Pradeep Verma *Editor*

Industrial Microbiology and Biotechnology

An Insight into Current Trends

Springer

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Dedicated to My Beloved Mother

Preface

The field of microbial biotechnology is one of the most robust moving areas in life sciences and has a significant impact on all areas of biology. Though microorganisms are ubiquitous, they are usually recognized as villains. However, the benefits of microorganisms and their sheer role in the existence of life and maintaining ecological balance cannot be overlooked. These beneficial microorganisms act as biofactories for industrially significant biomolecules. Also, the fast-paced technological advancements provide new insights into techniques that allow rapid identification of novel microorganisms and biomolecules along with genetic improvement of species that are market-driven. Thus, this book provides a multidisciplinary overview of all aspects of microbial biotechnology, beginning from cell biology to genetics and evolution.

The impact of modern-day microbial biotechnologies on healthcare, fermented food industries, health sectors, etc. lives globally. Besides, the emerging trends in oligosaccharide production and their potential application in sectors like prebiotics, their industrialization, and use of modern technologies further increase their utility in the world. Also, the amalgamation of microbial biotechnology in agriculture such as microalgae in biofertilizers, microbial two-component and regulatory systems during aerobic-anerobic shifts have proven to be very useful in the light of sustainable development. Thus, this book focuses on how modern technological advancements in microbiology have impacted lives globally. The book also includes its impact on various domains in the day-to-day world, such as food technology, agriculture, healthcare, and the synthesis of biomaterials. Considering all the points, this book is a lively mix of content for teaching, research, and developments across the field.

The third volume is focused on the role of bacteria, and fungi, in various biotechnological and industrial sectors, exploring the advanced approaches and techniques for enhanced production of industrially relevant bioproducts. The microbe-assisted agro-industrial waste valorization for green energy generation, a sustainable biorefinery (SB) approach, technological advancement, and the development of scale-up processes are also discussed. Further, the book includes a microbial technology role model to develop biobased and green environmental approaches in various domains such as bioremediation, biodegradation of chemicals, and emerging technologies in medical microbiology, i.e., detection of disease, treatment, prevention, and how it has impacted significantly on the global health of the human population. Current trends include biomaterial development using microbial products, nanotechnology, and hydrogels, and how biobased technological advancements can be incorporated into human lives. The book is developed with the motive to benefit students, academicians, as well as researchers and also find interest among microbiologists, biotechnologists, environmentalists, and engineers working in the application of the microbes-based approach for the development of greener technologies.

Pradeep Verma

Acknowledgment

First of all, I would like to convey my gratitude towards Springer Nature for accepting my proposal to act as editor for this book volume. This volume of the book series could not be possible without the support from all the researchers and academicians who contributed to the book. I thank them for their quick response to my invitations and immense support during the revision stage. I am also thankful to the Central University of Rajasthan (CURAJ), Ajmer, India for providing infrastructural support and a suitable teaching and research environment. The teaching experience to the graduate, postgraduate, and young researchers at CURAJ provided the necessary understanding of the needs of academicians, students, and researchers in an industrial microbiology book that was greatly helpful during the development of the book and also made all possible attempts to overcome existing limitations in the literature. I am also thankful to the Department of Biotechnology for providing me funds through sponsored projects (Grant No. BT/304/NE/TBP/2012 and BT/PR7333/PBD/26/373/2012) and for setting up of my laboratory "Bioprocess and Bioenergy Laboratory."

I am always thankful to God and my parents for their blessings. This book is affectionately dedicated to the most caring and loving women (mother and wife) in my life. Their love, care, and trust gave me the strength and motivation to contribute to the scientific world. I also express my deep sense of gratitude to my wife and kids for their support during the development of the book and in life.

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Editor and Contributors

About the Editor

Pradeep Verma completed his Ph.D. from Sardar Patel University Gujarat, India, in 2002. In the same year, he was selected as a UNESCO fellow and joined the Czech Academy of Sciences Prague, Czech Republic. He later moved to Charles University, Prague, to work as a postdoctoral fellow. In 2004, he worked as a visiting scientist at UFZ Centre for Environmental Research, Halle, Germany. He was awarded a DFG fellowship that provided him with another opportunity to work as a postdoctoral fellow at Gottingen University, Germany. Later in 2007, he returned to India and joined Reliance Life Sciences, Mumbai, and worked extensively on biobutanol production, which attributed a few patents to his name. Later, he was awarded JSPS Post-Doctoral Fellowship Programme and joined the laboratory of Biomass Conversion, Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Japan. Professor Verma has also been the recipient of various prestigious awards such as the Ron Cockcroft Award by Swedish Society, and UNESCO Fellow ASCR Prague. Recently for his contribution to the area of fungal microbiology, industrial biotechnology, and environmental bioremediations, he has been awarded the prestigious Fellow Award from Mycological Society of India (2020), P.C. Jain Memorial Award (MSI), and Biotech Research Society of India (2021). In 2020, he was also awarded fellow of Biotechnology Research Society of India (BRSI) and Fellow of Academy of Sciences of AMI India 2021 (FAMSc). Furthermore, he has also been awarded the JSPS Bridge Fellow Award in 2022 and made a short-term visit to Kyoto University, Kyoto, Japan, to strengthen ties between the two laboratories.

