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Review Article

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Role of Microbes in the Production of Dairy Products

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ABSTRACT

Microorganisms have a significant impact on the fermentation processes and health advantages of dairy products. Certain microbial strains are necessary for the fermentation, flavor, and nutritional value enhancement of traditional dairy products including kefir, cheese, and yoghurt. Yeasts, molds, and lactic acid bacteria are necessary for the transformation of lactose to lactic acid, which causes milk to coagulate and produce distinctive smells and textures. Recent developments in synthetic biology, fermentation technology, and microbial genetics have created new opportunities to improve the functioning and quality of dairy products. The present function of microbes in dairy production is examined in this review, with particular attention paid to their use in fermentation, probiotic production, and sustainability. The creation of new probiotic strains, the use of genetically modified microorganisms to produce dairy substitutes, and the application of microbes for more effective and sustainable dairy farming methods are some prospects. The future of the dairy business is expected to be significantly shaped by microbial innovation as customer demand for healthier, more sustainable dairy products increases.

INTRODUCTION

Many different types of microbiotas play an important role in dairy products. Dairy production and utilization can have negative and positive human health effects. Dairy production is a major source of high-quality protein and minerals that are accessible (e.g., Vitamin and iron. Dairy products can also play a significant role in local-regional and international-level economics and provide opportunities for employment and income generation. Different types of diseases are identified through dairy products including diet-related chronic disease, environmental change, foodborne hazards, occupational hazards and zoonotic disease (transmissible animals to humans) [1]. Microbes like Yeast, mold and bacteria have been used in fermentation. Thousands of years ago, humans used them to make food products such as bread, vinegar, beer, wine, cheese and yoghurt. Microorganisms have also been used to ferment fish, meat, and vegetables, producing a variety of foods [2]. Microbes produce various food products through fermentation. Today, microbes are commonly used to make food or improve its quality. Biotechnologists are working on creating special food products using microbes [3]. Microbes are important in both food spoilage and food production. While they can cause bad taste, odor and texture in spoiled food, they are also essential for making many fermented foods and drinks [4]. Bread is a staple food, especially in developing countries but it loses freshness quickly due to staling and microbial contamination. Microbes are used in bread production to increase the shelf life of bread products [5]. Bakery products are an important part of a balanced and come in many types, including unsweetened (bread, rolls), sweet (cookies, doughnuts) and filled goods (pies,

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sandwiches) [6]. Dairy products, like bread, biscuits and cereals are important food providing essential nutrients, including carbohydrates, proteins and vitamins. India is one of the largest food sector industries making breads and biscuits up over 80% of the total production. Common molds used in bakery products include Rhizopus, Mucor, and Penicillium [7]. Vinegar is a highly valued and unique fermented food product, particularly in European and Asian countries [8]. Vinegar is a liquid that contains at least 4% acetic acid and is consumed worldwide. *Aspergillus* species, lactic acid bacteria and other *Saccharomyces* and non-Saccharomyces yeasts are important in the fermentation of cereal vinegar. These microbes are essential for the breakdown of raw materials and the synthesis of bioactive chemicals. Vinegar is made through two types of fermentation. Such as Alcoholic fermentation (sugar to alcohol) and Acetous fermentation (alcohol to acetic acid). alcohol produced using yeast and acetic produced using acetic acid bacteria [9]. Ghee is a tasty and nutritious dairy product made by heating butter to remove water through evaporation and separateng non-fat solids through sedimentation. It is also known as animal oil or milk oil [10]. Ghee is widely produced and consumed in India, Sudan, Ethiopia, Pakistan and the Middle East [11].
Ghee is utilized for culinary purposes such as dressing and frying different foods [12]. Milk and dairy products have been important components in Africa to increase the number of people living in rural as well as urban settings. Milk and dairy products have rich amounts of nutrients and are available is contain chemical hazards and contaminants mostly obtained by the environments and farm management practices [13] (Figure 1).The utilization

