Review Article

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# Microbial Fermentation: A novel attempt of enhancing food quality

## Abstract

Microbial fermentation has been a vital means of revolutionizing food industry for deriving affirmative outcomes. Fermentation processes in foods often causes changes in nutritional value and biochemical eminence relative to the preliminary components. Fermented foods comprise very complex ecosystems comprising of enzymes from raw ingredients that interact with the fermenting microorganisms' metabolic activities. Fermenting foods using microorganisms has been an age old process to improve the quality of foods. Fermenting microorganisms provide a unique approach towards food stability through physical and biochemical changes in fermented foods. The fermented foods can offer several merits over the unfermented feed and benefit the consumers compared to simple foods in terms of antioxidants, production of peptides, organoleptic and probiotic properties, and antimicrobial activity. It also leads to the increased levels of nutrients and improves the level of digestibility. The quality and quantity of microbial communities in fermented foods vary based on the manufacturing process and storage conditions/durability. The current review attempts to decipher the role of microorganisms in improving the food quality and validates the prominence of microorganisms as a promising alternative to chemicals which can in turn hamper the quality and standard of foods. The review also emphasizes on the role of microorganisms in enhancing the shelf life and also attempts to explore the nutritional benefits of fermented foods.

**Keywords:** Lactic acid bacteria, fermentation, industrial microorganisms, fermented foods

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## Introduction

Microorganisms have been used as a means of improving food quality and fermentation process has revolutionized the scope of microbial use in food industry. In simple terms it is a kind of redox reaction that carries out metabolism in the absence of oxygen. During the breakdown process, the electrons are donated which in deed produces energy in the form of ATP.[1] Microbial fermentation is the breakdown sugars and carbohydrates, by metabolic enzymes from microbes in the absence of oxygen. Generally, many types of microorganisms are present during the fermentation process and each of them has a unique set of enzymes, leading to the formation of intricate byproducts that characterize the smell and taste of fermented foods.

Fermentation is a metabolic process carried out by microorganisms like bacteria, yeasts, or molds, where sugars (glucose, sucrose, etc.) are broken down into simpler substances, like acids, alcohols, and gases, usually in the absence of oxygen (anaerobic conditions). Fermentation is a process of industrial prominence because it is often used for the production of product of commercial significance.[2]

Fermentation is nature's way of

a. Preserving food
b. Creating unique flavors
c. Producing energy without oxygen

Louis Pasteur is often regarded as the father of fermentation technology because of his extensive work in the field and has provided the scientific evidence to validate fermentation as a biological process.[3]

## Types of Fermentation

**Table 1**.

| Type | Main products | Examples |
|---|---|---|
| Lactic Acid Fermentation | Lactic acid | Yogurt, pickles, sauerkraut, kimchi |
| Alcoholic Fermentation | Ethanol + $CO_2$ | Beer, wine, bread |
| Acetic Acid Fermentation | Acetic acid (vinegar) | Vinegar from wine, kombucha |
| Butyric Fermentation | Butyric acid + gases | Rancid butter smell (used in some cheeses) |
| Propionic Fermentation | Propionic acid + $CO_2$ | Swiss cheese (holes from $CO_2$ bubbles) |

### Process of Fermentation

General Steps:

a. Substrate: Sugars (like glucose, sucrose, lactose) act as the raw material.
b. Microorganism: A specific type of bacteria, yeast, or mold is introduced.
c. Fermentation Conditions: Warm temperature, low or no oxygen, correct pH.
d. Fermentation: The microorganism breaks down the sugar.
e. End Products: Acids (like lactic acid), alcohol, or gas (like $CO_2$) are produced.

## Microorganisms Used in Fermentation

Microbial fermentation occurs to some extent in every biomass. It is a vital bioprocess to break complex biomolecules into simpler building blocks while releasing chemical energy and returning it into the environment for the subsequent cycles of building complex organic matter by higher organisms like plants and animals. In terms of biochemistry, microbial fermentation uses enzymatic processes that digest carbohydrates and use it as a source for ATP (Adenosine triphosphate), the universal energy currency in all organisms, without the use of oxygen (i. e. anaerobically) (Table 2).[4]

**Table 2**

| Microorganism Type | Example Organism | Role in fermentation |
|---|---|---|
| Bacteria | *Lactobacillus, Streptococcus* | Lactic acid production |
| Yeasts | *Saccharomyces cerevisiae* | Alcohol and $CO_2$ production |
| Molds | *Aspergillus oryzae, Rhizopus* | Enzyme production, soy fermentation |