In 2009, Professor Verma began his academic career as a reader and founder head at the Department of Microbiology, Assam University. In 2011, he moved to the Department of Biotechnology at Guru Ghasidas Vishwavidyalaya (a Central University), Bilaspur, and served as an associate professor till 2013. He is currently working as a professor at the Department of Microbiology, CURAJ (Central University of Rajasthan), and was also the former head and dean, School of Life Sciences. He is a member of various National and International societies/academies and has also completed two collaborated projects worth 150 million INR in the area of microbial diversity and bioenergy. His area of expertise involves microbial diversity, bioremediation, bioprocess development, lignocellulosic, and algal biomass-based biorefinery. He holds 12 international patents in the field of microwave-assisted biomass pretreatment and biobutanol production. He has more than 92 research and review articles in peer-reviewed international journals and contributed to 64 published book chapters in different edited books. He has also edited 18 books for various international publishers. He is a guest editor to several journals.

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1 Significant Influence of Microbial Biodiversity in the Biotechnological and Industrial Sectors

Kumari Guddi, Renupama Bhoi, Sreemoyee Sensharma, and Angana Sarkar

Abstract

Microorganisms can thrive on a wide variety of chemical substrates and can be found practically anywhere, even under conditions of high pH, high salinity, high temperature, and high pressure. Because of the values and social implications of their industrially significant outputs, microorganisms and microbial products have become incredibly significant research issues. Fermentation is the primary source of microorganisms that are often used in large-scale production processes to create products or perform chemical treatments. Microbes are all around us and come in a variety of strains. To establish an economically feasible method, it is essential to identify and isolate the best strain and perform effective product extraction. The advancement of microbial screening procedures necessitates an interdisciplinary method that considers chemists, technologists, and microbiologists. saccharomyces cerevisiae, streptococcus etc. When it comes to large-scale production, microorganisms are an excellent choice because of their short time requirements and high pure-product output. Genetically engineered microorganisms have a variety of applications these days, such as bioremediation, industry, agriculture, medicine, and energy production, in order to improve product quality and yield. This book chapter provides an overview of industrially important microorganisms such as bacteria, yeasts, fungi, and genetically modified organisms in the manufacturing of various valuable products in different industries such as food and beverages, pharmaceuticals, and paint.

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Keywords

Microorganism · Industries · Bacteria · Fungi · Yeasts · Genetically modified organisms

1.1 Introduction

Microbes are the most important components of living systems on Earth, and they are found everywhere, including the air, water, soil, and also within our bodies. Other animals and plants contain them as well. Microbes vary in size and shape and are so tiny that they are invisible to the naked eye. They are only visible under a microscope. As a result, they are sometimes known as microscopic organisms. Bacteria, protozoa, algae, fungi, and viruses are examples of microorganisms. In the chemical industry, microbes are commonly used to manufacture a variety of chemicals useful to humans (Sengupta and Bhowal 2023). Many industrial items are synthesized from microorganisms, for example, food and beverages; antibiotics, vaccines, and other medicinal products; biofuels and pigments; and chemicals and bioactive molecules (Çobanoğlu and Yazıcı 2022). Microorganisms are like little chemical factories in biotechnology and biomanufacturing, producing essential products, including amino acids, enzymes, medications, and food additives. They have long been used to convert biological resources for the manufacture of fermented foods, cheese, and chemicals. For thousands of years, humans have utilized bacteria, fungi, and yeasts to produce a range of foods, including beer, bread, wine, yogurt, vinegar, and cheese along with fermented fish, vegetables, and meat. By utilizing huge quantities of microorganisms, a variety of biological preparations vital to the fields of medicine and pharmaceuticals have been created. Microorganisms have a significant impact on the production of food and beverages. Pasteurized milk is inoculated with a specific microbial culture in the process of milk fermentation. Yogurt and cheese are two fermented dairy products that are made from milk. They are useful for changing the nature of a substance so that it can be safely consumed. Bacteria are essential for the fermentation process, which yields a variety of products. Fruit juices, certain antibiotics, malted cereals, and fermented beverages are among the products obtained through industrial fermentation. Lactose, or milk sugar, is fermented by bacteria such as *Streptococcus salivarius*, *Lactobacillus acidophilus*, and *Streptococcus thermophiles*, which generate lactic acid (LA). All these bacteria are collectively called lactic acid bacteria or LAB (Oyeleke 2009). The business of milk fermentation is enormous, accounting for all milk-based drinks and yogurts, and is valued at about €46 billion globally (Marsh et al. 2014). Inoculation of milk with a microbial culture containing particular bacteria produces cheese. Yeast, which is a saprophytic and single-celled fungus, secretes enzymes that digest sugar and mineral-rich foods. It is mainly used in the baking of bread (Edema et al. 2005). *Yarrowia lipolytica*, a nonpathogenic yeast, is engaged in the production of foods, food components, biomass that may be utilized as food or feed, and in the efficient treatment of food wastes (Zinjarde 2014). Bioprocessing technology employs microbes and their enzymes to create valuable products with desirable quality attributes such as improved taste, shelf life, flavor, mouthfeel, color, and texture through amino acid conversions, acidification, proteolysis, and alcoholization (De Roos and De Vuyst 2018). Food, fine chemical, and pharmaceutical sectors all rely on bioprocessing plants. A bioreactor can be as little as 2–100 L in size in the lab, but it can be as large as 100 m^3 in commercial processes or large-scale operations. Microbes are employed in a variety of sectors to make vinegar and various forms of alcohol due to their high rate of activity. They are utilized in the pharmaceutical industry for chemical compound production and medicinal research. Nowadays, microorganisms are also used in the chemical industry for the production of biofuels and organic acids. In this sense, they are beneficial from an industrial standpoint due to their large influence on compound manufacture.