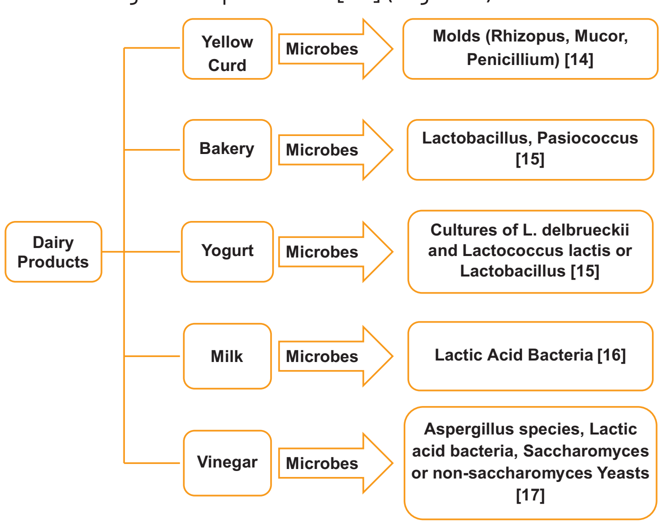

Figure 1: Different Types of Dairy Products and Microbiota Used in Dairy Production

of yoghurt increases day by day around the world. Yoghurt is the most important and popular cultured product. It contains a nutritional value and is beneficially important for human health. It is produced by the milk through the fermentation process. Yoghurt is a nutritious food with fat (0-3.5%), proteins (4.6-5.2%), lactose, and other minerals such as calcium, phosphorus, and potassium. It is made through milk fermented with cultures of L. delbrueckii and Lactococcus lactis or Lactobacillus plantarum [15]. Yellow curd (YC) is a traditional Iranian food that is made from yoghurt, wheat flour, and local herbs and species. The most abundant bacteria in yellow curd were Lactobacillus (57%), Pediococcus (14%), and Streptococcus (12%). Lactobacillus plays a crucial role in traditional fermentation samples and is known for its probiotic and technological benefits [15]. Custard cream spoilage is not well studied, even though it's widely used in desserts like cream puffs and pastries. It is made from milk, sugar, eggs and sometimes vanilla or starch custard cream is a nutrient medium that can encourage bacterial growth, even when chilled. Spoilage has been linked to bacteria such as *Bacillus cereus*, *Strephlococci* lactic acid, and Psychotropic Gram-negative rods [18].

Yeast

Yeasts contribute minimally to dairy fermentations, but some fermented milk products naturally contain yeast, resulting in unique characteristics. Unlike products made solely with lactic acid bacteria, these have different physical and microbiological properties. In these products, yeast activity leads to mild alcoholic fermentation alongside the lactic acid fermentation driven by bacteria.

Non-Starter Lactic Acid Bacteria

Mesophilic lactobacilli, though overshadowed by *Lactococcus* during milk acidification, play a role in cheese ripening as secondary flora. They are especially common in raw milk cheeses but are also found in pasteurized varieties. Propionic acid bacteria are key secondary microorganisms in Swiss-type cheeses. Following lactic acid fermentation, they convert lactate into propionate, acetate, and carbon dioxide, the latter creating the characteristic holes, or "eyes," in the cheese. Recently, there has been renewed interest in their role in enhancing flavor.

Curd

Curd is a dairy product that is obtained by coagulation of milk. And the process that is used is curdling. *Lactobacillus* is the genus of bacteria and its main function is to convert sugar into lactic acid by the process of fermentation. *Lactobacillus* can convert lactose into lactic acid and provide a sour taste to curd. When acidic substances like vinegar or lemon juice are added then it will curdle the milk into two separate parts. The liquid part is known as whey and the solid part is known as curd. So, the whey contains the whey protein of milk, whereas the curd contains casein. When the milk gets older it is highly separated without

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adding any citric acid. *Lactobacillus* and *Streptococcus* bacteria enhance the flavor and texture of the curd by producing volatile compounds like acetic acid, diacetyl, and acetaldehyde.

Yogurt

It is produced by the process of fermentation of milk by two specific species of bacteria *Lactococcus thermophilus* and *lactobacillus bulgaricus* which they used as a starter culture and added to the milk. It is prepared by heating milk at about 80C to kill any type of additional bacteria that are present in the milk. Milk is allowed to cool slowly and it is inoculated with a bacterium and then allowed to ferment at room temperature. The bacteria used in the formation of yoghurt are *Streptococcus Salivarius* subsp. *Thermophilus* and *lactobacillus delbrueckii* subsp. Probiotic bacteria which include lactobacillus acidophilus, bifidobacteria, and Streptococcus thermophilus these species are highly used in the formation of yoghurt and it is known as bioyogurt. As the fermentation process is used in the formation of yoghurt, then these microbes contain lactose that produces lactic acid [19]. So, lactic acid creates an acidic environment and lowers the pH of the milk. This acidic environment can cause casein milk protein to coagulate and denaturation, forming a semi-solid texture. On the other hand, it is responsible for yoghurt thickness and structure. Then, lactic acid is responsible for the tangy flavor while another bacterial activity provides a creamy texture to the yoghurt.

