

# The Beneficial Roles of Microbes in Food Production and Preservation: A Review

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## ABSTRACT

Microorganisms play a fundamental role in food production, contributing to the transformation of raw ingredients into a variety of nutritious and flavorful foods through processes such as fermentation and enzyme production. Beneficial microbes, including bacteria, yeasts, and molds, are responsible for the creation of staple food products like: yogurt, cheese, bread, wine and soy-based foods. *Lactobacillus* and *Bifidobacterium* species, for example, are widely used in dairy fermentation, enhancing not only taste and texture but also nutritional value by producing probiotics that promote gut health. In addition to their role in fermentation, microbes produce essential enzymes such as: amylases, proteases, and lipases, which aid in food processing by breaking down starches, proteins, and fats, respectively. These enzymes enhance food texture, improve digestibility and extend shelf life, making microbial involvement indispensable in modern food production. Beyond food production, microbes are equally significant in food preservation, helping to prevent spoilage and extend shelf life while maintaining food safety. Traditional preservation methods, such as: lactic acid fermentation in sauerkraut, kimchi, and pickles, rely on beneficial bacteria to create acidic environments that inhibit the growth of harmful pathogens. Similarly, acetic acid bacteria like *Acetobacter* species are responsible for vinegar production, which acts as a natural preservative in many foods. Some microbes also produce antimicrobial compounds, such as bacteriocins and organic acids that prevent the growth of spoilage organisms and foodborne pathogens. As food safety and sustainability become global priorities, harnessing microbial processes in food preservation for reducing food waste, enhancing shelf stability and food supply.

**Keywords:** Microbes, food production, food preservation, *Lactobacillus* species, *Bifidobacterium* species

## 1.0 INTRODUCTION

Food production and preservation are fundamental aspects of ensuring global food security especially as the world faces increasing challenges such as population growth, climate change and food shortage (Shehu *et al.*, 2020; Wang, 2021a). Climate change do contribute As microscopic organisms that are found throughout nature, microbes are essential to these processes because they provide effective and sustainable natural remedies (Thirumalaivasan *et al.*, 2024). From ancient times, humans have harnessed the power of microbes to produce and preserve food even before understanding their existence (Prajapati *et al.*, 2023). Today, we know that various species of bacteria, yeast and fungi contribute significantly to enhancing food quality, extending shelf life and ensuring safety (Zapašnik *et al.*, 2022). Microbes play an indispensable role in food production and preservation, transforming raw ingredients into a wide variety of consumables while

also enhancing shelf life and safety (Mahunu *et al.*, 2024). In food production, beneficial microorganisms such as bacteria, yeasts and molds are utilized in fermentation processes to create products like bread, cheese, yogurt, beer, wine, soy sauce and pickles (Chen, 2021). For instance, *Saccharomyces cerevisiae*, a type of yeast, is crucial in baking and alcoholic fermentation, while *Lactobacillus* species are essential in producing fermented dairy products by converting lactose into lactic acid (Xu *et al.*, 2021). This acidification not only imparts unique flavors and textures but also inhibits the growth of spoilage organisms. In food preservation, microbes are used to extend shelf life and maintain nutritional value (Ogwu and Ogunsola, 2024). Fermented foods inherently resist spoilage due to the production of organic acids, alcohol, and bacteriocins, which create hostile environments for harmful bacteria (Cheruvuri and Kammara, 2024).

Additionally, modern microbial technologies involve the use of probiotics to promote gut health and the application of microbial enzymes in food processing (Mazhar *et al.*, 2022). However, not all microbes are beneficial, as certain pathogens like *Salmonella* or *Listeria* can contaminate food, necessitating stringent food safety measures (Mkangara, 2023). Overall, the application of microbes in food systems exemplifies their dual role in innovation and preservation, ensuring food sustainability and security (Toor *et al.*, 2024). By delving into microbial mechanisms such as fermentation, bio-preservation, and enzyme production, this overview aims to highlight the benefits, challenges, and future prospects of microbes in food systems, focusing on their application in food production and preservation. Understanding the potential of microbes not only helps address modern food industry challenges but also opens avenues for innovation and sustainable practices, ensuring healthier, safer, and more accessible food for all (Chávez-Dulanto *et al.*, 2021). This review was aimed to outline the beneficial roles of microbes in food production and preservation.

## 2.0 THE BENEFICIAL ROLES OF MICROBES IN FOOD PRODUCTION AND PRESERVATION

### 2.1 Microbes in Food Production

Microbes have long been the backbone of food production, contributing significantly to the creation of diverse and nutritionally enhanced food products through processes like fermentation (Augustin *et al.*, 2024). Fermentation, driven by microbes such as: *Lactobacillus*, *Saccharomyces*, and *Aspergillus*, transforms raw ingredients into consumable products by breaking down sugars into alcohol, organic acids or gases (Anumudu *et al.*, 2024). This process not only preserves food but also enhances its flavor, texture and nutritional profile, giving rise to staples like yogurt, cheese, beer, wine, kimchi and tempeh (Ray *et al.*, 2024). Beyond fermentation, microbes are employed in industrial food processes through their ability to produce enzymes like amylases and proteases, which are essential in baking, brewing, and dairy production (Sattar *et al.*, 2024). Additionally, the rise of probiotics highlights the importance of beneficial microbes such as *Bifidobacterium* and *Lactobacillus* in promoting gut health and immunity through functional foods (Obayomi *et al.*, 2024). The diverse roles of microbes in food production underscore their importance not just in traditional practices but also in advancing modern food science, creating safer, healthier, and more sustainable food systems (Michel *et al.*, 2024).