This book chapter enlightens the role of microorganisms in industrial bioprocessing. The role of recombinant microbes in industries is also discussed.

1.2 Industrial Products Obtained from Microorganisms

Microbes have been used from the dawn of human civilization, with the Babylonians and Sumerians using yeast to make alcoholic drinks from barley as early as 6000 BC (Singh et al. 2016). Many parts of Europe, Asia, Africa, the Middle East, and South America are native to the fermentation of milk, grains, and other substrates to generate healthy drinks. In China, fermented rice, honey, and fruit drinks have been found in clay containers dating back to 7000 BB (McGovern et al. 2004).

Industrial microbiology uses different microorganisms, like wild-type organisms, selected mutants, and genetically modified organisms, to produce an extremely large assortment of industrial products in huge quantities. By utilizing microorganisms in significant quantities, a number of biological preparations important to the field of drugs and pharmaceuticals are developed. The bioprocesses developed for a huge range of economic products and microbial products in the last few years are listed in Table 1.1.

1.2.1 The Food and Beverage Industry

In the food and beverage industry, microbes have an excellent influence on both the quality and quantity of the products produced. Fermentation of milk is completed by its inoculation with a specific culture of microbes. Fermented milk drinks are popular in Africa, where the technique of fermenting items is transmitted from generation to generation. Suusac, amasi, kivuguto, and garris are examples of such drinks. Togwa, a nonalcoholic beverage, is one of the more well-studied grain drinks in Africa. Kvass, a fermented rye bread beverage, has become quite popular commercially in Russia. This beverage has a rye bread flavor that is effervescent, sweet, or sour. Hardaliye, a Turkish nonalcoholic fermented beverage, is prepared from red grapes, cherry leaves, benzoic acid, and black mustard seeds. Bushera is made from germinated or ungerminated sorghum grains. Amazake is one of the popular

Table 1.1 Microbial products in different industries

S. no.	Industries	Products	Microorganisms	Types of microorganisms	References
1.	Food and beverages	Bread	*Saccharomyces cerevisiae*	Yeasts	Asyikeen et al. (2013)
		Lactic acid	*Lactobacillus rhamnosus*	Bacteria	Bernardo et al. (2016)
		Wine	*Saccharomyces cerevisiae*	Yeasts	Ganucci et al. (2018)
		Nata	*Acetobacter xylinum*	Bacteria	Tamang et al. (2016a, b)
		Cocoa	*Fructobacillus pseudoficulneus*, *Acetobacter senegalensis*, *Tatumella ptyseos*, *Lactobacillus plantarum*, and *Tatumella citrea*	Bacteria	Tamang et al. (2016a, b)
			Issatchenkia orientalis, *Hanseniaspora uvarum*, *Pichia membranifaciens*, *Hanseniaspora guilliermondii*, *Saccharomyces cerevisiae*, and *Kluyveromyces*	Yeasts	
		Pidan	*Bacillus macerans*, *Staphylococcus cohnii*, *Staphylococcus warneri*, *Staphylococcus epidermidis*, *Bacillus cereus*, and *Staphylococcus haemolyticus*	Bacteria	Tamang et al. (2016a, b)
		Saké	*Aspergillus oryzae* and *Aspergillus sojae*	Fungi	Tamang et al. (2016a, b)
		Chocolate	*Lactobacillus fermentum* and *Acetobacter pasteurianus*	Bacteria	Tamang et al. (2016a, b)
		Cheeses	*Lactococcus lactis*, *Lactobacillus* spp., and *treptococcus* spp.	Bacteria	Macori and Cotter (2018)
		Ayran	*Lactobacillus bulgaricus* and *Streptococcus thermophiles*	Bacteria	Macori and Cotter (2018)
		Shubat or Chal	*Lactobacillus helveticus*, *Lactobacillus paracasei*, and *Streptococcus thermophilus*	Bacteria	Macori and Cotter (2018)
		Nunu	*Lactobacillus helveticus*, *Lactobacillus fermentum*, *Leuconostoc mesenteroides*, and *Lactobacillus plantarum*	Bacteria	Macori and Cotter (2018)
		Skyr	*Streptococcus thermophilus* and *Lactobacillus bulgaricus*	Bacteria	Macori and Cotter (2018)
		Ymer	*Lactococcus lactis*	Bacteria	Macori and Cotter (2018)
		Traditional yogurt	*Streptococcus thermophilus*, *Lactobacillus fermentum*, *Lactobacillus bulgaricus*, *Lactobacillus paracasei*, and *Lactobacillus helveticus*	Bacteria	Macori and Cotter (2018)

