural bacteria in accordance with long-established protocols based on cultural norms. Many products have been standardized and commercialized through indigenous fermentation (wines, natural yeast), while many more are produced and sold in small quantities for specialized marking or other purposes. [2] Fermentation is an incredible process that brings about a multitude of benefits in the food industry. The microbial or enzymatic actions during fermentation lead to biochemical changes that enhance the nutritional value of food. This includes the production of vitamins, essential amino acids, and proteins, as well as the reduction of anti-nutrients[3]. The duplet main components that affect fermented food are the make-up of the substrates utilized and the fermenting microorganisms. Food fermentation is also influenced by how the food is handled and how long the fermentation lasts during preparation. Lactobacillus are the most prevalent microbiota in all documented foods and drinks that have been undergone fermentation, and it has been thought that Lactobacillus. is primarily culpable for the positive benefits of beverages and foods which have undergone fermentation. The fermenting microorganisms mainly involve Lactobacillus like Enterococcus, Streptococcus, Leuconostoc, Lactobacillus, and Pediococcus [3] and bacteria as well as molds viz. Debaryomyces, Kluyveromyces, Saccharomyces, Geotrichium, Mucor, Penicillium, and Rhizopus species. [3]

II. TYPES OF FERMENTATION

1. **Lactic Acid Fermentation:** It defined as the process by which bacilli and *Saccharomyces cerevisiae* strains turn starches or sugars into lactic acids without the need of heat. Pyruvic acid requires nicotine amide adenine dinucleotide + hydrogen (NADH) to create lactic acid and NAD+ in these anaerobic chemical processes. The process yields sourdough bread, yogurt, and pickles. [4]

2. **Ethanol / Alcohol Fermentation:** To create wine and beer, yeasts further break down pyruvate molecules into alcohol and carbon dioxide molecules. Pyruvate molecules, which are the byproduct or output of the metabolism of glucose ($C6H12O6$), are produced during glycolysis. [4]

3. **Acetic Acid Fermentation**: Sugars and carbohydrates from grains and fruits ferment to create sour vinegar and sauces. [4] Industrial fermentations which are done based on

Industrial fermentation techniques are categorized.

- Based on the category of substrate
- Based on the feeding of substrate
- Based on the requirement for aeration

Related to the category of substrate, there are two variety types of fermentation processes..They are

- Solid State fermentation
- Submerged fermentation
- Solid State fermentation {SSF}

Solid State Fermentation (SSF) is an imperative fermentation process used to make a variety of food and bio-products, such as baker's yeast, antibiotics, organic acids, biomass, proteins, amino acids, dairy products, moisturizers, tobacco, oils, and pro-biotic cultures. SSF is a kind of fermentation in which the micro- organisms are normally cultivated on modified solids. The solid matrix can be prepared by blending a range of natural substrates, such as rice husk, straw, or sugarcane bagasse, which are left to settle down on the surface. This matrix will provide an adequate aeration and a well-distributed source of nutrients for the micro- organisms. The culture of microbes on the solid matrix helps to minimize cell death due to mechanical shear, which otherwise occurs if grown in a liquid medium. SSF can be implemented in a broad range of industries, ranging from the biotechnological and pharmaceutical industries to the food sector and beverage industries. By using SSF, mass production of bioactive materials can be accomplished without the use of expensive equipment. SSF is found to be affiliated with robust growth, low energy input, and also improved product quality. Consequently, SSF can be used to contribute a wide variety of different products on a large scale, making it a cost-efficient and sustainable form of fermentation [5].

4. **Submerged Fermentation:** Submerged fermentation is a kind of fermentation process in which the cells of the microorganism are suspended in a moisture media, which makes this type of fermentation an important form of industrial biotechnology. This process has several superiority for other forms of fermentation, such as open-state and solid-state fermentation. The advantages include increased cell growth rate, increased yields, improved product quality, and facileness of scale-up. Submerged fermentation is suitable for purposes such as the execution of pharmaceuticals, enzymes, organic acids, alcohols, and vitamins. [5]

