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Review Article

A review article on the microbes used for industrial and waste water treatment purposes

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A B S T R A C T

The term microbe is an umbrella term used to denote organisms of micro size that mainly includes bacteria, fungus and protists. This paper is focused on collecting the informations and giving an overview on the microbes and its applications in treatment of contaminated water, and it 's industrial application for the production and enhancement in industrial products. The methodology- searching the databases like "PubMed", "Research gate" and "google scholar" using the keywords like "microbes of dairy industry", "bacteria for leather industry" and "microbial application in industries". The microbes were selected for listing by coinciding different articles retrieved from the databases by making the names of the microbes as the keywords. findings are- the microbes like *Lactococcus lactis, Lactobacillus helveticus* and some others contribute to dairy industry, *Saccharomyces cerevisiae, Streptococcus thermophilus, Lactobacillus plantarum, Propionibacterium freudenreichii, Lactobacillus acidophilus*, and *Escherichia coli, Streptomyces sp.*, and some lipase and protease yielding bacteria are used in food, medical leather industries respectively. Moreover, the application of *Klebsiella aerogenes* and *Pseudomonas putida* in treatment of contaminated water are also included in this paper. This review article is highly recommendable and helpful for various industries to find out the microbes they need to culture and treat contaminated water.

1. Introduction

The term microbe is an umbrella term used to denote organisms of micro size. Bacteria is the major one of it and microbes have several application in different industries, in pollution treatment, health, agriculture and as biosensors. This paper is focused on collecting the informations and giving overview on the microbes and its applications in treatment of contaminated water and its industrial application for the production and enhancement in industrial products such as dairy, food, medicine and cosmetics. Since microbes are considered as the primary sources of enzymes in the above-mentioned industries, they are abundantly cultured and genetically altered by transferring target enzyme coding genes into simultaneously dividing and easily handleable other strains of microbes.[1–4]

Most of the microbes used in industrial purposes are environmental microbes having natural ability to synthesis enzymes when sufficient nutrient medium is provided and have the capability to grow and give multiple clones of it. The first utilisation of microbial enzymes for the industries was made by Dr. Jokichi Takamine from fungus, and Boidin and Effront from bacteria twenty years later.[5] In some industries like food industry, dairy industry and leather industry, microbes- such as *Saccharomyces cerevisiae*- are directly applied into the reactants or raw materials to carry out the fermentation process.[6,7] Nonetheless, in medical

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industry microbes are cultured to obtain their medically important products- like amino acids and enzymes- that are released into the bioreactors and isolated using different methods like Bio-affinity Chromatography and other purification techniques.[8,9]

In addition to it, microbes are used widely is pollution treatments by bioremediation method. The industrial effluents and debris that are ejected into water and soil can be eradicated using bacterias, algae and fungi.[10,11] In a case study conducted in Indonesia on the bioremediation of liquid waste oil collected from liquid waste petroleum oil and gas companies Prabumulih South Sumatra, Indonesia, the process of bioremediation and its rate were analysed.[12] In addition, the ability of *Pseudomonas putida* and *Bacillus cereus* in bioremediation of crude oil and petroleum was studied, in which P.putida degraded 60% of the oil from water sample within 7 days,[13] thus makes them a best bioremediation tool for treating oil contaminated water bodies.

2. Materials and Methods

2.1. Searching tools and keywords

All the articles for references are taken from databases like "PubMed", "Research gate", "google scholar" and "Science direct" using the keywords like "microbes of dairy industry", "bacteria for leather industry", "microbial application in industries", "application of microbe in food industry", "microbes in medical industry" and "microbes for bioremediation". The search also leads into databases like NCBI, NLM, encyclopaedia of food microbes and some other databases.

2.2. Conformation of microbial application

The information collected from one article was subjected to confirmation by researching the database by making the microbes' names as the keyword. The citation of each articles and studies were copied to give as references for this study.