Cheese

Cheese is a dairy product that is formed by the process of coagulation of milk protein, and then it separates the curds (solid part) from the whey (liquid part). Curd and whey help in the ripening and ageing of cheese. The production of cheese is similar to the production of yoghurt but it contains some additional steps and other enzymes are also involved [20]. So, the coagulation depends on two methods which include acidification and proteolysis. Acidification occurs when the lactic acid bacteria ferment the lactose then they produce lactic acid. Some bacterial strains which include Streptococcus thermophilus, Lactococcus lactis, and Lactobacillus sp. are used in the production of cheese. The acidification causes casein to coagulate also involved in the production of cheese which includes chymosin (it is a protease enzyme that helps to break protein). In the second step, the curd which holds the casein and milk fat is separated from the whey. Depending on the variety of cheese, the curd can be heated, salted, pressed, and after all, molded into various shapes and sizes [21]. Salt is added which helps to enhance the flavor and helps in the preservation of cheese. During the stage of ageing the cheese is transformed into fresh cheese in which its flavor, texture, nature, and of cheese are highly due to the presence of different microbes. The cheese flavor is highly associated with the catabolism of amino acids. Different amino acids are responsible for different flavors which are as follows. I-Aromatic amino acids which include (Phe, Trp, and Tyr) produce chemical, fecal flavors, and floral. I-sulfur-containing amino acids including Cys and Met) are transferred to meaty, garlic flavors and boiled cabbage. III-Branched chain amino acids including Leu, Ile, and Val) are converted into a fruity, sweaty flavor and malty [22].

Kefir

Kefir is a fermented dairy drink produced only when specific microbes act on milk. It is made up of kefir grains and some other combination of yeast, bacteria, acetic acid bacteria, and mycelial fungi. Lactic acid bacteria like lactobacillus acidophilus, lactobacillus casein, and lactobacillus kefir, etc. On the other hand, acetic acid bacteria include acetobacter acetic and yeast include Candida, Saccharomyces, and Torula kefir. These grains and bacteria are added to the milk and show a symbiotic relationship. Over time, typically about 12-48 hours at room temperature, yeast and bacteria in the grains start fermentation in the milk. This process produces carbon dioxide, lactic acid, and less amount of alcohol, giving a slightly tangy flavor. Accumulation of lactic acid makes the pH of the milk decrease and causes the protein to coagulate the milk to become thick. As a result, the creamy texture of kefir occurs. The last stage is after the fermentation, the kefir grains are removed and result in kefir [23].

Kumis

Kumis is also similar to the kefir but it contains liquid starter culture as compared to kefir grains which produce bactericides, antibiotics, and lactic acid. It is usually made by the process of fermentation (lactose into lactic acid and alcohol). Traditionally, mares' milk is used in Kumis because of lactose concentration. This lactose is essential for the fermentation process. As the milk is fermented, then the bacteria produce lactic acid which provides a sour flavor, while the yeast in the Kumis produce carbonation and alcohol. After ageing, kumis is aged for a few days to enhance their flavor complexity [24]. To ensure a thorough and systematic approach, this review article on the role of microbes in dairy product production was structured methodically. The initial step involved defining the scope, emphasizing prominent microbial species such as Streptococcus, Lactobacillus, and Bifidobacterium, which are integral to dairy fermentation processes. The review also sought to investigate their contributions to the production of various dairy products, including yoghurt, butter, cheese, kefir, and buttermilk. Additionally, it examined the impact of these microbes on the flavor, texture, nutritional profile, and shelf life of these products,

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while also addressing challenges and advancements in microbial applications across traditional and industrial dairy production systems.