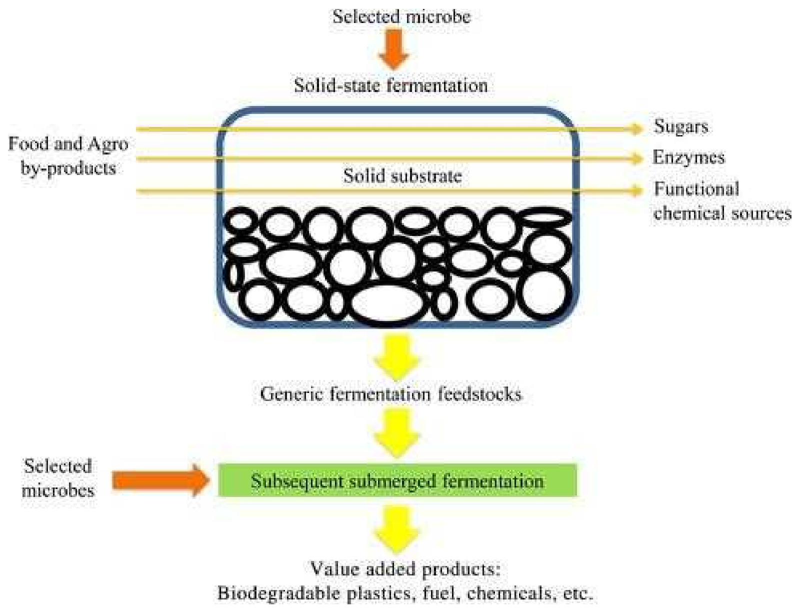

Figure 1: Solid State Fermentation [Source: https://shorturl.at/jrzFU]

In order to get the best possible cell development and product synthesis, the temperature and pH of the medium must be carefully regulated. The chief microbe used for submerged fermentation include yeasts, filamentous fungi, and bacteria. The submerged fermentation process offers high yields and unparalleled accuracy in the generation of different products. Due to these advantages, submerged fermentation is a vital industrial procedure that is used in numerous industries [5].

Amylases and proteases, which are typically made by the SmF process, use the aerobic fermentationpathway. The biggest drawback of SSF is that SmF operations do not suffer from the restrictions of heat masstransfer and are simple to automate. According to Babbar and Oberoi (2014) cite, the low productivity, high manufacturing costs, and medium complexity as the key drawbacks of SmF approaches.. Each submerged fermentation process type has benefits and drawbacks, and its application depends on the product's intended usage in addition to the type of microbe being utilized. [5]

As an example, continuous reactors have the potential to be more productive than batch reactors and toreduce the viscosity for fungus cultivation; but, because of the lengthy fermentation period, the risk of contamination is increased. [5]

Owing to its capacity to regulate the fermentation parameters using predetermined substrates, submerged fermentation is more frequently utilized in industrial fermentation than solid-state fermentation for producing the enzymes. However, complex substrates like agricultural, forestry, and food industry residues and wastes make submerged fermentation impractical. The microbes in the bioreactors must first process thesecomplex substrates before using them .[5]

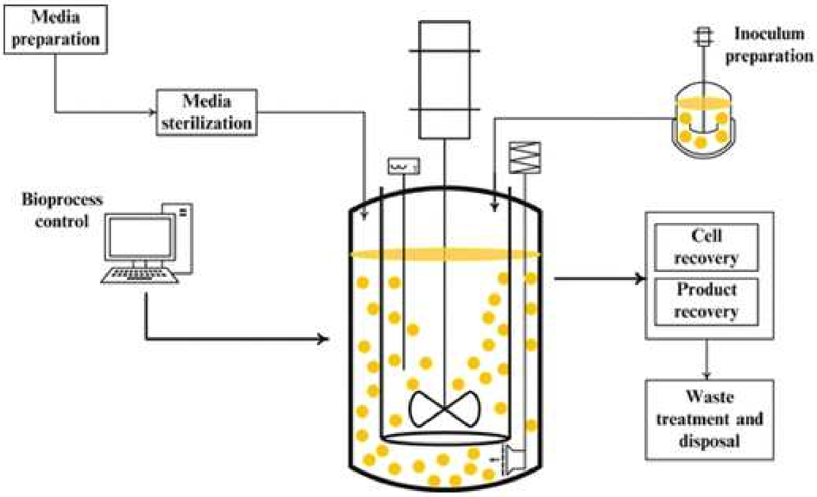

Figure 2: Submerged Fermentation [Source: https://shorturl.at/fnLV2]

With reference to the underlayer being fed into the fermenter. It is necessary to feed substrate into the fermenter for two different kinds of fermentation processes. They are

- Batch fermentation
- Continuous fermentation
- Fed-batch fermentation
- Batch fermentation