3. Microbes in Various Industries

3.1. Dairy industry

3.1.1. Lactococcus lactis

L. lactis is a gram-positive, non-motile, facultatively anaerobic bacteria. It is applied in dairy industries because of its ability to ferment lactose and produce lactic acid through hexose diphosphate pathway, hence it is also called as lactic acid bacteria.[14] It is used for the production of cheese. Through the fermentation process it increases the acidity and coagulate proteins in the milk to produce cheese, apart from it this helps to gives flavour, develop texture, and preserve various cheeses.[15 16] They can be cultured at a temperature of 10 °C and might become immotile at a temperature of 45 °C[14] and they are very less sensitive to low pH and NaCl.[17] Along with *Streptococcus thermophilus, L. lactis* is used for the production of yogurt.[18,19] In addition, it is also used for fermented milk production, sour cream production, kefir and butter productions.[17]

3.1.2. Streptococcus thermophilus

S. thermophilus is a gram-positive bacteria that ferments sugars like lactose, fructose, sucrose and glucose.[20] They are used in the manufacturing of yogurt, hard Italian and Swiss cheeses by its fermentation activity.[21] They are highly resistive against bacteriophages and especially the CRISPR system,[22] and relatively sensitive to antibiotics and sanitisers.[20] Their growth is promoted at an optimum temperature of 40–45 °C, and seemed to be minimum between 20–25 °C and maximum near 47–50 °C.[20] In addition to it, *S. thermophilus* contributes to the texture and flavour development in yogurt production, and by the production of lactic acid during fermentation they contribute to the reduction of pH of dairy products and inhibit the growth of pathogens making them a good preservative of dairy products.[23,24]

3.1.3. Propionibacterium freudenreichii

P. freudenreichii is a gram positive bacteria used in dairy industry for producing Swiss cheese and to give flavour to it.[25] The carbon dioxides released during the metabolisation of lactic acid produced by other bacteria brings pore in the cheese, making it soft and of good texture.[7,25] The flavour is given by the products like propionate and acetate from lactate fermentation, short-chain fatty acids from catabolism of branched amino acids, and free fatty aids from hydrolysis of fat in the milk.[26] Moreover, they contribute to the human nutrition by providing pivotal nutritional compounds like vitamin B12 and folate by fermentation, enhancing the nutritional value of Swiss cheese[27] and also preserve the cheese by producing propionic acid having antimicrobial properties that can inhibit the growth of spoilers.[24] *P. freudenreichii* are highly resistant to extreme hot and cold temperatures than other microbes of dairy industry, hence the subspecies *P. freudenreichii shermanii* is widely used in dairy industry that can grow in cheeses even at a temperature of 3.8 and 6.8 °C.[28]

3.1.4. Lactobacillus helveticus

L. helveticus is a proteolytic lactic acid bacteria used in production of hard and extra hard Italian and Swiss cheeses, and also contribute to improvement of texture and flavour through feunicellular) with 16 chromosomes. Since it is easy to rmentation process.[29] It is also a primary microbe used for the production of dairy products like cheese, yogurt and fermented milk.[30] Furthermore, *L. helveticus* gives peptides that are of antioxidant, antihypertensive, and antimicrobial properties, which contribute to health benefits of fermented products.[31] Moreover, they provide resistance against the fungal and bacterial pathogens, and it has shown protective action against several bacterial pathogens, which was observed through in-vitro studies.[32]

3.2. Food industry

3.2.1. Saccharomyces cerevisiae

S. cerevisiae is a fungus(unicellular) with 16 chromosomes. Since it is easy to genetically manipulate *S. cerevisiae*, they are used to bring advantage-able alterations by adding or deleting genes using advanced recombination technology,[33] hence it is considered as the best eukaryote studied.[34] It helps in production of fermented beverages and breads like alcoholic drinks and sourdough breads by converting sugar into alcohol, carbon dioxide and other metabolites through the fermentation process.[34,35] The carbon dioxides released during the metabolic process creates air holes in bakery products making them soft and easy to consume, and the flavour compounds like δ-decalatone, phenylethanol, yeast extract give tasty flavour to them.[33,36] In addition, due to their high protein content, vitamin B content and minerals, they are considered as a quality nutritional supplement. Moreover, *S. cerevisiae* is used as a preservative for processed food products like juices, alcoholic beverages, fruit pieces, fruit yogurts and bread products by production of compounds that inhibit the growth of other microbes.[33]