		Kefir	*Lactobacillus acidophilus*, *Lactococcus lactis*, *Bifidobacterium bifidum*, *Lactobacillus kefiranofaciens*, *Lactobacillus bulgaricus*, *Micrococci*, *Lactobacillus helveticus*, and *Leuconostoc* spp.	Bacteria	Macori and Cotter (2018)
			Kluyveromyces marxianus, *Saccharomyces cerevisiae*, and *Kluyveromyces lactis*	Yeasts	
		Garris	*Lactobacillus* (*Lb. fermentum*, *Lb. paracasei*, and *Lb. plantarum*), *Lactococcus*, *Leuconostoc*, and *Enterococcus*	Bacteria	Marsh et al. (2014)
		Kefir	*Lactococcus*, *Acetobacter, Lactobacillus*, and *Leuconostoc*	Bacteria	Marsh et al. (2014)
			Naumovozyma, *Kazachstania*, and *Kluyveromyces*	Yeasts	
		Kumis	*Lactobacillus cremoris*, *Enterococcus*, and *Lactococcus lactis*	Bacteria	Marsh et al. (2014)
			Clavispora lusitaniae, *Galactomyces geotrichum*, *Candida tropicalis*, and *Pichia kudriavzevii*	Yeasts	
		Nyarmie	*Lactobacillus lactis*, *Lactobacillus bulgaricus*, *Leuconostoc mesenteroides*, *Lactococcus lactis*, and *Lactobacillus helveticus*	Bacteria	Marsh et al. (2014)
			Saccharomyces cerevisiae	Yeasts	
		Suusac	*Leuconostoc mesenteroides* and *Lactobacillus* (*Lb. raffinolactis*, *Lb. plantarum*, *Lb. salivarius*, and *Lb. curvatus*)	Bacteria	Marsh et al. (2014)
			Candida krusei, *Rhodotorula mucilaginosa*, and *Geotrichum* sp.	Yeasts	
		Amazake	*Aspergillus* spp.	Fungi	Marsh et al. (2014)
		Kombucha	*Lactobacillus*, *Gluconacetobacter*, and *Acetobacter*	Bacteria	Marsh et al. (2014)
			Zygosaccharomyces, *Dekkera*, *Pichia Hanseniaspora*, *Candida*, *Torulaspora*, and *Saccharomyces*	Yeasts	
		Hardaliye	*Lactobacillus* spp.	Bacteria	Marsh et al. (2014)
		Bushera	*Streptococcus*, *Enterococcus*, and *Lactobacillus* sp.	Bacteria	Marsh et al. (2014)

(continued)

Table 1.1 (continued)