### Applications in Food

**Table 3**.

| Food Product | Type of fermentation | Microbes involved |
|---|---|---|
| Yogurt | Lactic acid | *Lactobacillus, Streptococcus* |
| Cheese | Lactic acid & molds | Bacteria & Penicillium molds |
| Bread | Alcoholic (yeast) | *Saccharomyces cerevisiae* |
| Wine/Beer | Alcoholic | *Saccharomyces cerevisiae* |
| Vinegar | Acetic acid | *Acetobacter* species |
| Tempeh | Fungal fermentation | *Rhizopus oligosporus* |
| Miso/Soy Sauce | Mold & yeast | *Aspergillus oryzae*, yeasts |

### Lactic acid fermentation

Lactobacillus species use sugars, carbohydrates and starches to extract energy for the production of lactic acid. It is very common in dairy products like yogurt and related probiotics. In the pharmaceutical industry, lactic acid is used in implants, pills, dialysis, surgical sutures, and controlled drug release systems. In the cosmetic industry, lactic acid is used in the manufacture of hygiene and aesthetic products used as for skin care because of its moisturizing, antimicrobial, and rejuvenating effects on the skin.[5]

### Ethanol fermentation

Yeasts digest sugars to produce ethanol and carbon dioxide. Such yeasts are commonly used in breweries, wine-making and bakeries. Pharmaceutical ethanol fermentation is used as a solvent to dissolve the active ingredient in some medicines, or used as a means for extracting vital ingredients from medicinal herbs leading to products of commercial importance. Ethanol has also been used as an antimicrobial preservative, possessing bactericidal and fungicidal activity.[6]

### Acetic acid fermentation

Sugars are converted into acetic, propionic and butyric acids and other flavoring agents, which gives the complex sour taste of vinegar. In medicine, acetic fermentation has antiseptic properties that are used to cure bacterial infections. The characterization of the involved microorganisms has led to the development of biotechnology tools to exploit them for scale-up in bioreactors to secure the large supply demands.[7]

## Why is Fermentation Important?

Fermentation is a process that helps break down complex organic molecules through the action of microorganisms into simpler ones. Yeast enzymes convert sugars and starches into alcohol, while proteins are converted to peptides/amino acids. The microbial actions on food ingredients tend to ferment food, leading to desirable biochemical changes responsible for the vital modification to the food. Fermentation is a natural way of enhancing vitamins, essential amino acids, anti-nutrients, proteins, food appearance, flavors and improved aroma. Fermentation also assists in the reduction of the energy needed for cooking as well as making a safer product.[8,9] Therefore, microorganisms' activity plays a prominent role in the fermentation of foods by causing changes in the foods' chemical and physical properties. Fermented foods have several advantages.[10,11]

a. Fermented foods have a longer shelf life than the original foods.

b. The improvement of organoleptic properties; for example, cheese has more enhanced organoleptic properties in terms of taste than its raw substrate viz. milk.

c. The removal of harmful ingredients from raw materials—for example, during garri preparation, there is a reduction in the poisonous cyanide content of cassava, and the flatulence factors in soybeans are removed by fermentation.

d. Fermented foods have shown better nutrient content compared to conventional foods like yeast in bread and yeast and lactic acid bacteria in garri add to its nutritive quality.

e. The fermentation process reduces the cooking time of food

f. The fermented products have known to show higher amounts of anti oxidants which is known to safe guard the authenticity of any biological system by preventing oxidation that can lead to the formation of super oxide radicals.[10-12]

g. Fermented milk and yogurt consist of higher antioxidant properties compared to milk, as there is a release of biopeptides that follow the proteolysis of milk proteins, particularly α-casein, α-lactalbumin, and β-lactoglobulin.[13]

### Positive influence of microbial fermentation

**Flavor, Texture & Aroma**

Fermentation transforms basic ingredients into **rich, complex flavors** and **textures** that are hard to achieve otherwise.

i. Cheese → from milk

ii. Bread → from flour

iii. Soy sauce & miso → from soybeans

iv. Wine & beer → from fruit or grains

**Health & Probiotics**

Some fermented foods contain **live cultures** (like *Lactobacillus* or *Bifidobacterium*) which are **beneficial for gut health.**[12]