### 2.2 Fermentation: A Cornerstone of Microbial Applications

Fermentation is a metabolic process carried out by microbes that convert organic substances, particularly carbohydrates, into simpler compounds like alcohol, organic acids, and gases (Nanda *et al.*, 2024). This biochemical transformation occurs under anaerobic or low-oxygen conditions and is one of the oldest methods of food production and preservation known to humanity (Ameen *et al.*, 2024). The historical significance of fermentation cannot be overstated, as it played a crucial role in the development of civilizations by enabling the storage of surplus food, improving its nutritional value, and enhancing its flavor. Long before the scientific understanding of microbial activity, ancient cultures across the globe independently discovered and perfected fermentation techniques, creating foods like bread, beer, wine, yogurt, and soy-based products (Sarkar *et al.*, 2023). These methods were not only practical for preservation but also became deeply embedded in cultural and culinary traditions (Galimberti *et al.*, 2021).

For instance, ancient Egyptians relied on fermentation for brewing beer and leavening bread, while Asian cultures developed fermented soy products like soy sauce and miso (Tamang *et al.*, 2020). In the absence of refrigeration, fermentation provided a natural and effective way to extend the shelf life of perishable foods, ensuring food availability during periods of scarcity (Lys, 2024). Today, the historical roots of fermentation continue to inspire modern food technologies, combining traditional practices with advanced microbial science to meet contemporary demands for sustainability, health benefits, and flavor diversity (Mujahid *et al.*, 2024). The science of fermentation is called zymology (Boantz, 2022).

#### 2.2.1 Types of Fermented Foods and Beverages

##### 2.2.1.1 Dairy Products

###### i. Cheese

Cheese is made by separating the curds from the whey of fermented milk. The fermentation process uses microorganisms like bacteria and yeast to break down the sugars and starches in the milk, which produces lactic acid, alcohol, and other compounds. These compounds give cheese its distinctive flavors, aromas, and textures (Trujillo Escorza, 2024). According to Zheng *et al.* (2021) Semi-skimmed milk, cream, or buttermilk from ruminants like cows and goats, or a combination of these products, gets coagulated to create cheese, which is then separated from the whey.

###### ii. Yoghurt and Fermented Milk Foods

According to Hadjimbei *et al.* (2022), Milk and yogurt are fermented using probiotic bacteria usually, *Lactobacillus bulgaricus* and *Streptococcus*

*thermophiles* which thickens the product thus, extending its shelf-life. And also, it is vital to know that fermented milk is highly nutritious and is a great source of minerals and vitamins.

### 2.2.1.2 Baked and Baking Products

#### i. Bread

Bread has long been a staple diet consumed on a regular basis by humans. An essential component of a nutritious and healthy diet is baked bread, because it contains a variety of vitamins, antioxidants, and nutrient elements (Aghalari *et al.*, 2022). Fermentation of the dough by *Saccharomyces cerevisiae* is the most important stage in making bread (Parapouli *et al.*, 2020). Bread is produced by mixing baker's yeast, sucrose and hot water. *Saccharomyces cerevisiae* make use of the sucrose as its nutrient. The yeast acquires its energy by breaking down the sugar for their growth. *S. cerevisiae* reproduce and grow asexually by budding leading to the production of CO<sub>2</sub> bubbles in the flour mixture (Microbiology Society, 2022). The CO<sub>2</sub> gas released caused the dough to rise by making bubbles. Ingredients are added into the dough such as potatoes or potato boiled liquid, eggs and sugar, so as to hasten the development of the yeast cells and ease fermentation (Rabiu and Isah, 2023). Fermentation stops and the yeast is killed as the dough is being heated, and the entrapped CO<sub>2</sub> gas expands and softens the bread by giving it the spongy texture and stop it from further expanding (Mudgil and Mudgil, 2024). The yeast fermentation of dough also produces alcohol which evaporates during baking (Timmermans *et al.*, 2022).

### 2.2.1.3 Beverages

#### i. Beer and Wine

Yeast is a single-celled fungus that metabolizes sucrose as food. In the production of beer and wine, the yeast *Saccharomyces cerevisiae* ferments glucose into CO<sub>2</sub> and ethanol. The beer contains Ethanol, and the CO<sub>2</sub> produced make it to emit gas (bubbles)(BBC Bitesize, 2022). It converts sugars from various sources like grape sugars in the case of wines or barley for beers into alcoholic beverages and carbon dioxide. Compared to wild yeast strains, Brewer's yeast is a good source of the essential minerals and B-complex vitamins except vitamin B<sub>12</sub> (Libre, 2021).

Each phase of alcohol production involves fermentation, starting with the use of crude raw materials, malting and its stability during packaging stage (Bokulich and Bamforth, 2013). Although all *Saccharomyces* species produce alcohol as the final product of fermentation, ale and lager yeasts are the strains predominantly employed worldwide in beer production (Boulton and Quain, 2001). The quality of alcohol is contingent upon the yeast's activity during fermentation. In addition to the

creation of alcohol, the fermentation activity of the yeast that produces compounds that enhance the content and organoleptic qualities is directly linked to the quality of beer (Iorizzo *et al.*, 2021). The ingredients or substrate that brewer's yeast ferments to create alcohol are water, malted grains, and hops. The processes of malting, mashing, alcoholic fermentation, and maturation are typically included in beer processing. Brewer's yeast uses its enzymes to convert glucose to pyruvate through the glycolytic pathway. Pyruvate is broken down anaerobically by the yeast to yield CO<sub>2</sub> and ethanol (Iorizzo *et al.*, 2021).

### 2.3 Plant-Based Foods

Fermentation of plant-based foods is a transformative process that not only preserves vegetables and legumes but also enhances their nutritional value, flavor, and digestibility. Sauerkraut, kimchi, and tempeh are excellent examples of this microbial activity (Abbaspour, 2024).

#### 2.3.1 Sauerkraut and Kimchi

Sauerkraut and kimchi are produced through the lactic acid fermentation of cabbage and other vegetables by bacteria such as *Lactobacillus* and *Leuconostoc* (Fijan *et al.*, 2024). These microbes convert natural sugars into lactic acid, creating a tangy flavor and acidic environment that inhibits the growth of harmful pathogens while retaining essential nutrients (Anumudu *et al.*, 2024). In addition to their extended shelf life, these fermented vegetables are rich in probiotics, which promote gut health and boost immunity (Tang *et al.*, 2023).