Batch fermentation is a type of fermentation method that can be employed in many different contexts to produce a wide range of goods. A fixed amount of substrate is combined with a fixed amount of microorganisms, media, and other components in this process to get the desired final result. Batch fermentation takes place in a closed system, typically in the shape of a tank or other vessel, and requires meticulous management of the environment inside the tank. This entails regulating variables including pH, oxygen concentrations, stirring rate, and temperature. The resultant broth is loaded onto any downstream processing machinery when fermentation is finished, and the old broth is swapped out for fresh feed before the next roundof fermentation. This method is repeated periodically in the same tank until the desired target product is achieved. Batch fermentation is commonly used and is one amongst the popular type of fermentation processes as it is cost-effective and efficient. [6]

It is highly dynamic yet closed system where all the medium components are added to the reactor at the beginning of cultivation with the exception of gases like oxygen, acids or bases for pH regulation, and anti-foaming agents. There is neither an addition nor a removal of nutrients during the process. The system continues to be in a dynamic, unstable condition as the nutrient concentrations change throughout time. Due to its considerable downtime (nonproduction time spent for cleaning, sterilization, and startup of another batch cultivation during two batch cultivations), batch cultivation has a key drawback in that it has low productivity. [6]

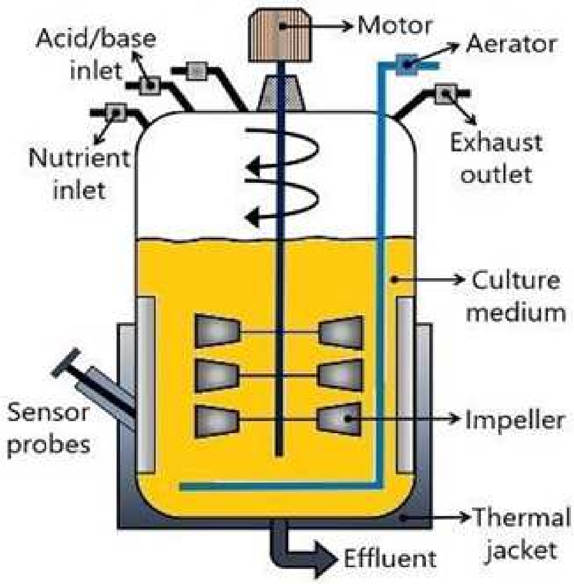

Figure 3: Batch Fermentation [Source: https://shorturl.at/lmFO4]

5. **Continuous Fermentation:** Continuous fermentation is another efficient method of industrial production of various chemical and biochemical products. It is a method in which a continuously supplied feedstock is used to produce products through a steady and uninterrupted process. During this process, the same starter culture is used throughout the production, creating a continuous, homogeneous fermentation environment. This leads to more robust production and stability of fermentation. The utilization of continuous processes generates greater overall yields than batch fermentation, with shorter processing times and increased energy efficiency. Continuous fermentation is also beneficial to the control and maintenance of quality standards of the products. By using closed systems in continuous fermentation, the transfer of contamination is decreased, resulting in products with superior quality. The costs associated with mechanical filter systems and evaporation are lower because of the closed nature of the system, making continuous fermentation an attractive process from an economical perspective. [7]

   Continuous fermentation is indeed an open operation system that involves a continuous flow of both input (microorganisms and sterile nutrient solution) and output (product and byproducts) from the bioreactor. [7] A continuous flow of culture media passes through the reactor during continuous fermentation, which is a microbial process. The key distinction from an animal cell perfusion technique is that no mechanism prohibits the biomass from continuing to ferment continuously inside the culture vessel. In industrial applications, the volume of a continuous fermentation is typically constant, but it might vary in particular procedures, including waste water treatment. The chemostat, where one nutrient is growth limiting and utilized to determine growth rate, is connected to the idea of continuous fermentation processes. There are, however, an aggregate of additional, less usual methods for controlling a continuous fermentation, including maintaining a constant pH (pH-auxostat), a constant optical density (turbidostat), and a constant substrate (nutristat). [7] The goal is to maintain a balanced and controlled environment for microbial growth and product formation [7].