Literature Search Strategy

The literature search strategy for this review on the role of microbes in dairy product production was designed to be thorough and systematic, aiming to identify relevant research from various scientific sources. Key databases, including PubMed, Scopus, and Google Scholar, were searched to gather a diverse range of studies related to microbial activity in dairy production. The search used specific keywords such as "microbes," "lactic acid bacteria," "dairy production," "probiotics," "fermentation," "starter cultures," and "microbial enzymes," combined with Boolean operators to narrow and refine the results [25]. The search was limited to articles published between 2010 and 2024 ensuring that only the most up-to-date research was included. Studies were selected based on predefined criteria, focusing on peer-reviewed research that explored microbial roles in fermentation, flavor enhancement, texture changes, and preservation in dairy products [26]. Special emphasis was placed on studies discussing starter cultures, probiotics, and microbial enzymes. Articles that were non-peer-reviewed, unrelated to dairy production, or published in languages other than English were excluded. The screening process began with an assessment of titles and abstracts, followed by a full-text review of the relevant studies to assess methodological quality and relevance. Data management tools like EndNote and Excel were used to organize references and extract essential information. This strategy enabled the review to comprehensively synthesize current knowledge on the microbial role in dairy product production, emphasizing recent advancements and identifying research gaps for future exploration.

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for this review were established to ensure the selection of relevant and high-quality studies focusing on the role of microbes in dairy production. Studies eligible for inclusion specifically addressed microbial contributions to processes such as fermentation, flavor development, texture improvement, and preservation in dairy products [27]. Priority was given to research on key microbial strains such as Lactococcus, Bifidobacterium, Streptococcus, and Lactobacillus as well as their use in starter cultures, probiotics, and microbial enzymes. Only peer-reviewed original research articles, systematic reviews, and meta-analyses published between 2010 and 2024 were included to capture recent advancements in the field. Articles were required to be in English and employ either traditional microbiological methods or modern techniques like metagenomics, proteomics, and metabolomics. The review also incorporated studies exploring a range of dairy products, including cheese, kefir, yoghurt, buttermilk, and other fermented milk products. Studies were excluded if they did not specifically address dairy production or the role of microbes in dairy-related processes. Research that concentrated on non-microbial aspects, such as chemical or mechanical methods, was not considered [28]. Non-peer-reviewed sources, including conference proceedings, promotional materials, and opinion pieces were also excluded. Articles written in languages other than English or those that lacked adequate methodological detail or clear conclusions were omitted. Additionally, research focusing on microbes in non-dairy food products or unrelated industrial applications was not included. Studies published before 2010 were excluded unless they offered significant foundational insights crucial for understanding historical progress in the field. These exclusion criteria were implemented to maintain a precise and thorough analysis of microbial contributions to dairy production [29]. Tools like EndNote and Excel were employed to effectively manage and organize the data gathered from the literature search. EndNote was mainly used to store and arrange references, ensuring accurate citation management and easy access to relevant studies. It also enabled the classification of articles based on key topics such as microbial species, fermentation processes, and types of dairy products. For data extraction and organization, Excel was used to summarize key details from each study, including the microbial strains investigated, the methodologies applied, and the results obtained. This approach facilitated an efficient comparison of findings across the studies. By leveraging these tools, the review process was made more efficient, providing a structured and organized way to synthesize the literature on microbial roles in dairy product production [30].

Quality Assessment of Studies

The quality assessment of studies was an essential part of the review process to ensure the inclusion of dependable and high-quality research [31]. Each study was examined based on several critical factors, such as the clarity and rigor of its design, the suitability of the methodologies used, and the reliability of the results. Preference was given to studies that employed robust experimental designs, including appropriate control groups, sufficient sample sizes, and reproducible outcomes [32]. The transparency of the methodology was another important consideration, with studies that provided clear protocols for microbial identification, fermentation techniques, and data analysis being favoured. Additionally, the quality of the study's reporting was evaluated, with a focus on how comprehensive the findings were, whether relevant data were included, and how well-supported the conclusions

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were. Only studies demonstrating strong methodological quality and scientific rigor were included in the review, ensuring that the findings were credible and directly relevant to understanding the role of microbes in dairy product production[33]. In some fermented milk products, certain yeasts have limited roles, and that too, are not important. They release only moderate alcohols and carbonation along with the lactic acid that is formed by the bacteria. This alters the product's texture, taste, as well as the smell of the product, making the product mildly effervescent and possess a different taste. These differences make them different from products that contain only lactic acid bacteria, which give a relatively simple sour taste and rather stiff structure(Table 1).