3.2.2. Streptococcus thermophilus

As mentioned above in 3.1.2 it is used in dairy industries and cheese production commonly. Apart from it, *S. thermophilus* is also used for the production of cottage cheeses.[37] Moreover, it considered as a potential and healthy probiotics in dairy products.[38]

3.2.3. Lactobacillus plantarum

L. plantarum is a gram positive lactic acid bacteria used in dairy industry, in production of fermented food items like pickles, kimchi, sauerkraut and other vegetable fermented products, furthermore in probiotic food productions.[39,40] They are widely seen in human mucosa and can survive in gastrointestinal conditions, these capabilities in them bring health benefits for the consumers. Moreover, they are applied for antioxidant activity and flavour development in rice and wheat bran due to their improved hydroxyl radical scavenging and oxygen radical scavenging activity,[41,42] and improves the vitamins and amino acid compositions of cauliflower and white beans.[42,43] Additionally, the combination of *L. plantarum* with chitosan improves the quality and shelf life of fresh cut apples by reducing the aerobic mesophilic bacteria.[42,44]

3.2.4. Propionibacterium freudenreichii

As mentioned above in 3.1.3 *Propionibacterium freudenreichii* is commonly used in production of dairy items. Since they have the ability to produce vitamins, folate and other bioactive compounds they are applied in biotechnological industries to increase the quantity of their productions. Moreover, they contribute to improve health benefits by their ability of immunomodulation and production of bioactive peptides.

3.2.5. Lactobacillus acidophilus

L.acidophilus is a gram positive, homo-fermentative, micro-aerophilic, lactic acid bacteria used for food fermentation processes and developing flavour and texture in foods.[45] The food items like vegetables, fish, sausages and silage are fermented using *L. acidophilus*.[45] Moreover, they are used as a food bio-preservative as they produce lactic acid and bacteriocins.[46] In addition it has the ability to survive is very acidic conditions making them a recommendable probiotic.[47]

3.3. Medical Industry

3.3.1. Escherichia coli

E. coli is generally disease-causing gram-negative bacteria, but they are also having several applications in the production of medicines. They are mainly used in production of recombinant proteins, in bioremediation, vaccine development, and gene expression studies by introduction of target foreign gene into them making them a recombinant *E. coli*.[48] Since they can be cloned easily and produce large amount of proteins with in a short period of time, they are highly recommended for the mass cultivation of proteins[48] and human insulin is a typical example for hormones produced from *E.coli* using recombinant technology.

3.3.2. Streptomyces sp

Several *Streptomyces sp*. are known for their application in medicinal industry for the production of antibiotics and some other bioactive compounds. Few of them are, *Streptomyces griseus* that produces the streptomycin-an antibiotic used in treatment of TB,[49] *Streptomyces erythreus* that synthesis erythromycin for the treatment of several bacterial infections,[50] *Streptomyces aureofaciens* that gives chlortetracycline used as an alternative drug in treatment of various infections,[51] *Streptomyces noursei* that yields nystatin one of the anti fungal drug and *Streptomyces hygroscopicus* that generate hygromycin B which is used for antiviral and antibacterial treatments (Table 1). Moreover, some compound like bleomycin and mitomycin c. derived from *Streptomyces sp.* shows anti-cancer properties and rapamycin derived from them are used as an immunosuppressant in organ transplantation and autoimmune disease treatments.[52]

Table 1: Products and application of *Streptomyces sp.*

Streptomyces sp.	Products	Application	Ref.
Streptomyces griseus	Streptomycin	Antibiotic used in treatment of TB	49
Streptomyces erythreus	Erythromycin	Treatment of several bacterial infections	50
Streptomyces aureofaciens	Chlortetracycline	Alternative drug in treatment of various infections	51
Streptomyces noursei	Nystatin	Drug for treating fungal diseases	
Streptomyces hygroscopicus	Hygromycin B	Antiviral and antibacterial treatments	