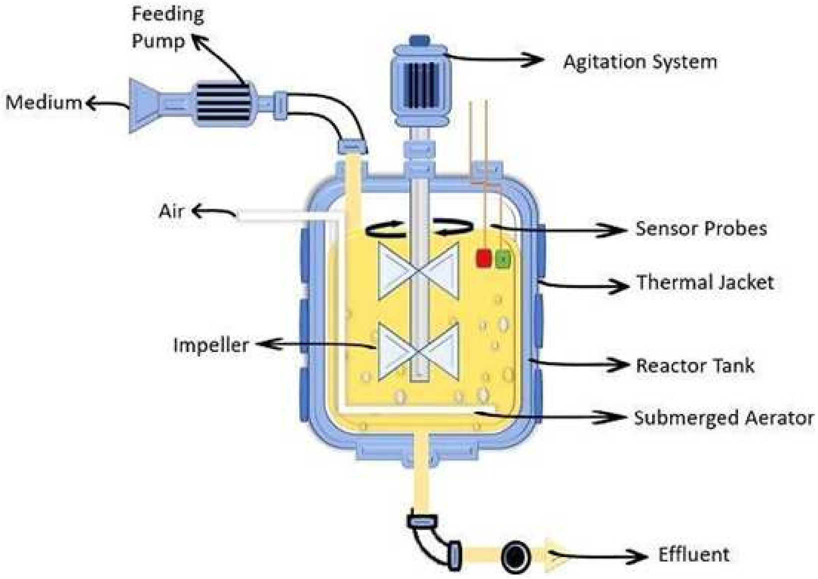

Figure 4: Continuous Fermentation [Source: https://shorturl.at/yEGW1]

6. **Fed-Batch Fermentation:** Fed-batch fermentation is a kind of fermentation process commonly used in industrial-scale production. Unlike batch fermentation, where all the nutrients are added at the commencement of the process, fed-batch fermentation involves the gradual addition of nutrients during the fermentation process. [8]

   In fed-batch fermentation, the initial culture is started with a limited amount of nutrients to precise over the growth rate of the microorganism. As the fermentation progresses, additional nutrients, such as sugars, amino acids, or other growth-promoting substances To ensure ideal circumstances for microbial growth and product creation, ingredients are continuously supplied to the culture. [8]

   This feeding strategy helps to maximize product yield and improve process efficiency. By controlling the nutrient supply, the growth of the microorganism can be regulated, preventing excessive growth and promoting the production of desired metabolites. [8]

   Analyzing the organism's growth phase is crucial for providing controlled feeding. The synthesis of organic acids like acetate, succinate, fumarate, etc. leads to an elevation in pH, which is also affected by cell saturation and lysis. [8] The upper pH set point can be increased or decreased according on the anticipated growth by altering the feeding rate. Similar to this, the turbidity of the culture is used to analyze cell development. To achieve a steady log phase, nutrients are increasing the culture to dilute it. This procedure ultimately yields nearly 150-fold greater accumulation of biomass than batch fermentation, is used to develop high cell density cultures. Certain organisms may not be able to grow in the presence of organic solvents as carbon source.[9]

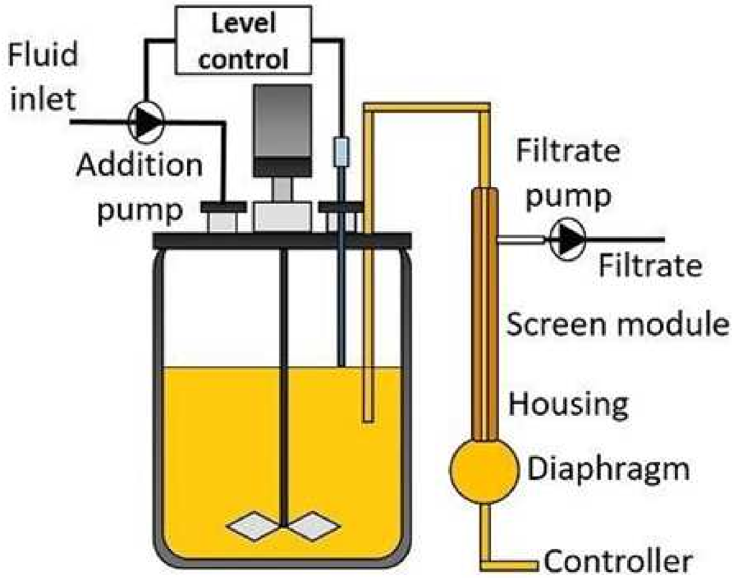

Figure 5: Fed-Batch Fermentation [Source: https://shorturl.at/prwHZ]

Based on requirement for Aeration there are Two Types of Fermentation Processes.They are

7. **Aerobic Fermentation:** The majority of large-scale fermentation activities take place in an aerobic environment. Aerobic fermentation involves either forcing sterile air into the fermenter or using an impeller to stir the components in the fermenter. In this process, it is necessary to maintain the dissolved oxygen concentration above the specified minimal level [10].Oxygen limitation can indeed be a significant problem in aerobic fermentations, where microorganisms require oxygen to support their metabolic activities and growth [10].