Benefits include:

i. Better digestion

ii. Boosted immune system

iii. Reduced inflammation

iv. Improved mental health (gut-brain connection)

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Examples: yogurt, kefir, kombucha, kimchi

**Environmental Impact**

Fermentation is often **eco-friendly** and **low-energy** compared to other food processing methods.

i. Doesn't require high heat or synthetic preservatives.
ii. Can reduce food waste by preserving surplus crops (like cabbage → kimchi).
iii. Used in **biofuel** production (like ethanol)[11]

**Industrial Applications**

Fermentation is used way beyond food:

**i. Pharmaceuticals**: Antibiotics (like penicillin), vaccines, insulin.
**ii. Biotech**: Enzymes, vitamins, hormones.
**iii. Agriculture**: Silage fermentation to preserve animal feed.
**iv. Biofuels**: Ethanol from sugarcane or corn.

**Cultural & Traditional Importance**

Fermented foods are often tied to **cultural identity and heritage**[9]

i. Japan → miso, soy sauce
ii. Korea → kimchi
iii. Germany → sauerkraut
iv. Ethiopia → injera
v. India → idli, dosa, curd

**Summary Table: Importance of Fermentation**

**Table 4**.

| Area | Why it's important |
|---|---|
| Food Preservation | Stops spoilage and extends shelf life |
| Taste & Texture | Adds flavor, aroma, and texture to foods |
| Nutrition | Boosts vitamins, breaks down toxins |
| Health Benefits | Probiotics help gut and immune health |
| Environmental Impact | Sustainable & reduces waste |
| Industrial Use | Makes medicines, biofuels, enzymes |
| Cultural Significance | Part of culinary traditions around the world |

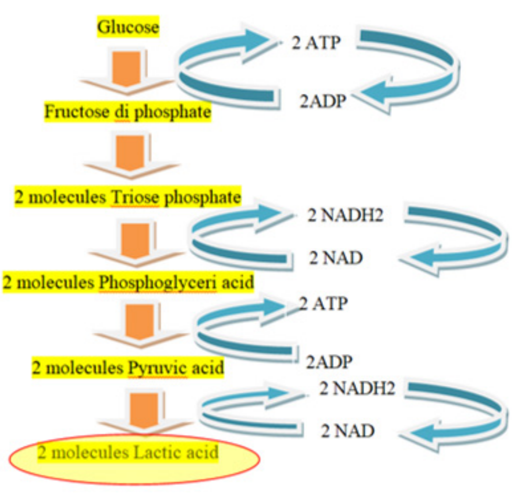


**Figure 1** Sugar metabolism by lactobacillus.[11,13]

Fermentation has been used for thousands of years to **extend the shelf life of food**.

i. Acids (like lactic acid or acetic acid) or alcohols produced during fermentation **inhibit harmful bacteria**.
ii. Allows foods to be stored for **longer periods without refrigeration**.
iii. Examples: yogurt, kimchi, sauerkraut, pickles[10,11]
iv. Food Preservation
v. Inhibits spoilage bacteria
vi. Increases shelf life

**Flavor Development**

Produces unique tastes and aromas

**Nutritional Enhancement**

i. Increases B-vitamins and bioavailability
ii. Adds probiotics for gut health

**Economic and Industrial Use**

i. Used in large-scale dairy, alcohol, and baking industries
ii. Enables production of antibiotics, vitamins, and enzymes

## Nutritional Benefits

It has been proven that fermented foods have higher nutritious value than their unfermented counterparts.[14] The enhanced nutritional value in fermented foods is due to the role fermenting microorganisms that has resulted in elevated nutrient content. Microorganisms are both catabolic and anabolic, break down complex compounds, and synthesize complex vitamins and other growth factors.[15]

Indigestible substances release the nutrients that are locked into plant structures and cells. This process occurs with individual seeds and grains. In the milling process, cellulosic and hemicellulosic structures covering the endosperm have been physically shattered to liberate nutrients. Crude milling is used in less developed regions to extract nutritional contents, but it is not that effective in extracting nutrients because it leads to inadequate release of nutrients from the plant products. Even after the cooking process, a few of the bounded nutrients remain inaccessible to the human digestive system. At the same time, this issue can be resolved by certain bacteria, molds, and yeasts that decompose or breaks the cell walls and indigestible coatings of these products both physically and chemically.