S. no.	Industries	Products	Microorganisms	Types of microorganisms	References
		Togwa	*Lactobacillus* spp.	Bacteria	Marsh et al. (2014)
			Saccharomyces cerevisiae and *Candida* spp.	Yeasts	
		Pozol	*Lactococcus lactis*, *Lactobacillus* (*Lb. delbrueckii*, *Lb. plantarum*, *Lb. alimentarium*, and *Lb. casei*), *Bifidobacterium*, *Streptococcus suis*, and *Enterococcus*	Bacteria	Marsh et al. (2014)
		Kvass	*Leuconostoc mesenteroides* and *Lactobacillus casei*	Bacteria	Marsh et al. (2014)
			Saccharomyces cerevisiae	Yeasts	
2.	Pharmaceuticals	Amphotericin B (antifungal)	*Penicillium nalgiovense*	Fungi	Svahn et al. (2015)
		Tetracycline (antibiotic)	*Streptomyces aureofaciens*	Bacteria	Bisen (2014)
		Probiotics	*Saccharomyces cerevisiae*	Yeasts	Gaziano et al. (2020)
		Vitamin K2	*Flavobacterium* sp.	Bacteria	Mahdinia et al. (2017)
		L-asparaginase	*Aspergillus terreus*	Fungi	Jozala et al. (2016)
		Lovastatin	*Monascus ruber* and *Aspergillus terreus*	Fungi	Jozala et al. (2016)
		Proteases	*Aspergillus* sp. and *Penicillium* sp.	Fungi	Jozala et al. (2016)
		Cyclosporin A	*Tolypocladium inflatum*	Fungi	Gupta et al. (2014)
		Pneumocandins	*Glarea lozoyensis*	Fungi	Gupta et al. (2014)
		Vitamin B12	*Pseudomonas denitrificans* and *Propionibacterium shermanii*	Bacteria	Gupta et al. (2014)
		Antioxidants	*Streptomyces* sp. USF-319	Bacteria	Gupta et al. (2014)
3.	Chemical	1,2-Propanediol	*Escherichia coli*	Bacteria	Conrado et al. (2012)
		Myo-inositol	*Escherichia coli* L19S	Bacteria	Gupta et al. (2017)
		Triacylglycerol	*Phaeodactylum tricornutum*	Algae	Daboussi et al. (2014)
		Ethanol	*Yarrowia lipolytica*	Yeasts	Tsigie et al. (2013)
		Isobutanol	*S. cerevisiae*	Yeasts	Avalos et al. (2013)

		Butanol	*Clostridium* spp., *Clostridium acetobutylicum*, and *Bacillus subtilis*	Bacteria	Bhatia et al. (2017)
		2,3-Butanediol	*Enterobacter cloacae* and *Klebsiella pneumonia*	Bacteria	Bhatia et al. (2017)
		Ethanol	*Saccharomyces cerevisiae*	Yeasts	Bhatia et al. (2017)
4.	Pigment	Carotenoid	*Phaffia rhodozyma* *Rhodococcus* sp. SC1	Yeasts Bacteria	Gupta et al. (2011) Çobanoğlu and Yazıcı (2022)
		Arpink red	*Penicillium oxalicum*	Fungi	Kumar et al. (2015)
		β-Carotene	*Blakeslea trispora*	Fungi	Gupta et al. (2014)
			Dunaliella salina	Algae	
		Lycopene	*Blakeslea trispora*	Fungi	Gupta et al. (2014)
			Streptomyces chrestomyceticus	Bacteria	
		Astaxanthin	*Xanthophyllomyces dendrorhous*	Yeasts	Gupta et al. (2014)
		Violacein	*Chromobacterium violaceum*	Bacteria	Malik et al. (2012)
		Torularhodin	*Rhodotorula glutinis*	Yeasts	Malik et al. (2012)
		Prodigiosin	*Streptoverticillium rubrireticuli*	Actinomycetes	Malik et al. (2012)
		Canthaxanthin	*Bradyrhizobium* (*photosynthetic*) and *Halobacterium* spp.	Bacteria	Malik et al. (2012)
		Pyocyanin	*Pseudomonas aeruginosa*	Bacteria	Sengupta and Bhowal (2023)
		Xanthophyll	*Erythrobacter* sp.	Bacteria	Jeong et al. (2022)

Japanese beverages prepared from fermented rice and serves as a nonalcoholic predecessor to saké. Pozol is made up of a range of microbes, including yeasts, LAB, fungi, and non-LAB, and is abundant in southeastern Mexico (Marsh et al. 2014). The Chinese eat pidan, which is a dish made from preserving fresh duck eggs treated with alkali as well as hydrogen sulfide and ammonia odor. The Philippine delicacy nata, bacterial cellulose generated by the action of *Acetobacter xylinum*, is consumed as candy. During the first phase of cocoa fermentation, *Lactobacillus plantarum*, *Acetobacter senegalensis*, *Tatumella citrea*, *Fructobacillus pseudoficulneus*, and *Tatumella ptyseos* are among the most common species used. In spontaneous cocoa fermentation for taste formation, *Pichia membranifaciens*, *Hanseniaspora uvarum*, *Issatchenkia orientalis*, *Saccharomyces cerevisiae*, *Hanseniaspora guilliermondii*, and the *Kluyveromyces* species are used. Chocolate is made from fermented cocoa beans, with the bacteria *Lactobacillus fermentum* and *Acetobacter* being the most commonly used cultures. In Japan, a mixture of *Aspergillus oryzae* and *Aspergillus sojae* is widely used to make koji, which is utilized to make alcoholic drinks such as saké (Tamang et al. 2016a, b). *Streptococcus thermophilus* and *Lactobacillus bulgaricus* protosymbiotic cultures are commonly used to make yogurt. Kefir, a beverage with health advantages, is fermented by the action of both bacteria and yeasts. The traditional Turkish fermented milk drink, Ayran, is prepared with the help of several bacteria like *Lactobacillus bulgaricus* and *Streptococcus thermophiles.* Shubat or Chal, fermented camel milk, is generated by the action of *Lactobacillus helveticus* and *Streptococcus thermophilus*. Camel milk is used to produce Gariss, which is a traditional fermented raw milk product (Macori and Cotter 2018).