8. **Anaerobic Fermentation:** The provision for aeration and mixing devices is not needed in anaerobic fermentation. But in a few cases, aeration and mixing may be needed in an initial period. Once fermentation starts, the gas created throughout the process creates enough mixing. The air accounted for the headspace should be restored by CO_2 or N_2 or a suitable combination. During this variety of fermentation, the released CO_2 and H_2 are collected and reused. [11]

III. IMPORTANCE OF FERMENTATION IN HUMAN CIVILIZATION

Fermentation has played a pivotal part in the development and progression of human civilization for thousands of years. Its importance can be seen in various aspects of our history, culture, and daily life. Before the advent of refrigeration, fermentation was a part of the primary methods used to preserve food. By creating an acidic or alcoholic environment through the measures of microorganisms, fermentation prevents the extension of harmful bacteria and extends the longevity of perishable foods. [12] The allowed civilizations to cumulate guzzle food for slender times, reducing waste and ensuring a more stable food supply. The earliest and most critical uses of fermentation was the conservation of food.

Before the advent of modern refrigeration and canning methods, fermentation was a primary means of preventing food spoilage. [13]

Communities store and consume food over extended periods, reducing waste and ensuring a stable food supply. Fermented foods are deeply intertwined with cultural cuisines around the world. Every culture has developed distinctive fermented foods and drinks that have been handed down through the years. [14] Fermentation is also responsible for many of the world's most beloved and culturally significant foods and beverages. Examples include loaf, cheddar, curd, beverage, cocktail, kimchi, sauerkraut, and soy sauce. These fermented foods reflect the culinary customs and identities of various geographic and cultural regions in addition to offering distinctive flavors and textures. In modern times, fermentation has gained importance in biofuel production. [15]

In several nations, gasoline is combined with ethanol, a biofuel are manufactured by the ebullition of carbohydrates, which is utilized as an alternative fuel source. Brewing, winemaking, and biotechnology are examples of sectors based on fermentation that have had a large economic influence throughout history and continue to do so now. The world economy benefits significantly from the fermentation sector. It involves the creation of dairy products, fermented vegetables, and alcoholic drinks, among other things. Industrial chemicals and biofuels are also produced via fermentation techniques. Fermentation is linked to customs and rituals in many different civilizations. For instance, celebrations of bread-baking, wine-making, and the sharing of foods which have undergone fermentation has also contributed significantly to communal cohesiveness. [16]

1. How Does Fermentation Happen?

According to definitions, fermentation is a chemical process whereby bacteria break down organic molecules (e.g. bacteria and yeast). This acts as an energy-yielding metabolic process by which sugar or dextrose particles are broken down to carbon dioxide, (CO2) and alcohol/ethanol (C2H5OH) in the absence of air, anaerobic respiration Fermentation involves the action of desirable micro-organisms or their enzymes on food ingredients to make biochemical changes. [17]

Due to anaerobic action, the fermentation does not require oxygen. The presence of oxygen will cause some species to completely oxidize to carbon dioxide and water instead of producing ethanol. Another element that needs to be taken into account is the temperature. There is a specific temperature limit for fermentation to continue in a normal way. [17]

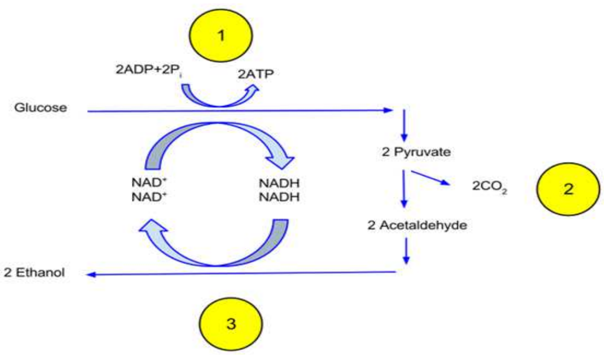

Figure 6: Representation of Fermentation Process [Source:https://shorturl.at/lzNO3]