An alternative mechanism to increase plant material's nutritional properties is by using enzymes which causes enzymatic degradation of polymers that are not digested by humans into simple sugars and their derivatives like cellulose, hemicelluloses. Microbial enzymes have successfully broken down cellulose and cellulose-containing substrates in fermented foods that are beneficial for human consumption.[16] Many cereal foods are low in their nutritional content and are consumed as an essential staple diet for poor people. However, L.A.B. and yeast fermentation were observed to enhance nutritional content and food digestibility. The fermentation process also increases the microbial enzyme activity as it provides an acidic environment at temperature 22–25 °C [16]. The critical function of enzymatic hydrolysis in fermented foods includes a reduction in levels of anti-nutrients viz. tannins and phytic acid (degradation with the help of phytases), resulting in enhanced bioavailability of simple

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sugars or polysaccharides (amylases), proteins (proteases), free fatty acids (lipases), and iron.[17]

Major factors adding to food's nutritional value include its digestibility and the number of vital nutrients present. Nutrients, and digestibility, may be improved by the process of fermentation. During the fermentation process, the microbial enzymes may initially digest the macronutrients.[2] The different ways by which the nutritional quality of food can be influenced by fermentation include increasing the amount and bioavailability of nutrients and enhancing nutrient density. The latter may be achieved by synthesizing promoters for absorption, the degradation of anti-nutritional factors, influencing the uptake of nutrients by the mucosa, and pre-digestion of individual food components.[1] Fermentation also plays an important role in altering the extent of solubility which in turn adds up to the enhanced palatability. The solubility of proteins and the availability of some micronutrients and limiting amino acids are enhanced by the process of lactic acid fermentation.[18] By this process, tannins (50%), phytates, and oligosaccharides (90%) are also reduced.[19] There can be a direct or indirect nutritional impact of fermented foods on nutritional diseases. The fermentation process of food has a direct curative effect.[20] Likewise, food fermentation contributes directly to consumers' health by increasing the number of available vitamins such as niacin, thiamine, folic acid, or riboflavin.[3] It also enhances iron utilization through the breakdown of complex substances into inorganic iron with vitamin C.[1] Food fermentation increases mineral and trace elements' bioavailability by reducing non-digestible material in plants such as glucuronic and polygalacturonic acids, cellulose, and hemicelluloses.[21] It also reduces serum cholesterol by inhibiting cholesterol synthesis in the liver and dietary and endogenous cholesterol absorption in the intestine.[22] It is robust, stable, and safe for the product, thereby preempting diseases/infections such as diarrhea and salmonellosis.[23]

Fermentation **enhances the nutritional profile** of many foods.

i. Increases **B-vitamins**, **amino acids**, and **digestibility**.
ii. Breaks down **antinutrients** (like phytic acid), making minerals more bioavailable.
iii. Reduces **lactose** in dairy (good for lactose-intolerant people).
iv. Adds **probiotics** (good bacteria that support gut health).

## Food Preservation

Microbial hazards and food oxidation has been an issue of severe concern from the context of food quality maintenance and efforts are being made to counter act the dire consequences that could possibly compromise the food standards. Use of microorganisms has been prominent and promising in achieving this goal. Administration of a variety of food additives in conjunction with strict preservation processes are applied to suppress the development of pathogenic microorganisms and oxidation reactions, as well as to prolong the shelf life of foods. Today, there is mounting pressure on food industries to either totally avoid the use of chemical preservatives or to implement "natural" alternatives. The use of microorganisms as a significant alternative has proven to be effective. The use of natural bioactive compounds, functional microbial starter cultures and antioxidants for "synthetic preservative-free" products are included among the latest and most successful accomplishments in the food industry.[24] Mei *et al.*[1] have validated the significance of microbial products as potential preservative agents over chemical as majority of chemicals have the tendency of altering the texture and flavor of the food product which in turn compromises the commercial value of the food commodity. They have reviewed potential replacement of chemical antimicrobials by natural preservatives from microorganisms, plants and animals.