1.2.2 The Pharmaceutical Industry

Several microbial compounds that can suppress an immune response have been discovered. An "antibacterial agent" inhibits or kills bacterial growth. The term is primarily used as a synonym for the term "antibiotics." However, today, as knowledge about the causative agents of various infectious diseases is increasing, antibiotics are becoming a broader spectrum of antimicrobial compounds, including antifungals and other compounds. Cyclosporin A was first launched as a narrow-spectrum and antifungal peptide generated by aerobic fermentation of *Tolypocladium nivenum* (formerly known by the name *Trichoderma polysporum* and subsequently *Tolypocladium inflatum*). It is utilized for heart, kidney, and liver transplants. Pneumocandins were effectively employed to produce an antifungal medicine that has been recently authorized by the Food and Drug Administration. Caspofungin acetate is a semisynthetic pneumocandin that is an aza-substituted derivative of pneumocandin, the natural compound generated from the fermentation of the fungus *Glarea lozoyensis*. Microorganisms such as *Pseudomonas denitrificans* and *Propionibacterium shermanii* produce vitamin B12. *Streptomyces* sp. generates three antioxidants that scavenge free radicals, one of which inhibits 5-lipoxygenase. Carotenoids are the last category of antioxidants that bacteria may produce. Carotene from *Blakeslea trispora* and *Dunaliella salina* as well as lycopene from *B. trispora* and *Streptomyces chrestomyceticus* have been authorized for use as colorants in human meals. Microbial sources of astaxanthin, such as *Xanthophyllomyces dendrorhous*, have been licensed for their use in fish feeds (Gupta et al. 2014). Live bacterial or other microbial supplements are also employed, which have positive effects on the host by enhancing the intestine's microbial balance. *Lactobacillus casei* is a probiotic that is used to treat gastrointestinal problems.

1.2.3 The Chemical Industry

Microorganisms play a vital part in the preprocessing of the lignocellulosic substrate, where enzymes present in microbes transform the grain into a hydrolysate that contains sugars, phenolic compounds, furans, and organic acids. The widely used microorganisms for industrial biofuel generation are baker's yeast, *Zymomonas mobilis*, and *Escherichia coli*. *Yarrowia lipolytica*, a nonpathogenic yeast, is usually regarded as harmless. An acid-hydrolyzed *Y. lipolytica* strain was used as a feedstock for the generation of ethanol (Tsigie et al. 2013). Butanol, like ethanol, is a renewable fuel that may be used to replace gasoline. It has a comparable energy content and octane rating to gasoline and may be used in engines without modification. Butanol is produced at a rate of 14.4 g/L by *Clostridium* spp. fermentation. *Clostridium acetobutylicum* and *Bacillus subtilis* coculturing have also been observed to produce butanol. *Saccharomyces cerevisiae* has been reported to produce 69.2 g/L ethanol. 2,3-Butanediol is utilized as a direct liquid fuel or as a starting point for the production of other compounds. For the manufacturing of 2,3-butanediol, many renewable feedstocks and pure carbon sources have been reported. The most well-studied bacteria for 2,3-butanediol fermentation are *Enterobacter* and *Klebsiella* (Bhatia et al. 2017).

1.2.4 The Pigment Industry

Color extraction from microbial sources is a relatively new area. Bacteria, fungi, yeasts, and algae are among the microorganisms that are colored. Simple and successful techniques are frequently used to extract natural colors from these sources. The advantages of making pigments from microbial sources include weather resistance, quick growth, ease, and the ability to produce a wide range of colors by growing on inexpensive substrates. Red, yellow, and blue pigments are the most common colors generated by microorganisms. The astaxanthin pigment is assembled by the yeast *Xanthophyllomyces dendrorhous* (*Phaffia rhodozyma*). These carotenoid pigments impart an orange-red color to livestock species when supplemented in their feeds (Gupta et al. 2011; Jeong et al. 2022).