IV. BIOTECHNOLOGICAL USES FOR FERMENTATION

Due to biotechnological processes, we can now enjoy fluffy bread and delicious yogurt. Kefir, a dairy product created by fermenting milk with specific types of microorganisms, is a prime example of the food- related uses of fermentation. Vegetables, such as the cabbage used in sauerkraut and kimchi, are also frequently fermented to create new and exciting flavors. [18]

Cheese-making, a favorite of many people, also involves fermentation which is one amongst the main steps. There are three basic reasons why fermentation is so crucial to the food-production process: transformative aspects, health benefits, and flavor. The transformative aspects of fermentation involve turning ingredients, such as flour, into products to which people are similar with, like loaf. In absence the use of yeast, baking bread would result in a heavy, dense texture rather than the fluffy one we are habituated to have. [18]

The carbon dioxide produced during the fermentation process is crucial in giving bread its desired flavor and texture. Fermentation also produces acidophilus, which are bacteria thought to be helpful for enhancing health, in addition to flavor and texture. Acidophilus can interfere with the growth of pathogens, therefore providing us with a healthier gut. Furthermore, fermentation can produce great-tasting foods like yogurt and cheese, creating complex flavors. Besides its various food-based applications, also been used as a ferment in other fields of biotechnology. Scientists use fermentation to generate antibiotics and antiviral drugs, such as penicillin, which have saved countless lives. [18]

Yogurt is one of the most widely consumed fermented dairy products. The fermentation of milk sugars (lactose) into lactic acid by lactic acid bacteria, such as Lactobacillus bulgaricus and Streptococcus thermophilus, thickens milk and gives yogurt its sour flavor and creamy texture. [19] Acidophilus dairy products, like acidophilus yogurt and kefir, are made by adding specific beneficial bacteria strains (acidophilus) to milk. These bacteria have health benefits when consumed, such as promoting gut health. [20]

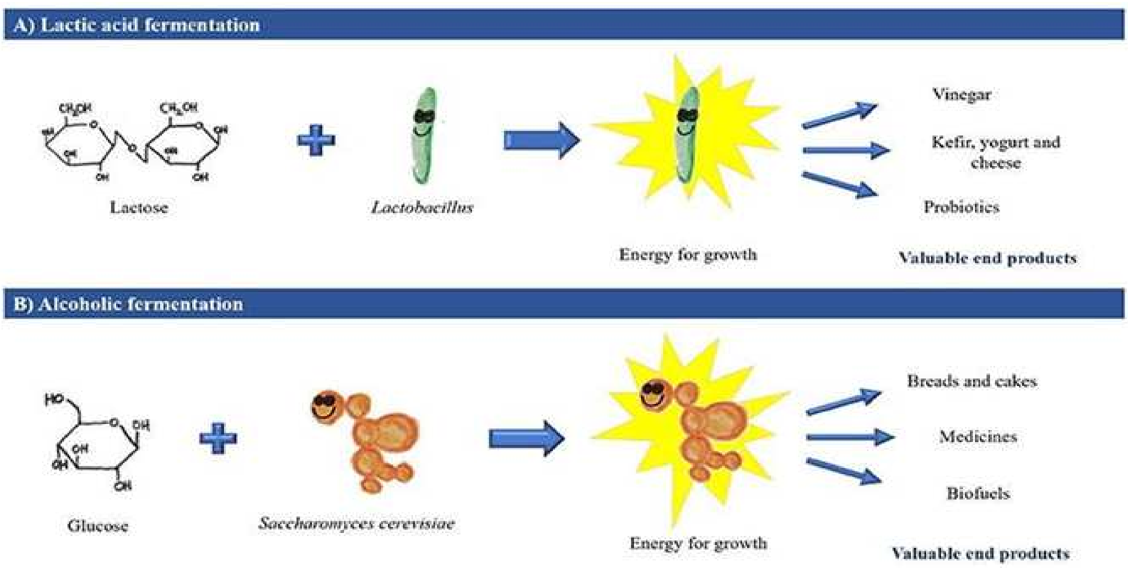

Figure 7: Biotechnological use of Fermentation [Source: https://shorturl.at/gprFO]

V. CONCLUSION

Recent advancements in genetic engineering have led to the enlargement of high-performing strains specifically designed for the production of biofuels, such as cellulosic ethanol, and commodity chemicals. These developments have the aptitude to revolutionize the industry and drive further innovation in the activity area of industrial microbiology and biotechnology. Fermentation strategies have been universally used for the fabrication of beneficial substances in various industries.