#### 2.3.2 Tempeh

Tempeh is made from soybeans fermented with the fungus *Rhizopus oligosporus* (Rizal *et al.*, 2020). This process binds the soybeans into a firm, cake-like structure and enhances their protein content, digestibility, and bioavailability of nutrients like iron and calcium (Duguma *et al.*, 2023). The unique flavors and textures of these fermented plant-based foods have made them staples in various culinary traditions worldwide, from the tangy crunch of sauerkraut in European diets to the spicy, umami-rich kimchi of Korean cuisine (Pua *et al.*, 2022).

### 2.4 Biochemical Processing During Fermentation Foods

The fermentation process takes place in an anaerobic condition to produce energy (Buckel, 2021). The first step in all three forms of fermentation is a glycolysis reaction, which turns glucose into pyruvate; it then converts the pyruvate into lactate, acetate, or ethanol and

carbon dioxide, depending on the pathway (Dwivedi, 2023). Fermentation products are dependent on the microorganisms that perform the fermentation (Shiferaw *et al.*, 2020). Yeast produces alcoholic fermentation, lactic acid bacteria (LAB) produce lactic acid fermentation, and either LAB or yeast produces acetic acid fermentation (Zapašnik *et al.*, 2022).

#### 2.4.1 Lactic Acid Fermentation

Lactic acid fermentation is a metabolic process which takes place anaerobically (Spriet, 2022). Glucose or other hexose carbohydrates, including disaccharides



such as sucrose or lactose, are being broken down into pyruvate through glycolysis, pyruvate is then reduced to lactic acid by the activity of the enzyme lactate dehydrogenase coupled with the oxidation of  $\text{NADH} + \text{H}^+$  into  $\text{NAD}^+$  (Salih *et al.*, 2022). Key bacterial genera involved in lactic acid synthesis includes; *Lactobacillus*, *Leuconostoc*, *Pediococcus*, and *Streptococcus thermophiles* (Hu, *et al.*, 2022). Example of lactic acid fermented foods include; yogurt, kimchi, sauerkraut, sourdough bread and cheese. The pathway involved in lactic acid fermentation was outlined in Figure 1 below.

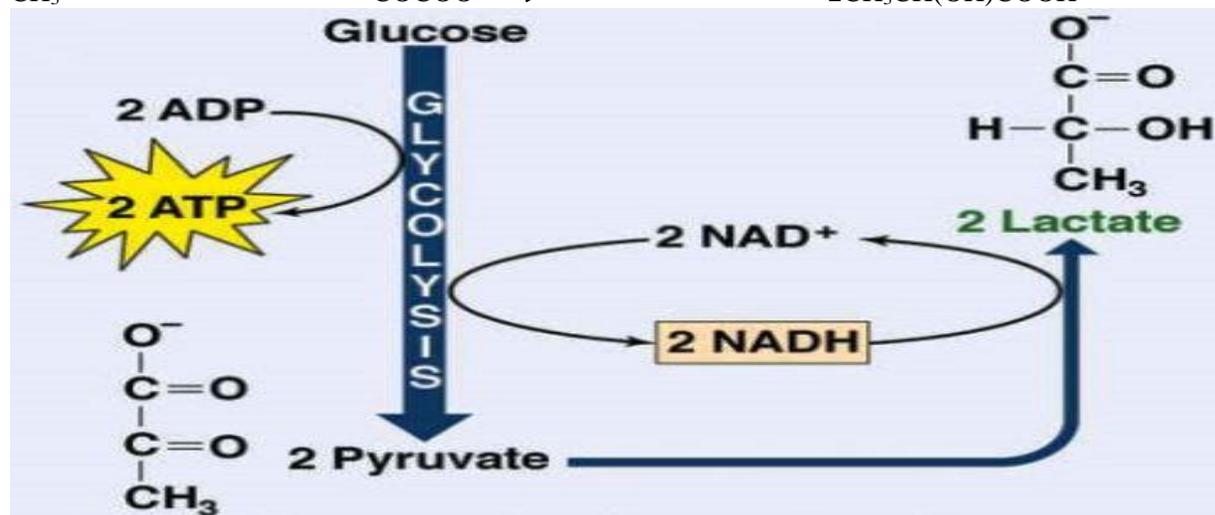


Figure 1: Lactic acid Fermentation (Van Niel, 2021)

#### 2.4.2 Alcohol Fermentation

Alcohol fermentation also called ethanol fermentation is anaerobic, metabolic process achieved mostly by the activity of yeast (*Saccharomyces cerevisiae*) which converts sugar into pyruvate through glycolysis, pyruvate is then broken down yielding acetaldehyde and carbon dioxide by the enzyme pyruvate decarboxylase, acetaldehyde is then subsequently converted by the enzyme alcohol dehydrogenase into ethanol utilizing  $\text{NADH}$  (Yan, 2024). This type of fermentation is used in the production of wine, beer, bread, baking product etc. In the case of bread and baking products, the  $\text{CO}_2$  produced makes the dough to rise by making bubbles and the ethanol produced evaporates in the baking process, leaving less than 2% of the ethanol after baking (Suchintita *et al.*, 2023). The pathway involved in alcohol fermentation was outlined in Figure 2 below.

$\text{CH}_3\text{COCOO}^- + \text{H}^+ \rightarrow \text{CH}_3\text{CHO} + \text{CO}_2$  (Pyruvate  $\rightarrow$  acetaldehyde + carbon dioxide) by Pyruvate decarboxylase.

$\text{CH}_3\text{CHO} + \text{NADH} + \text{H}^+ \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{NAD}^+$  (acetaldehyde +  $\text{NADH} \rightarrow$  ethanol +  $\text{NAD}^+$ ) by Alcohol dehydrogenase.