Use of bacteriocins and organic acids from bacteria served as possible antimicrobial agents which has demonstrated high efficacy against pathogenic microorganisms.[25] Several researchers have also demonstrated the ability of microorganisms in reducing the extent of oxidation which in turn avoids the formation of reactive oxygen species which are potential free radicals. Several components of microbial origin have been used as anti oxidants in order to avoid oxidation damage in foods. In addition, certain algae and mushroom species may also serve as a potential source of novel natural preservatives.[26] There is a constant need to maintain the food standards and industrial domain over the years have evolved rapidly and are in tug of war with their contemporaries. So there is a need to use a means which enhances the food standards without influencing the food quality in order to exist in the market for a long run which has in turn supported the use of microorganisms and their products in food industry as an alternative to enhance food quality and standards. Microbial behavior is closely related to the properties of food itself like water activity, pH, storage conditions, temperature and relative humidity. The effect of these factors on microbial growth in food systems can be predicted by mathematical models issued by quantitative studies on microbial populations.[27]

## Health benefits of fermented foods

Beneficial effects of fermented foods on health were unknown till the recent past, and the use of microorganisms were confined to food preservation for improving shelf life and flavor enhancement. Fermented foods became a vital part of the diet among people, and fermentation has been associated with many health benefits. As a matter of fact, the fermentation process and the fermented products have recently attracted scientific interest as several researchers have extensively worked with an intent of exploring the associated health benefits of fermented foods. In addition, microorganisms contributing to the fermentation process have recently been associated with many health benefits, and so these microorganisms have become another focus of attention. Lactic acid bacteria (LAB) have been widely studied due to their commercial and industrial prominence.[28] During fermentation, these bacteria synthesize vitamins and minerals, produce biologically active peptides with enzymes such as proteinase and peptidase, and remove some non-nutrients. Among these peptides, conjugated linoleic acids (CLA) have a blood pressure lowering effect, exopolysaccharides exhibit prebiotic properties, bacteriocins show anti-microbial effects, sphingolipids have anti-carcinogenic and anti-microbial properties, and bioactive peptides exhibit anti-oxidant, anti-microbial, opioid antagonist, anti-allergenic, and blood pressure lowering effects. Fermented foods provide health benefits which include anti-oxidant, anti-microbial, anti-fungal, anti-inflammatory, anti-diabetic and anti-atherosclerotic activity.[29] As a matter of fact several scientific findings and demonstrations have validated the significance of fermented foods and beverages among the processed food products for human consumption. Production of fermented foods like yogurt and cultured milk, wine and beer, sauerkraut and kimchi, and fermented sausage were initially valued because of their enhanced shelf life, safety, and organoleptic properties. It is increasingly cohesive that fermented foods can also have increased nutritional and functional properties due to transformation of substrates and formation of biologically active end-products. Many fermented foods also contain living microorganisms of which some are genetically similar to strains used as probiotics.[30] Fermented milks and milk products are extensively produced and consumed globally.

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The production of these products is an old process that was used for enhancing the storage life of milk and milk products. Over the course of time, numerous traditional and industrial fermented milks with various texture and aroma can be found as a consequence of microbial fermentation which has indeed become an important part of human diet due to several health benefits. In recent past, research studies have demonstrated the significance of fermented milk through consumers' awareness measures in order to elucidate about the effect of diet on health and tendency for consuming healthful food products. In this perspective, production of probiotic food products is a common approach with the intent of improving health benefits. Several extensive research works have also demonstrated the importance of these fermented foods in improving the gut micro flora which has in turn provided several health benefits. Fermented milks are appropriate carrier for probiotics and their production and consumption can be a beneficial way for enhancing human health. For development of probiotic fermented milks, probiotic viability during fermentation and storage time, their interaction with starter cultures in the product as well as their effect on sensory properties of the product should be taken into account.[31] Microorganisms like lactobacillus, saccharomyces, propionibacteria etc have been extensively used for fermentation process and have resulted in affirmative outcomes. Propionibacteria is one of the beneficial microbes that are mainly found in dairy products and fermented milks. Several sources have also substantiated the presence of propionibacteria other foods as well. Dairy propionibacteria have the potentiality to be used as a promising probiotic due to its positive bioactivity and the recent studies have claimed the significance of propionibacteria in exhibiting potential probiotic activities such as production of propionic acid, vitamins, bacteriocins, essential enzymes, and other vital metabolites. Moreover, this bacteria has known to instigate the immune system and reduces the blood cholesterol level. They have a wide spectrum of antimicrobial activities, and are known to inhibit the growth of harmful gram-positive and some gram-negative bacteria, as well as some yeasts and molds that are undesirable. At industrial scale, they are used in cheese making, especially Swiss (hard) cheeses, as dominant starter cultures. There is a rising trend to use propionibacteria in fermented milks as probiotic.[32]