The two types of pigments are organic or natural pigments and inorganic or synthetic pigments. The natural occurrence and structural affinities of biological pigments can be used to classify them. Many microorganisms create riboflavin, a yellow water-soluble vitamin. Orange as well as dark pink-pigmented bacteriochlorophyll-containing *Bradyrhizobium* strains generate canthaxanthin as the primary carotenoid pigment. Canthaxanthins are powerful antioxidants that prevent lipid oxidation in liposomes. Carotenoids are pigments that range in color from yellow to orange-red and are found in abundance in nature. *Serratia* and *Streptomyces* are two bacteria that generate this pigment. Violacein is a multifunctional pigment produced by the bacterium *Chromobacterium violaceum*, which has a variety of biological functions. It is becoming more important in industrial markets, including medicines, food, textiles, and cosmetics (Malik et al. 2012).

1.3 Mechanism of Production of Industrial Products

1.3.1 Production of Antibiotics in the Pharmaceutical Industry

Antibiotics are pharmaceuticals or drugs that prevent bacteria from multiplying. They are often effective at killing microorganisms and curing bacterial illnesses. In pharmaceutical enterprises, the antibiotic fermenting step is performed out and in fed-batch fermenters. Corn starch, glucose, phosphate buffer, butyl ethanoate, chloroform, diethyl solution, bicarbonate of soda, and other compounds are used to make antibiotic penicillin utilizing apparatus such as fermenters, centrifuges, rotary vacuum filters, and fluid bed dryers (Morin and Gorman 2014). Because it includes the use of microorganisms, culture preparation is required to acquire the result. The culture is inoculated with carbon sources for the penicillin fungus. Salts like sodium nitrate, Epsom salt, and monopotassium salt are added to the medium, which is then sterilized using high pressure and heat. High heat is utilized to prevent culture performance from degrading. Typically, penicillin is fermented using the fed-batch method because glucose is not supplied in large amounts at the start of development, which inhibits antibiotic synthesis. The fed-batch mode is appropriate for high penicillin synthesis because penicillin is a secondary product of fungus. The temperature is kept between 20 and 24 °C, whereas pH is maintained between 6.0 and 6.5. The rotor is necessary because it distributes the culture evenly across the culture media. It is introduced into the bioreactor by surface culture and submerged culture once it has grown to the zones identified. Impurities must now be removed from the growth minimal medium's antibiotic product. A rotating vacuum filter is widely used to remove pollutants. To dissolve the antibiotic in the filtrate, an organic solvent is applied. Centrifugal extraction is used to separate the solid debris from the antibiotic-containing liquid solution. Continuous extractions of an antibiotic dissolved in a solvent are performed to obtain a purified antibiotic product. Finally, drying the antibiotic salt eliminates the moisture content (Fig. 1.1) (Kardos and Demain 2011).

1.3.2 Production of Organic Acids in the Food and Beverage Industry

Lactobacillus is the biggest genus of organic acid bacteria, comprising species with highly variable metabolic and molecular features as well as specific tolerance to

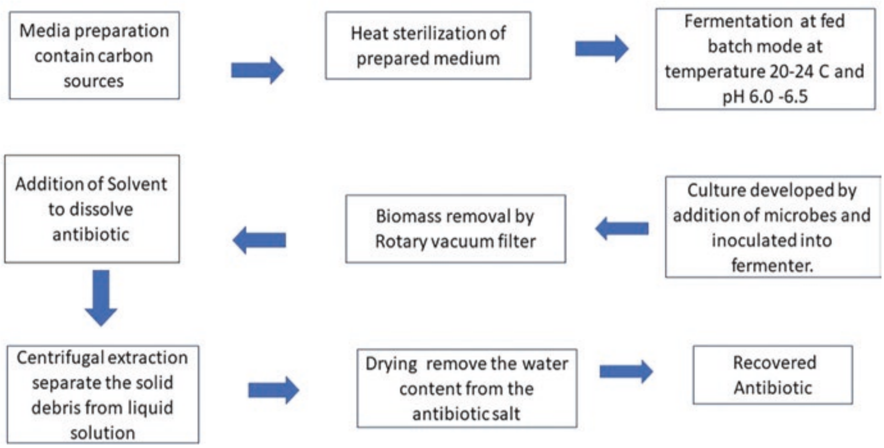

Fig. 1.1 Production of antibiotics in the pharmaceutical industry

acid media. This genus' organisms have been used in key manufacturing processes because of their rapid expansion and efficiency. Two methods are mainly utilized to ferment glucose: organic acid generation from glucose and the split of the associated fermentation pathways into two phases. The former, known as glycolysis or the Embden–Meyerhof–Parnas pathway, converts glucose into pyruvic acid, even though it is converted to organic acid by a reducing power already found in the form of NADH (nicotinamide adenine dinucleotide (NAD) + hydrogen). As per the overall equation, acid is produced as the only outcome from sugar.

$$\text{Glucose} \rightarrow \text{Organic acid} + \text{Energy}$$

L. acidophilus, *L. amylophilus* (*Lactobacillus amylophilus*), *L. bulgaricus*, *L. helveticus*, and *L. salivarius* are examples of obligatory isolated process microorganisms. Homolactic fermentation should hypothetically provide 2 mol of organic acid to the molecule of ingested glucose, with a theoretical output of 1 g for each gram of the substrate because empirical values remain comparatively lesser since some of the carbon supply is required for biomass synthesis..