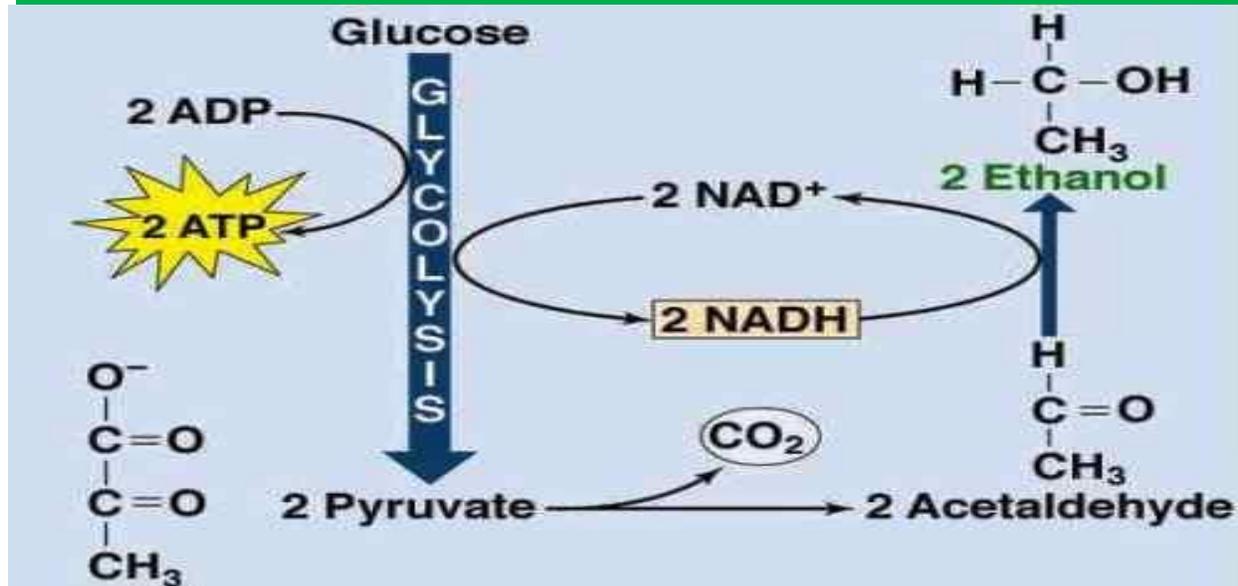
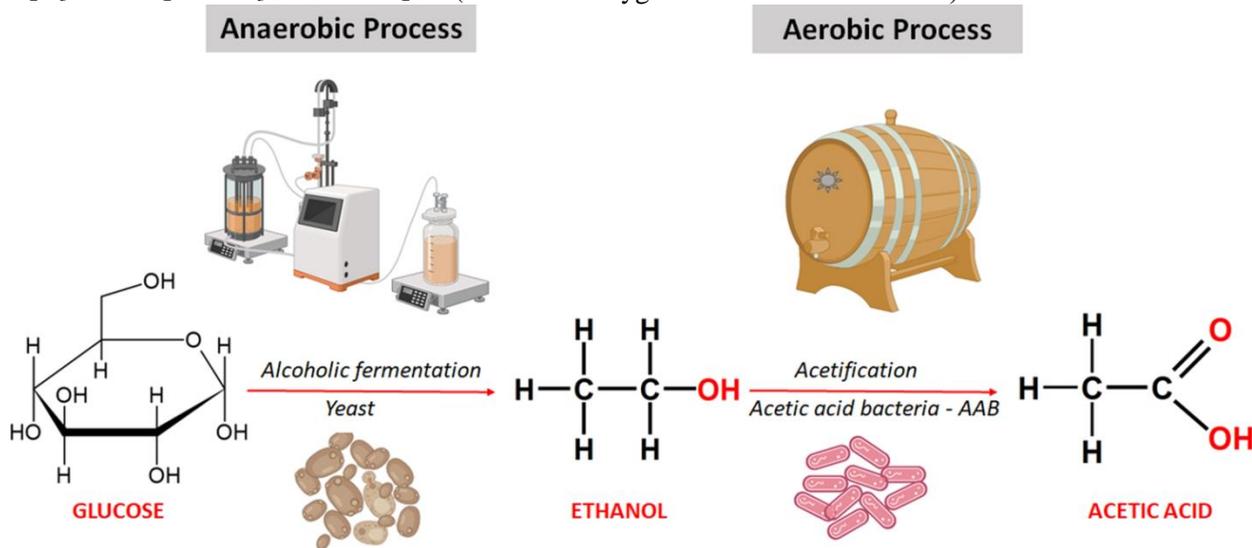


Figure 2: Alcohol Fermentation (Van Niel, 2021)

### 2.4.3 Acetic Acid Fermentation

Acetic acid fermentation is another type of fermentation that takes place in two phases. Firstly, sugars are being fermented into ethanol anaerobically by yeast mainly *Saccharomyces cerevisiae*, the second phase is the oxidation of ethanol aerobically by acetic acid bacteria mainly *Acetobacter* species to yield acetic acid (vinegar) (Maske *et al.*, 2024). Some of the vital species of microorganisms that produce acetic acid (vinegar) because of their ability of oxidizing ethanol to form acetic acid includes the genera; *Acetobacter*, *Gluconobacter*, *Komagataeibacter*, and *Gluconacetobacter* (Chen *et al.*, 2023). The pathway involved in acetic acid fermentation was outlined in Figure 3 below.

$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$ . (Ethanol + Oxygen  $\rightarrow$  Acetic acid + water).