Table 1: Yeast Involvement in Dairy Products

Aspects	Yeast-Involved Products	Lactic Acid Bacteria Products	Reference
Taste	Unique, Mildly Effervescent	Simple Sour Taste	[34]
Texture	Softer, with Slight Carbonation	Stiffer Structure	
Aroma	Distinct, Due to Alcohol Traces	Plain, Lactic Acid-Driven Aroma	

As stated in the research article, the results that we should discuss here are in Mesophilic lactobacilli though less active than Lactococcus in the initial periods of milk acidification they occupy an important secondary position in the cheese ripening process. These bacteria are most commonly seen in cheeses made from raw-milk cheese however this bacterium can also be found in pasteurized ones as well. They clarify it during the ripening process in that they take part in the formation of the cheese characteristics which is maturing. These bacteria not only improve the taste of cheese but also improve the texture of the cheese ultimately making the cheese more enjoyable (Table 2).

Table 2: Bacteria Used in Different Metabolism

Process Steps	Actions	Results	Reference
Lactate Metabolism	Propionic Acid Bacteria Break Down Lactate	Formation of Propionic and Acetic Acids	[35]
Carbon Dioxide Production	Byproduct of Fermentation	Creation of 'Holes' In Swiss Cheese	
Flavor Development	Fermentation Products Influence Taste	Unique Flavor Profile	
Research Focus	Study of Bacterial Roles in Cheese-Making	Diversification of Cheese Varieties	

As mentioned in the research article the results have been interpreted should become in Propionic acid bacteria are important for the formation of Swiss-type cheeses. After that, they metabolize lactate into propionic acid, acetic acid, and carbon dioxide Their fermentation products include. Carbon dioxide forms the 'holes' or eyes in the cheese. In the recent past, there has been much focus on understanding the role of these bacteria in creating flavor profiles and exponentially increasing the diversification of cheese [17]. The results we have interpreted that curd is formed by coagulating milk where Lactobacillus change the lactose into lactic acid resulting in the curd having an acceptably sour taste. When a larger quantity of acid like vinegar or lemon is included in milk the milk separates into curd and whey. Lactobacillus and Streptococcus bacteria add to the flavor of curd and in the case of diacetyl the texture(Table 3).

Table 3: Different Process Used in Curd Products

Process Steps	Actions	Results	Reference
Coagulation	Lactobacillus Ferments Lactose To Lactic Acid	Sour Taste and Curd Formation	[36]
Acid Addition	Vinegar or Lemon Causes Curd-Whey Separation	Rapid Curdling	
Bacterial Activity	Lactobacillus and Streptococcus Enhance Flavor	Improved Taste and Texture	
Diacetyl Production	Created by Bacteria	Contributes to Smooth Texture	

Yoghurt is produced using bacteria such as Lactococcus thermophilus and Lactobacillus bulgaricus that help change lactose to lactic acid. This acid reduces the pH of milk, solidifies the proteins to a semi-solid state and imparts taste to yoghurt and the core It also imparts a tangy taste and creamy texture to yoghurt(Table 4).

Table 4: Different Processes Used in Milk

Process Steps	Actions	Results	Reference
Fermentation	Bacteria Convert Lactoseinto Lactic Acid	Acidification of Milk	[37]
Protein Solidification	Reduced pH Solidifies Milk Proteins	Semi-Solid Texture	
Flavor Development	Lactic Acid Activity	Tangy Taste and Creamy Consistency	

As we can consider, as the article reviewed, we researching might, Cheese is a dairy product that is produced through the process of coagulation of milk proteins. Some lactic acid bacteria are specialized in lactose to lactic acid conversion, which makes casein clump and thus form a curd while the waste material is known as whey. Such enzymes as chymosin continue the protein coagulation leading to curd formation. Those curds are subjected to heat, salt, pressure and ripening to form textures and flavors in the cheese. Microorganisms act on amino acids during ageing to create a litany of various flavors(Table 5).

Table 5: Different Process Used in Cheese Products

Process Steps	Actions	Results	Reference
Coagulation	Lactic Acid Thickens Casein	Separation of Curds and Whey	[38]
Enzymatic Breakdown	Chymosin Breaks Down Proteins	Formation of Curds	
Processing	Heating, Salting, and Pressing	Improved Texture and Preservation	
Ageing	Microbial Breakdown of Amino Acids	Development of Distinct Flavors	

when reviewing the researched article results could be, during fermentation, bacteria for example, Lactobacillus and Streptococcus and yeast by way of Saccharomyces

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and Candida catalyze the change of lactose into lactic acid, alcohol and carbon dioxide. This process provides kefir with a sour flavor, mild carbonated, and smooth. Kefir can be used as a friendly bacterial culture for yoghurt yoghurt-making process. There are both bacteria and yeast in kefir therefore making it a good source of probiotics, which are good for the tummy. Furthermore, the process of fermentation increases the nutritional quality of the included components(Table 6).