## Discussion

Fermentation is regarded as one of the earliest scientific methods of food preservation and processing to be comprehensively applied globally.[33] The current trends in fermented-based foods are growing and will likely gain its pace in future. The initial report on fermented foods dates back into time which is around 13,000 BC.[34] Fermentation is a process of chemical transformation of organic matter through the action of microorganisms leading to microbial metabolism which is mediated by microbial enzymes enzymes. Several research studies have emphasized on the engineering of microbial fermentation to allow manifestations from the context of improving the product quality and the key advantages of engineering microbial fermentation over multicellular (higher eukaryotic) tissue culture have proven to be higher. Microbial fermentation engineering has indeed resulted in less fastidious growth requirements; significantly faster growth cycles; and less ethical controversy and market resistance in biomedical and food applications.[35] Anaerobic fermentation can produce prominent chemicals from food waste, such as lactic acid, butyric acid and ethanol.[36] It has been reported that the production of fermented foods is based on the use of starter cultures which will in turn decide the type of end product to be produced.[37]

Solid state fermentation has been commonly employed and has been widely used for the growth of microorganisms for microbial fermentation. Organisms applied in solid state fermentation (SSF) are usually of pure, single species, mixed distinct cultures or as totally diverse indigenous microorganisms. Solid state fermentation of products like, tempeh, and ontjom, may need the specific growth of organisms, like molds, which requires low levels of moisture to perform fermentation utilizing extracellular enzymes produced by microorganisms. However, bacteria and yeasts, which require more moisture for effective fermentation, can be utilized to create SSF, but amount of product recovery is low.[38] Solid state fermentation requires the raw materials to be pre treated through mechanical, chemical or biochemical means to enhance the availability of bound nutrients. Complex substrates like polysaccharides and proteins should be hydrolyzed in order to make the environment conducive for the microorganisms to act on and convert the raw materials in to finished products. The final step includes the separation and purification of end products which in turn depends on the type of end product produced.[39] Research studies have also validated the role of fermented foods in avoiding or reducing the extent of oxidation due to their antioxidant properties. Consumption of fermented foods has indeed reduced the amount of ROS (reactive oxygen species) which has prevented oxidative damage. Antioxidant activity in the fermented foods has indeed added on to health benefits and has contributed towards the normal well being of the individual. Many Asian soybean fermented foods have antioxidant properties, for example, tungrymbai and bekang (Indian fermented soybean foods).[40]

In addition to the above added merits, proteolytic microorganisms have known to produce bioactive peptides during the fermentation of foods.[41] These peptides exhibit antihypersensitive properties and scientific investigators have substantiated their role as antithrombic[42] and immunomodulatory agents.[43] *Lactobacillus delbrueckii* and *L. bulgaricus* have been extensively used for the production of bioactive peptides.[44] *Bacillus* is one of the extensively used microbes for fermentation because of its ability to produce enzymes like amylase, proteinase, mannase, catalase, cellulose.[45] Fungi such as Amylomyces, Actinomucor, Aspergillus, Mucor, Monascus, Rhizopus and Neurospora produce enzymes like amyloglucosidase, α-amylase, maltase, pectinase, invertase, cellulase, alkaline proteases, lipase, and β-galactosidase which have the ability to breakdown carbohydrates.[46] Hence it is quite evident that microbial fermentation has its own significance of commercial and industrial echelon which has improvised the techniques used for enhancing the food quality and standards.

## Conclusion

Microorganisms have a wide range of industrial significance and one of the recent findings in the last millennium is their role in improving the food quality standards. Fermented foods have gained importance over the last decade and its demand is growing among the people globally. Several benefits as a result of microbial fermentation have been extensively demonstrated by several scientific investigators and have validated the importance microorganisms in improving the food quality. Fermented foods have known to exhibit several advantages over the conventional foods like increased palatability, and nutrient content with extended storage life. As a matter of fact some of these fermented products have been recommended to lactose intolerant individuals due to their manifested nutrient content and enhanced digestibility. However, the fact of they being microorganism makes their role more speculative and tentative as we have to consider

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the other side which needs further studies to be performed in order to validate the hidden scientific facts.

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## Conflict of interests

Authors declare no conflict of interest.

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