Figure 3: Acetic acid Fermentation (Bertan *et al.*, 2022)

### 2.5 Microbial Enzymes in Food Production

Microbes play a pivotal role in the production of industrial enzymes, which are essential tools in modern food manufacturing (Kalsoom *et al.*, 2020). Enzymes such as amylases, proteases, and lipases, derived from

microorganisms such as bacteria (*Bacillus subtilis*), fungi (*Aspergillus niger*), and yeasts (*Saccharomyces cerevisiae*), have revolutionized the efficiency and quality of food processing (Agrawal, 2024). Amylases for example, break down starches into simpler sugars

and are critical in baking to improve dough texture, volume, and shelf life as well as in brewing to convert starches in grains into fermentable sugars for alcohol production (Jothyswarupha *et al.*, 2024). Proteases, which hydrolyze proteins into peptides and amino acids, are widely used in dairy production to accelerate cheese ripening and enhance flavor. They are also vital in tenderizing meat and producing plant-based protein products (Sattar *et al.*, 2024).

Lipases, the enzymes responsible for breaking down fats, contribute to flavor enhancement in dairy products such as butter and cheese and play a key role in the creation of specialty oils (Kumar *et al.*, 2024). The applications of these enzymes extend beyond improving efficiency; they also enable sustainable practices by reducing energy consumption and waste in food processing. For instance, enzymes allow for precise modifications of food components without the need for harsh chemicals, resulting in safer and more natural products. By leveraging microbial enzymes, industries have achieved consistent quality in baking, brewing, and dairy production, meeting consumer demands for innovative, high-quality and environmentally friendly food options (Arya *et al.*, 2022).

### 2.6 Probiotics in Foods

Probiotics are live microorganisms, primarily bacteria and yeasts, that when consumed in adequate amounts, confer health benefits to the host (Das *et al.*, 2022). These beneficial microbes are increasingly being incorporated into food products such as yogurt, kefir and dietary supplements due to their profound effects on human health (Yilmaz *et al.*, 2022). Common probiotic strains include members of the *Lactobacillus* and *Bifidobacterium* genera, as well as the yeast *Saccharomyces boulardii* (Chelliah *et al.*, 2021). Each strain offers unique health benefits, with some aiding in digestion, others enhancing the immune response, and many contributing to the overall balance of the gut microbiota (Fu *et al.*, 2023).

The gut microbiome, often referred to as the "second brain," plays a pivotal role in digestion, nutrient absorption, and protecting against harmful pathogens (Bilgin and Hanci, 2023). Probiotics contribute by restoring and maintaining a healthy gut microbiome, particularly after disruptions caused by antibiotic use, illness, or poor diet (Stavropoulou & Bezirtzoglou,

2020). They produce short-chain fatty acids (SCFAs) and antimicrobial compounds that inhibit the growth of harmful bacteria, reduce inflammation, and strengthen the gut barrier (Ma *et al.*, 2022).

Additionally, probiotics are linked to enhanced immune system function, with certain strains stimulating the production of immune cells such as macrophages and T-cells (Mazziotta *et al.*, 2023). This immunomodulatory effect not only helps prevent infections but may also reduce the severity of allergic reactions and autoimmune disorders (Eslami *et al.*, 2020). As scientific understanding of the gut microbiome expands, the role of probiotics in functional foods continues to grow, emphasizing their importance in promoting overall health and well-being while addressing modern dietary and lifestyle challenges (Meher *et al.*, 2024).

### 2.7 The Roles of Microbes in Food Preservation

Food preservation is the process of extending the shelf life of food by inhibiting the growth of microorganisms, enzymes, and other factors that can cause food spoilage (Rahman, 2020). Preservation methods can be physical, chemical, or biological;

- i) Physical preservation methods includes: Heat processing such as; pasteurization, sterilization, frying and blanching. Refrigeration and freezing. Drying (dehydration) such as: sun drying, hot air drying and freeze-drying. And irradiation (use of gamma rays). Refrigeration and freezing slow down the growth of microorganisms and enzymes, while drying and irradiation eliminate them by removing or destroying the water needed for their growth (Ogwu and Ogunsola, 2024).
- ii) Chemical preservation methods include the use of preservatives, such as salt, vinegar, and citric acid, providing an acidic environment which inhibits the growth of microorganisms and prevent spoilage (Ben Braïek and Smaoui 2021).
- iii) Biological preservation methods include the use of beneficial microorganisms, such as lactic acid bacteria, to ferment and preserve food, application of bacteriocins, application as antioxidant etc. (Zapašnik *et al.*, 2022). In this write up, we will concentrate more on the biological preservation.

Other roles of microbes in food production and preservation are presented in Table 1 below.

**Table 1: Roles of Some Microorganisms in Food Production and Preservation**

Microorganisms	Role in Food	References
<i>Acetobacter</i> sp.	Acetic acid production	Chen <i>et al.</i> (2023)