Table 6: Different Processes Used in Kefir Products

Component	Role in Fermentation	Results	Reference
Lactic Acid Bacteria	Ferments Lactose into Lactic Acid	Tart Taste, Probiotic Benefits	[39]
Yeast (Saccharo-myces, Candida)	Produces Alcohol and Carbon Dioxide	Fizz and Creamy Texture	
Combined Action	Synergistic Fermentation	Nutritional Enhancement	

Milk and milk products have been a significant part of Pakistan's agricultural and food market and the basic products in this sector include milk, cheese, yoghurt and butter. Biological technologies in the production and processing of these products have remained the key factors in improving the quality, nutritional value and shelf life of such products. Given the fact that Pakistan is among the largest producers of milk in the world, the country presents a lot of risks for industries that engage in the use of microbes in the dairy business. These are in areas such as food processing, pharmaceuticals, biotechnology and farming. Players in the dairy chains source microbes like lactic acid bacteria (LAB), probiotics and enzymes to fulfil the consumer's need for healthy, functional and sustainable products. It is only in recent times that the biopharmaceutical industry of Pakistan has begun to realize the opportunities offered by dairy-based substrates for microbial enzyme production. Some of the microorganisms with enzymes such as lactase aid in the production of lactose-free products. Moreover, certain components of dairy are employed in the subculture of microbes for antibiotic production especially Penicillium strains [40]. Even though this industry is not fully developed in Pakistan, dairy products are easily available and relatively low-cost inputs are required for microbial boosters in pharmaceutical production. Biofuels and bioplastics that are developed industries also often use microbes farmed on dairy leftovers. Cheese manufacture results in whey, and because of the nutritional value of this product, microbial fermentation is highly recommended [17]. In Pakistan, research is being conducted and attempted on the usage of whey for the generation of bioethanol and several other biofuels. Likewise, some bacterium transforms the waste generated by the use of milk into poly-hydroxy-alkanoates (PHAs), a kind of bioplastic. In addition, these applications help to put value in dairy waste, solve environmental issues, and produce a circular model [41]. This food and beverage sector in Pakistan incorporates high ingredients of dairy products for microbial fermentation. Examples of foods that use bacterial cultures include yoghurt which uses Lactobacillus and Streptococcus bacteria, cheese and kefir. Currently, the demand for probiotic-containing dairy products is on the rise and therefore; food manufacturing firms both domestic and international players in Pakistan have been directing their investments on these products. Beneficial microbes dominate dairy substrates where milk is converted into functional foods in accordance to the health-conscience market. The increasing understanding of gut health has introduced an opportunity that calls for integration between the dairy industry and microbial research facilities. This sector employs agents such as Rennet through microbial fermentation in the preparation of cheese. Lactose is also excluded through microbial enzymes to meet the lactose-sensitive market demand. In Pakistan, the biotechnology industry has also started implementing these processes to exploit its home and export markets [42]. The cosmetics industry is using microbes cultured in a dairy substrate to develop bioactive chemicals. Microbial fermentation-based compounds for instance hyaluronic acid and peptides are used in cosmetics [43]. This industry in Pakistan is inclined towards these natural and environmentally friendly approaches and can fulfil international customer demands for organic makeup [44]. In the dairy sector, microbes are very useful for the preparation of cultures that are used to support products such as cheese and yoghurt. Pakistan's dairy businesses are now exploring microbial technology to enhance fermentation operations product quality and shelf life [45]. In their internal application, these microbes encourage local manufacturing and lower reliance on imported cultures. Waste from the dairy industry including whey and spoilt milk can be converted to biofuels and fertilizer through the use of microbes. Sewage waste such as such waste is today finding its way into Pakistan's biogas plants with microbes decomposing it into methane and carbon dioxide. This approach of taking time to implement energy solutions fits well with the country's strategy to embrace sustainable energy solutions[46].