Under challenging circumstances like carbon supply constraints and the presence of alternative biomass feedstocks apart from glucose, alkaline pH, or reduced temperature, some homofermentative bacteria are able to create methanoic acid via acidogenic agitation via the action of pyruvic acid lyase. Heterolactic acid fermentation is distinguished by the creation of coproducts like carbon dioxide, alcohol, and/or acetate with a combination of an organic acid like lactate as a final result (Fig. 1.2). The pentose phosphate pathway, the very initial stage of glucose breakdown, generates 3-phosphoglyceraldehyde, acetyl phosphate, and carbon dioxide.

As per the general equations, glyceraldehyde 3-phosphate undergoes glycolysis and is turned into lactate, whereas acetyl phosphate is converted into acetate and/or alcohol.

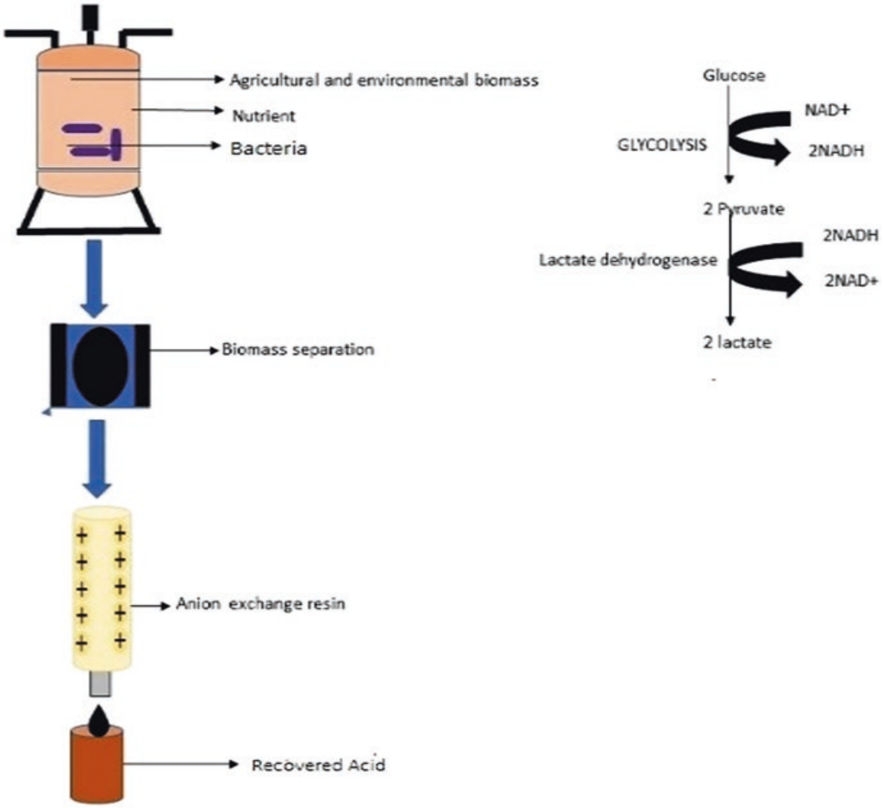

Fig. 1.2 The process of formation of an acid in industries

$$\text{Glucose} \rightarrow \text{Organic acid} + CO_2 + \text{Alcohol} + \text{Energy}$$
$$\text{Glucose} \rightarrow \text{Organic acid} + CO_2 + \text{Acetic acid} + 2\,\text{ATP} + 2\,\text{NADH}$$

Pentose catabolism necessitates extra converting processes that enable the biochemical processes of glucose 6-phosphate. As such an example, xylose is converted into xylulose, which is then covalently linked to form xylulose 5-phosphate, whereas arabinose is turned into ribulose, which is then phosphorylated to form ribulose 5-phosphate. The utilization of lignocellulosic biomass as a raw resource for the production of organic acid necessitated technological innovation for efficient xylose use. Organic acid bacteria can also metabolize carbohydrates broken down by peripheral cellular hydrolytic enzymes, including lactate, maltose, and sucrose. Furthermore, certain species, such as *Lactobacillus rhamnoses*, can ingest carbohydrates, a disaccharide composed of two glucose subunits joined by b(1e4) bonds that are particularly important in processes that involve cellulose hydrolysates. Examples include organic acids like lactic acid, succinic acid, acetic acid, etc.