Ref.: References

3.3.3. *Bacillus subtilis*

B. subtilis are not known to produce any medicines directly. But are used for the production of proteases and amylases that may help in tissue engineering and wound heeling[53,54] and used for degradation of several substrate, and this production of enzymes in the market is about 60%.[55] Moreover, they are used to produce bacteriocins like subtilosin[56] that can resist infections caused by other microbes.[39]

3.3.4. *Corynebacterium glutamicum*

C. glutamicummare does not directly involve in medicine production, but widely used as bio-refinery strain in producing essential amino acids like l-lysin and non essential amino acids like l-glutamic acid that are used in pharmaceutical sectors to increase the availability for those are insufficient of these amino acids and for some other purposes too.[57] The annual output of amino acids l-lysin and l-glutamic acid from *C. glutamicummare* in industries are unto 1.48 and 2.16 million tons.[58] Glutamic acid derived from them are used as structural block of peptides and proteins, and also used as a vehicle to deliver certain compounds to target cells in injectable drugs due to their ability to maintain stability of that compounds.[59] Moreover, they are genetically altered to make amino acids by utilising hexose and pentose.[57]

3.4. *Leather industry*

Microbes that synthesis lipases and proteases are mainly used in leather industry for de-hairing and degreasing processes of animal skin to convert them into a good looking high quality leathers for the consumers. Few of them are, *Bacillus subtilis* that can produce both the enzymes protease and lipase,[13] *Bacillus licheniformis* that produces proteases for leather processing, *Pseudomonas flurescens* that gives thermolabile lipases,[60] and *Aspergillus niger* a fungus that yields lipases for the processing of leather (Table 2).

Table 2: Enzymes and microbes of leather industry

Enzymes for leather industry	Microbes	Ref.
Lipase	*Bacillus subtilis, Pseudomonas flurescens, Aspergillus niger*	61 13, 60
Protease	*Bacillus subtilis, Bacillus licheniformis*	61 13

Ref.: References

4. Microbes in Treatment of Contaminated Water

4.1. *Klebsiella aerogenes*

Is a bacteria that synthesis the powerful catalyst, urease, that are applicable in hydrolysis of urea into ammonia and carbon dioxide as the gas by-products, making them a gas producing bacteria.[62] The genes responsible for the production of active urease in *K. aerogenes* are found to be *ureA, ureB, ureC, ureE, ureF* and *ureG*.[63,64] The first three genes are responsible for the production of inactive apo-urease and rest of the three genes incorporate Ni to make the protein active, so *Klebsiella aerogenes* will require sufficient amount of Ni for the production of active urease.[63–65] In addition, the introduction of large number *K. aerogenes* into the well waters might prevent the contamination of drinkable water by urea penetrated from septic tanks through soil. Moreover, the above mentioned genes can be transferred into other microbes that can tolerate adverse environmental conditions for better result.

4.2. *Pseudomonas putida*

Is a bacteria used in bioremediation of oil and petroleum from water bodies.[66,67] They have the efficiency to eradicate 65% of crude oil from the water with in 7 days, found from a study conducted to analyse the biodegradation activity of *Pseudomonas putida*.[67] This method of bioremediation using naturally adapted *Pseudomonas putida* is applicable in oil and petroleum industries to reduce water body contamination.[66,67]

5. Conclusion

Microbes have been using as a main source of bio-refinery for recent decades. The natural ability of microbes are mainly utilised by industries to improve quality and enhance quantity of their production. In general, this review article on overview of different microbial application in industries including their name, application, industry type and characteristics of some microbes can provide an accurate data for industries. It might help them to grab quick informations on microbes and its applications which they are looking for, by searching the database with suitable keywords. Furthermore, this article has mentioned microbes that industries can implement for bioremediation of industrial effluents like oil from water which are mainly the contributors of water pollution.

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None.

7. Conflict of Interest

None.