Microorganisms, such as yeast and bacteria, play a crucial role in fermentation, which is a synthetic procedure that cease to function organic materials. Without oxygen, fermentation can only take place within a cocksure span of temperatures. It acts as a key factor in the advancement of humanity and may be considered as some of the earliest applications of biotechnology.

Fermentation is still crucial to many industries that sustain human society, including the production of food on a larger scale to meet the increasing demand. In food industry, fermentation is accustomed to create products like kefir, bread, yogurt, cheese, and other foods with complex flavors. Additionally, fermentation produces the helpful microorganisms known as acidophilus, which enhance intestinal health.

In addition to its food-based applications, fermentation has accustomed in other fields of biotechnology, such as the process of making antibiotics and antiviral drugs like penicillin. These advancements in fermentation technology have had a significant collision on the global food system and various industries.

REFERENCES

[1] Authors: HariomYadav, Shalini Jain, Reza Rastmanesh, AlojzBomba
[2] Year: January 2012
[3] Title: Fermentation Technology in the Development of Functional Foods for Human Health
[4] Author: Rosa María Martínez-Espinosa
[5] Year: January 2019
[6] Title: New Advances of Fermentation Processes
[7] Authors: . Marco M.L., Heeney D., Binda S., Cifelli C.J., Cotter P.D., Foligné B., Gänzle M., Kort R., Pasin G., Pihlanto A.,
[8] Year: 2017
[9] Title:Health benefits of fermented foods: Microbiota and beyond. Curr.Opin.Biotechnol. ;44:94–102. doi: 10.1016/j.copbio.2016.11.010.
[10] Authors:Constance ChinyereEzemba and Arinze Steven Ezemba
[11] Year: February 2022
[12] Title: Fermentation, Types of fermenter, Design and use of fermenter and optimization of fermentation process
[13] Authors: SubramaniyamRavichandran and Vimala R
[14] Year: March 2012
[15] Title: Solid state and submerged fermentation for the production of bioactive substances: a comparative study
[16] Authors: A.K. Srivastava and S. Gupta
[17] Year:2011
[18] Title: Engineering Fundamentals of Biotechnology

[19] Authors: Eva K. Lindskog Year:2018
[20] Title: The Upstream Process: Principal Modes of Operation
[21] Authors: : A.K. Srivastava and S. Gupta
[22] Year:2011
[23] Title: Engineering Fundamentals of Biotechnology
[24] Authors: Manya Behl and Arvind Kumar Bhatt
[25] Year:2023
[26] Title: Fundamentals of fermentation technology
[27] Authors: Wei-Cho Huang, I-Ching Tang Year:2007
[28] Title: Bacterial and Yeast Cultures – Process Characteristics, Products, and Applications
[29] Authors: Wei-Cho Huang, I-Ching Tang Year:2007
[30] Title: Bacterial and Yeast Cultures – Process Characteristics, Products, and Applications
[31] Authors: E Caplice and G F Fitzgerald
[32] Year: September 1999
[33] Title: Food fermentations: role of microorganisms in food production and preservation
[34] Authors: Norman Wilfred Desrosierand R.Paul Singh
[35] Year: August 2023
[36] Title: Food Preservations
[37] Authors: Aabid Manzoor Shah , Najeebul Tarfeen , Hassan Mohamed and Yuanda Song
[38] Year: January 2023
[39] Title: Fermented Foods: Their Health-Promoting Components and Potential Effects on Gut Microbiota
[40] Authors: Ruth MacDonald and Cheryll Reitmeier
[41] Year: 2017
[42] Title: Food Processing
[43] Authors: J Microbiol
[44] Year:2022
[45] Title: Current Ethanol Production Requirements for the Yeast Saccharomyces cerevisiae
[46] Authors: Marco, M. L., Heeney, D., Binda, S., Cifelli, C. J., Cotter, P. D and Foligné, B
[47] Year:2017
[48] Title: Health benefits of fermented foods: microbiota and beyond
[49] Authors: Eirini Dimidi, Selina Rose Cox, Megan Rossi, and Kevin Whelan
[50] Year: August 2019
[51] Title: Fermented Foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease
[52] Authors: Seiji Nagaoka
[53] Year: 2019
[54] Title: Yogurt Production
[55] Authors: J.M. Kongo, F.X. Malcata
[56] Year: 2016
[57] Title: Acidophilus Milk