<i>Aspergillus</i> sp.	Fermentation, Enzyme production (Amylase, xylanses and proteases).	Anumuda <i>et al.</i> (2024) Chen <i>et al.</i> (2023) Gonzatek-curbelo and Kabek (2023)
<i>Bacillus</i> sp.	Amylase, protease and lipases production	Agrawal (2024)
<i>Bifidobacterium</i> sp.	Probiotics	Obayomi <i>et al.</i> (2024)
<i>Blakeslea trispora</i>	Lycopene and $\beta$ -carotene (antioxidant) production	Liu <i>et al.</i> (2021)
<i>Dictyola</i> sp.	Antimicrobial activity	Baghi <i>et al.</i> (2021)
<i>Dunaliella salina</i>	$\beta$ -carotene antioxidant production	Liu <i>et al.</i> (2021)
<i>Gluconacetobacter</i> sp.	Acetic acid production	Chen <i>et al.</i> (2023)
<i>Gluconobacter</i> sp.	Acetic acid production	Chen <i>et al.</i> (2023)
<i>Haligra</i> sp.	Antimicrobial activity	Kodaparthi <i>et al.</i> (2024)
<i>Himanthalia elongate</i>	Antimicrobial activity	Kodaparthi <i>et al.</i> (2024)
<i>Komagataeibacter</i> sp.	Acetic acid production	Chen <i>et al.</i> (2023)
<i>Lacobacillus reuteri</i>	Reuterin (bacteriocin) production	Mani-López <i>et al.</i> (2022)
<i>Lactobacillus</i> sp.	Food fermentation and Preservation	Xu <i>et al.</i> (2021)
<i>Lactococcus lactis</i>	Nisin (bacteriocin) production	Darbandi <i>et al.</i> (2022)
<i>Laminaria digitate</i>	Antimicrobial activity	Baghi <i>et al.</i> (2021)
<i>Leuconostoc</i> sp.	Lactic acid production	Fijan <i>et al.</i> (2024)
<i>Padina</i> sp.	Antimicrobial activity	Baghi <i>et al.</i> (2021)
<i>Pediococcus</i> sp.	Pediocin (bacteriocin) production	Khorshidian <i>et al.</i> (2021)
<i>Pediococcus</i> sp.	Fermentation and Lactic acid production	Hu <i>et al.</i> (2022)
<i>Rhizopus oligosporus</i>	Fermentation	Rizal <i>et al.</i> (2020)
<i>Saccharina latissimi</i>	Antimicrobial activity	Baghi <i>et al.</i> (2021)
<i>Saccharomyces boulardii</i>	Lactic acid production	Chelliah <i>et al.</i> (2021)
<i>Saccharomyces cerevisiae</i>	Fermentation and amylase production	Parapoali <i>et al.</i> (2020)
<i>Streptomyces</i> sp.	Lycopene antioxidant production	Li <i>et al.</i> (2020)
<i>Synechocystis</i> sp.	Antimicrobial activity	Kodaparthi <i>et al.</i> (2024)
<i>Xanthophyllomyces dendrorhous</i>	Astaxanthin (antioxidant) production	Hara <i>et al.</i> (2021)
<i>Bacillus firmus</i>	Lactic acid production	Rabah <i>et al.</i> (2014)

## 2.8 Biopreservation

Biopreservation refers to the act of preserving foods not often classified as fermented foods, by using microorganisms (including bacteriophages), their metabolic products, or the combination of both. Biopreservation employs natural or controlled bacteria or antimicrobials to preserve food and prolong its shelf life (da Silva *et al.*, 2024). Beneficial bacteria and their fermentation products are utilized in biopreservation to mitigate deterioration and inactivate pathogens in food (Aguirre-Garcia *et al.*, 2024). It is a non-threatening ecological methodology that is receiving growing recognition. Furthermore, bacteriocins are used presently as an integral part of hurdle technology which is a food preservation method that combines multiple antimicrobial strategies to improve the effectiveness of biopreservation (Rendueles *et al.*, 2022).

### 2.8.1 Lactic Acid Bacteria (LAB) in Extending Shelf Life

These are bacteria that synthesize huge amount lactic acid from sugars (carbohydrates) (Wang *et al.*, 2021b). The lactic acid produced, which is known to be ten times more acidic than acetic acid, lowers the pH of the food (i.e. raises the acidity of the food) thereby creating an environment that inhibits the growth of pathogens and other spoilage organisms (Fidan *et al.*, 2022). Lactic acid bacteria (LAB) possess antagonistic properties that make them mainly useful as biopreservatives. During nutritional competition among LABs, their metabolites frequently comprise active antimicrobials, including lactic acid, acetic acid, hydrogen peroxide and peptide bacteriocins.

Certain LABs generate the antimicrobial nisin, a very potent preservative (Verma *et al.*, 2022). Currently, an important part of hurdle technology is the use of LAB bacteriocins (Ruiz-Ramírez *et al.*, 2024). Employing them alongside further preservation techniques can efficiently manage spoilage bacteria and other pathogens, while also suppressing the activities of a broad range of organisms, including Gram-negative bacteria which are naturally resistant. Particular species of lactic acid bacteria also, such as; *Lactobacillus plantarum*, *Lactobacillus fermentum*, *Lactobacillus reuteri* produces metabolic compounds with antifungal properties that could be used to control fungal spoilage of food during storage (Liu *et al.*, 2022).

### 2.8.2 Microorganisms as Source of Antioxidant in Food

Microbial diversity produces a substantial reservoir of novel chemicals, providing a significant opportunity for innovative biotechnology (Barzkar *et al.*, 2021). There are more than 23,000 known microbial secondary metabolites, from which actinomycetes exclusively produces 42%, fungi also produces almost similar amount (42%), and remaining the 16% are produced by eubacteria (Chandra *et al.*, 2020). Antioxidants are a group of chemical compounds that inhibit or delay the oxidation process or and eventually helps to prevent of cell damage (Sadiq, 2023).

Recently, use of antioxidants has become more significant in nutrition and food industry because it doesn't only minimize the oxidative damage to the consumer's body but also prolong the shelf life of food while retaining its nutritional quality. Carotenoids such as astaxanthin,  $\beta$ -carotene and lycopene are the most frequently used antioxidants (Jing *et al.*, 2022). Astaxanthin presently being used in fish food is produced by the yeast *Xanthophyllomyces dendrorhous* (Hara *et al.*, 2021). The mold *Blakeslea trispora* and algae *Dunaliella salina* produces  $\beta$ - carotene which is used in human foods (Liu *et al.*, 2021). Lycopene is produced by *Streptomyces* sp. and also *B. trispora* used in human foods as both antioxidants as well as food color (Li *et al.*, 2020).

### 2.8.3 Microorganisms as Source of Antimicrobial in Food

Bacteriocin is discovered by Andre Gratias in the year 1925, when he observed that antibacterial compound which he called colicin V, hindered the growth of some *E. coli* strains (Ofteidal, 2023). Bacteriocins are polypeptides with low molecular weight synthesized in ribosomes and contain 20–60 amino acid residues, produced by bacteria to inhibit or kill the growth of similar or closely related bacterial strain(s) (Zimina *et al.*, 2020). Pharmaceutical and food industries search for promising marine algae derivatives (Imchen and Singh, 2023).