References

1. Anbu P, Gopinath SCB, Chaulagain BP, Lakshmipriya T. Microbial Enzymes and Their Applications in Industries and Medicine 2016. *Biomed Res Int*. 2017;2017:2195808. doi:10.1155/2017/2195808.
2. Anbu P, Gopinath SCB, Cihan AC, Chaulagain BP. Microbial Enzymes and Their Applications in Industries and Medicine. *BioMed Res Int*. 2013;2013. doi:10.1155/2013/204014.
3. Anbu P, Gopinath SCB, Chaulagain BP, Tang TH. Microbial Enzymes and Their Applications in Industries and Medicine 2014. *BioMed Research International*. 2015;2015. doi:10.1155/2015/816419.
4. Gopinath SCB. Strategies to Characterize Fungal Lipases for Applications in Medicine and Dairy Industry. *Biomed Res Int*. 2013;2013:154549. doi:10.1155/2013/154549.
5. Underkofler LA, Barton RR, Rennert SS. Production of Microbial Enzymes and Their Applications. *Appl Microbiol*. 1958;6(3):212–21.
6. Raveendran S, Parameswaran B, Ummalyma SB, Abraham A, Mathew AK, Madhavan A, et al. Applications of Microbial Enzymes in Food Industry. *Food Technol Biotechnol*. 2018;56(1):16–30.
7. Fox PF, Guinee TP. Formation and properties of cheese. *Food Sci Technol Int*. 2000;6(6):445–70.
8. Scawen MD. Large-scale Purification of Enzymes. *Ciba Found Symp*. 1985;111:40–56.
9. Bruton CJ, Thomson AR, Lowe CR. Large-Scale Purification of Enzymes [and Discussion]. *Phil Trans R Soc Biol Sci*. 1983;300:249–61.
10. Ayilara MS, Babalola OO. Bioremediation of Environmental Wastes: The Role of Microorganisms. *Front Agron*. 2023;5. doi:10.3389/fagro.2023.1183691.
11. Gao H, Xie Y, Hashim S, Khan AA, Wang X, Xu H. Application of Microbial Technology Used in Bioremediation of Urban Polluted River: A Case Study of Chengnan River, China. *Water*. 2018;10(5):643. Available from: https://doi.org/10.3390/w10050643.
12. Hasmawaty. Bioremediation of Liquid Waste Oil Through Bioreactor: A Case Study. *Curr World Environ*. 2016;11(3):715–9.
13. Sana B, Hussain MS, Anwer R. Isolation and characterization of protease-producing Bacillus subtilis from tannery waste. *Int J Environ, Agriculture Biotechnol*. 2015;1(3):313–8.
14. Mills S, Ross RP, Coffey A. Lactic Acid Bacteria | Lactococcus lactis. In: Fuquay JW, editor. Encyclopedia of Dairy Sciences. Academic Press; 2011. p. 132–7.
15. Bautista-Gallego J, Arroyo-López FN, Rantsiou K, Jiménez-Díaz R, Garrido-Fernández A. Use of Lactococcus lactis subsp. lactis CECT 539 as a starter in table olive fermentation. *Food Microbiol*. 2013;34(1):92–100.
16. Mcsweeney P, Sousa M. Biochemical pathways for the production of flavor compounds in cheeses during ripening: A review. *Le Lait*. 2000;80(3):293–324.
17. Ziarno M, Godlewska A. Significance and Application of Lactococcus Species in Dairy Industry. *Medycyna Weterynaryjna*. 2008;64(1):35–9.
18. Tamime AY, Robinson R. Yoghurt Science and Technology. 2nd ed. United Kingdom: Woodhead Publishing; 2007.
19. Guzel-Seydim ZB, Kok-Tas T. The Functionality of Yogurt Cultures. *Food Rev Int*. 2011;27(1):3–22.
20. Harnett J, Davey G, Patrick A, Caddick C, Pearce L. Lactic Acid Bacteria | Streptococcus thermophilus. In: Fuquay JW, editor. Encyclopedia of Dairy Sciences. Academic Press; 2011. p. 143–8.