Future Perspective

Although microbes have played a vital part in dairy production for centuries, their significance is only expected to grow in the upcoming decades as a result of developments in biotechnology, rising consumer demand for environmentally friendly and healthier food products, and a better understanding of microbial ecosystems. Some of the future perspectives are mentioned. The market for dairy products, notably kefir and yoghurt that contain bacteria that are beneficial to health when ingested in sufficient quantities is already expanding. Probiotic dairy

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products will proliferate in the future, with a wider variety of strains designed to enhance immune function, improve gut health, or treat certain medical issues like lactose intolerance or even mental health [47]. Also, by improving the beneficial microbial populations in the gut or producing strains that are resistant to pathogens, advanced genetic engineering may enable the creation of personalized probiotics that can more successfully target illnesses. While current technological advances allow for more control over microbial activity, traditional fermentation techniques have relied on naturally occurring microbial populations. By altering their genetic composition, scientists will be able to create microorganisms with extremely precise characteristics, such as the capacity to manufacture specific tastes, vitamins, or bioactive peptides, because of the development of synthetic biology. This will make it possible to produce dairy products with even more accuracy, enhancing their texture, flavor profiles, and nutritional value. Furthermore, dairy proteins like casein or whey can be produced using precision fermentation instead of animal milk, resulting in completely new kinds of dairy-like products that may help satisfy consumer desire for plant-based or lab-grown substitutes [48]. Dairy production is probably going to be significantly impacted by personalized nutrition. Developments in microbiome science may make it possible to produce dairy products that are especially suited to a person's genetics, gut microbiota, and medical requirements [49]. To maximize the health advantages for every customer, this might involve developing customized probiotic strains, prebiotics, or even particular kinds of dairy proteins. There is growing pressure on the dairy business to adopt a more sustainable practice. Improved feed digestibility and lower methane emissions from dairy cows are a couple of demonstrations of how microbial technologies may help dairy farmers adopt more environmentally friendly methods [50]. To reduce waste and increase resource efficiency, microbes may also be utilized to upcycle dairy waste, such as whey, into useful goods like protein isolates or bioactive compounds. There will probably be a big change in the dairy industry in the future toward functional meals. Dairy products will be more often designed to provide particular health advantages, such as reduced inflammation, better digestion, or boost immunity, as scientific understanding of the microbiome and gut health improves [51]. Synthetic biology-created microbial cell factories can produce dairy proteins like whey and casein for use in plant-based or allergy-free substitutes that replicate the flavors and textures of traditional dairy products [52]. Probiotic strains that can tolerate environmental stressors like heat and acidic pH are being found and improved using genomic methods. These resistant strains increase the probiotics' stability and effectiveness in dairy products, guaranteeing that their health benefits continue even after processing and storage. NGPs are modified strains created to offer improved advantages such as customized medicinal effects, targeted delivery, and gut microbiota manipulation. They might be significant in creating dairy products that are enhanced with bioactive substances for therapeutic and individualized nutrition. This invention is the result of developments in bioinformatics and synthetic biology, which enable accurate strain engineering and selection [53]. The use of microbial fermentation to produce non-dairy functional foods that replicate the nutritional profile and sensory qualities of conventional dairy products is becoming more popular as lactose sensitivity and veganism increase. This includes goods like probiotic-fermented plant-based cheeses and yoghurts, which broaden the range of dairy-like uses while preserving health advantages [54-57]. AI and machine learning are becoming more and more useful technologies for improving fermentation and microbial strain selection. These technologies can improve flavor profiles, anticipate microbial behaviour, and maximize the nutritional content of dairy products by evaluating massive databases [58-60].

CONCLUSIONS

It was concluded that as customers look for more creative, sustainable, and nutrient-dense food options, microbes will become more and more significant in the manufacture of dairy products. Microbes will increasingly shape the future of dairy products as a result of developments in fermentation technology, synthetic biology, and microbial genomics. The future of dairy is probably going to be impacted by the untapped potential of microbial innovation, whether it is through the development of novel probiotic strains, the application of microbes in environmentally friendly production methods, or the creation of entirely new dairy-like products. By enabling customized and regionalized flavor profiles that satisfy a range of customer tastes, microbial collaborations could be used to improve the taste, texture, and shelf life of products. Additionally, combining artificial intelligence with microbial fermentation systems could optimize industrial procedures, lowering expenses and increasing productivity.

Authors Contribution

Conceptualization: MN
Methodology: MN, AA, JE, FS
Formal analysis: MN
Writing review and editing: SP, KAK

All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

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