The algae *Himantalia elongate*, *Synechocystis spp.* and *Haligra spp.* extracts, was screened for both had antioxidant capacities and antimicrobial action against *S. aureus* and *E. coli* (Kodaparthi *et al.*, 2024). Relatively, it was stated that *Hymantalia elongata*, *Saccharina latissima*, *Laminaria digitate*, *Padina*, and *Dictyota* have antimicrobial activity against *L. monocytogenes*, *Salmonella*, *Enterococcus faecalis*, *P. aeruginosa*, *B. cereus*, and *E. coli* (Baghi *et al.*, 2022). A specie of Gram-positive bacteria, *Pediococcus* spp. which includes *P. ethanolidurans*, *P. acidilactici*, *P. inopinatus*, *P. claussenii*, *P. cellicola*, and *P. parvulus* synthesizes Pediocin used in preserving fermented

sausages, vegetables, and dairy products (Khorshidian *et al.*, 2021).

Nisin, a heat-stable bacteriocin is synthesized by strains of *Lactococcus lactis* which are active against Gram-positive bacteria, such as *Micrococcus*, *C. sporogenes*, *C. botulinum*, *Leuconostoc*, *L. monocytogenes*, *Staphylococcus*, *Lactobacillus*, *B. cereus*, and *Enterococcus* spp.. Nisin effectiveness is seen in several food products, including canned foods, brewing, animal & sea-foods, dairy products, and poultry (Darbandi *et al.*, 2022). In the presence of glycerol and fatty acids, another effective bacteriocin Reuterin is being synthesized by a *Lactobacillus reuteri*. Reuterin is discovered to be effective against *Campylobacter jejuni*, *S. aureus*, *S. choleraesuis*, *E. coli* O157:H7, and *Y. enterocolitica*. It is used in food product like cooked pork and beef-sausage (Mani-López *et al.*, 2022).

Additionally, Bacteriophages are abundant in all environments and found in various foods. They can inhibit bacterial communities, regulate animal diseases, cleanse processed meats, and sanitize work surfaces (Guo *et al.*, 2024). Bacteriophages are used in the food sector to increase shelf-life, reduce germs in animals, and act as biosanitants in biofilms. They can also work as bio-preservatives in food manufacturing and processing sectors, eliminating *L. monocytogenes* from cheese, reducing *Salmonella* in cheddar production, and stopping the growth of *S. aureus* in curds (Ibrahim *et al.*, 2021).

### 2.9 Advances and Innovations in Microbial Food Application

Advances in microbial food applications are revolutionizing the food industry, leveraging cutting-edge technologies to enhance sustainability, nutritional value, and efficiency in food production (Zatsu *et al.*, 2024). One of the most transformative innovations is the application of synthetic biology and genetic engineering to microbes (Eskandar, 2023). Scientists are engineering microbial strains to perform specific tasks, such as producing novel enzymes, synthesizing bioactive compounds, or creating entirely new food ingredients (Ghosh *et al.*, 2022). For instance, engineered yeast and bacteria are now capable of producing milk proteins and meat-like flavors, enabling the production of animal-free dairy and cultured meat, addressing both ethical concerns and environmental challenges associated with traditional animal farming (Rønning *et al.*, 2024). Beyond this, precision fermentation is being used to develop alternative protein sources, such as microbial-based proteins, which are touted as a sustainable

solution to meet the growing global demand for protein while minimizing land and water use (Negowetti, 2020). These proteins, derived from fungi or algae, are nutritionally rich and highly versatile, making them an ideal component in plant-based diets (Boukid *et al.*, 2022). Microbial innovations are also making strides in reducing food waste, as microbes are used to convert surplus or byproducts of food production into valuable ingredients like biofuels, bioplastics, or nutraceuticals (Chavan *et al.*, 2022).

Additionally, advances in bio-preservation techniques utilize engineered or natural microbes to extend the shelf life of perishable foods while maintaining their safety and quality (Lohita and Sriyaya, 2024). Such innovations not only cater to the growing demand for clean-label and minimally processed foods but also align with the global push towards circular economies and sustainable food systems (Biltekoff and Guthman, 2023). With continuous research and technological progress, the role of microbes in transforming food production is expanding rapidly, opening up exciting possibilities for healthier, more sustainable, and innovative food solutions.

## 2.10 Safety Consideration: Microbial Risk in Food

Apart from species of microorganisms that are beneficial in production and perseveration of food, some other species occur as pathogenic microbes causing microbial risk in food. Microbial risks in food refer to the potential for contamination by harmful microorganisms such as bacteria (*Salmonella*, *Escherichia coli*), viruses (*Norovirus*), or fungi that can cause foodborne illnesses (Gallo *et al.*, 2020). These risks can arise during various stages of food production, processing, storage, or handling, often due to poor hygiene, improper cooking, or cross-contamination (Mohammed Saeed, 2023). Pathogenic microbes can lead to severe health issues, ranging from mild gastrointestinal discomfort to life-threatening conditions (Jagirdhar *et al.*, 2023).

Furthermore, microbial spoilage caused by non-pathogenic microorganisms can degrade food quality, leading to waste and economic losses. Addressing microbial risks requires strict adherence to food safety standards, such as good manufacturing practices (GMPs), Hazard Analysis and Critical Control Points (HACCP), and regular testing to ensure safe consumption (Sameen *et al.*, 2022).

## 2.11 Harmful Microbes in Food

### 2.11.1 Pathogenic Bacteria in Food

Foodborne diseases are mostly caused by bacteria which exist in different shapes, types and properties. The most common pathogenic bacteria includes: *Bacillus cereus*, *Campylobacter jejuni*, *Clostridium botulinum*, *Clostridium perfringens*, *Cronobacter sakazakii*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella spp.*, *Shigella spp.*, *Staphylococcus aureus*, *Vibrio spp.* and *Yersinia enterocolitica* (Anum *et al.*, 2024). Certain pathogenic bacteria are highly heat-resistant due to their spore forming characteristic (e.g. *Clostridium botulinum*, *C. perfringens*, *Bacillus subtilis*, and *Bacillus cereus*) (Juneja *et al.*, 2024). Some have the ability to produce heat-resistant toxins (e.g. *Staphylococcus aureus*, *Clostridium botulinum*) (Cetin, 2020). Pathogenic microbes are mostly mesophiles, with their optimal growth temperature ranging from 20°C to 45°C (Mekonnen *et al.*, 2021). Although, some foodborne pathogens are psychrotrophs, like *Listeria monocytogenes*, and *Yersinia enterocolitica* having the potential to grow under refrigerated conditions or temperatures less than 10 °C (S Thabet and Thabet, 2021).

### 2.11.2 Fungal Contamination in Food

Fungal contamination in food can occur when certain molds and fungi produce toxic metabolites called mycotoxins when they colonize the foodstuffs (Pandey *et al.*, 2023). These mycotoxins are mutagenic, teratogenic, and carcinogenic thus, regarded as potent toxins having severe health consequences in people (Awuchi *et al.*, 2022). The contamination of mycotoxins is more rampant in agricultural products. Many fungi can produce mycotoxins on agricultural goods during or after harvesting, resulting in considerable detrimental effects on both animals and humans (Janik *et al.*, 2020).

The most common mycotoxins found in food products are aflatoxins and ochratoxins produced by *Aspergillus* species. Ochratoxins and patulin are synthesized by *Penicillium*, and *Fusarium* species also, synthesizes fumonisins, deoxynivalenol, and zearalenone (González-Curbelo and Kabak, 2023). Globally, a variety of acute and chronic illnesses in humans and domestic animals are caused by fumonisins, patulin, aflatoxins, and ochratoxins, among others (Janik *et al.*, 2020).

## 2.12 Measures to Prevent Contamination

### 2.12.1 Good Manufacturing Practices

Good Manufacturing Practices (GMPs) are a set of guidelines and standards designed to ensure the consistent production and control of food products, pharmaceuticals, and other consumer goods to meet safety, quality, and regulatory requirements (Sharma *et*

*al.*, 2023). These practices cover all aspects of production, including raw material sourcing, equipment maintenance, hygiene protocols, personnel training, and documentation (Okpala and Korzeniowska, 2023).

In food production, GMPs play a critical role in minimizing risks of contamination, spoilage, and product inconsistencies. They mandate strict cleanliness in facilities, proper handling of ingredients, regular equipment sterilization, and monitoring of environmental conditions like temperature and humidity (Sahoo *et al.*, 2024). Employee hygiene, including handwashing, protective clothing, and health monitoring, is also emphasized to prevent microbial contamination (Trmčić *et al.*, 2021). GMPs require thorough record-keeping to trace products and identify issues swiftly in case of recalls or safety concerns (De Silva, 2020). By adhering to GMPs, companies ensure that their products are safe for consumption, meet regulatory standards, and maintain consumer trust in the brand (Sharma *et al.*, 2023). As a foundation of food safety systems, GMPs are integral to global efforts in providing high-quality, reliable, and safe food products (Bucknavage and Campbell, 2020).

### 2.12.2 Hazard Analysis and Critical Control Points

Hazard Analysis and Critical Control Points (HACCP) is a systematic approach to food safety that focuses on identifying, evaluating, and controlling biological, chemical, and physical hazards throughout the food production process (Awuchi, 2023). Developed as a preventive strategy, HACCP aims to ensure that food is safe for consumption by monitoring critical points in the production chain where hazards are most likely to occur (Dlamini and Adetunji, 2023). The system is based on seven principles: conducting a hazard analysis, determining critical control points (CCPs), establishing critical limits, implementing monitoring procedures, defining corrective actions, verifying the system's effectiveness, and maintaining detailed records (Gonzalez, 2024). HACCP is widely applied in food industries to address risks such as microbial contamination, allergen cross-contact, and chemical residues (Reelfs, 2022).

By emphasizing prevention rather than reaction, HACCP minimizes food safety incidents, ensures compliance with regulatory standards, and protects public health (Okpala and Korzeniowska, 2023). Its adaptability makes it effective across various sectors, from primary production and processing to packaging and distribution, fostering consumer confidence in the safety and quality of food products (Prasanna *et al.*, 2024).

## CONCLUSION

In general, microbes play a vital role in food production and preservation, offering natural, sustainable, and innovative solutions to enhance food quality, safety, and shelf life. From fermentation and enzyme production to probiotics and bio-preservation, microbial applications have transformed traditional practices and continue to drive advancements in modern food systems. As science progress, the potential for microbes to address global challenges like food security, sustainability, and health becomes even more significant. By embracing these tiny yet powerful organisms, we can create healthier, safer, and more sustainable food solutions, paving the way for a future where innovation meets the demands of a growing population.

## RECOMMENDATIONS

It can be recommended that:

- i. To fully harness the potential of microbes in food production and preservation, it is essential to prioritize educational initiatives to promote awareness of microbial benefits,
- ii. Educating consumers and food industry professionals about the roles of microbes in improving food quality, safety, and health benefits should be strictly followed.
- iii. Policymakers and industry leaders should strengthen food safety protocols and encourage the use of probiotics through implementing robust systems like HACCP and GMPs to minimize microbial risks while maintaining food safety and quality standards.
- iv. Incorporating probiotics into daily diets through functional foods like yogurt and fermented beverages to support gut health and overall well-being should be given attention.
- v. Furthermore, government and policymakers should enhance research on microbial innovations.
- vi. Investing in studies to focus on genetic engineering, synthetic biology and precision fermentation to develop new microbial applications in food systems should be prioritized.
- vii. Getting access to fermented foods through encouraging the production and consumption of traditional and modern fermented foods as a natural way to enhance nutrition, flavor, and preservation should be supported locally.

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