21. Gobbetti M, Calasso M. Streptococcus | Introduction. In: Fuquay JW, editor. Encyclopedia of Food Microbiology. Academic Press; 2014. p. 535–53.
22. Hutkins R, Goh YJ. Streptococcus: Streptococcus thermophilus. In: Encyclopedia of Food Microbiology. Academic Press; 2014. p. 554–9.
23. Hutkins RW, Nannen NL. pH homeostasis in lactic acid bacteria. *J Dairy Sci*. 1993;76(8):2354–65.
24. Hammes WP, Hertel C. The genera Lactobacillus and Carnobacterium. In: The Prokaryotes. New York: Springer; 2009. p. 320–403.
25. Soda ME, Awad S. Cheese: Role of Specific Groups of Bacteria. In: Encyclopedia of Food Microbiology. Academic Press; 2014. p. 416–20.
26. Thierry A, Falentin H, Deutsch SM, Jan G. Bacteria, Beneficial: Propionibacterium . In: Encyclopedia of Dairy Sciences. Academic Press; 2011. p. 403–11.
27. Rouault A, Sivignon A, Moura RD, Helden DFV, Gaudu P, Loubière P, et al. Extending the classification of respiratory-deficient mutants of Propionibacterium freudenreichii based on genetic and biochemical characterization. *Microbiology*. 2010;156(6):1938–46.
28. Deborde C. Propionibacterium spp. In: Encyclopedia of Dairy Sciences. Netherlands: Elsevier; 2002. p. 2330–9.
29. Lortal S, Chapot-Chartier M. Role, mechanisms and control of lactic acid bacteria lysis in cheese. *Int Dairy J*. 2005;15(6-9):857–71.
30. Shah NP. Functional cultures and health benefits. *Int Dairy J*. 2007;17(11):1262–77.
31. Corsetti A, Settanni L. Lactic acid bacteria in sourdough fermentation. *Food Res Int*. 2007;40(5):539–58.
32. Taverniti V, Guglielmetti S. Health-Promoting Properties of Lactobacillus helveticus. *Front Microbiol*. 2012;3:392. doi:10.3389/fmicb.2012.00392.
33. Stewart GG. Saccharomyces: Saccharomyces cerevisiae. In: Encyclopedia of Food Microbiology. Academic Press; 2014. p. 309–15.
34. Parapouli M, Vasileiadis A, Afendra AS, Hatziloukas E. Saccharomyces cerevisiae and its industrial applications. *AIMS Microbiol*. 2020;6(1):1–31.
35. Walker GM, Stewart GG. Saccharomyces cerevisiae in the Production of Fermented Beverages. *Beverages*. 2016;2:30.
36. Ross RP, Morgan S, Hill C. Preservation and Fermentation: Past, Present and Future. *Int J Food Microbiol*. 2002;79(1):3–16.
37. Vinderola G, Ouwehand A, Salminen S, Wright A, Wright A. Lactic Acid Bacteria: Microbiological and Functional Aspects. 4th ed. CRC Press; 2019.
38. Ljungh Å, Wadström T. Lactic Acid Bacteria as Probiotics. *Curr Issues Intest Microbiol*. 2006;7(2):73–89.
39. Parvez S, Malik KA, Kang SA, Kim HY. Probiotics and their fermented food products are beneficial for health. *J Appl Microbiol*. 2006;100(6):1171–85.
40. Holzapfel WH. Appropriate Starter Culture Technologies for Small-Scale Fermentation in Developing Countries. *Int J Food Microbiol*. 2002;75(3):197–212.
41. Wang M, Lei M, Samina N, Chen L, Liu C, Yin T, et al. Impact of Lactobacillus plantarum 423 Fermentation on the Antioxidant Activity and Flavor Properties of Rice Bran and Wheat Bran. *Food Chem*. 2020;330(15):127156.
42. Yilmaz B, Bangar SP, Echegaray N, Suri S, Tomasevic I, Lorenzo JM, et al. The Impacts of Lactiplantibacillus plantarum on the Functional Properties of Fermented Foods: A Review of Current Knowledge. *Microorganisma*. 2022;10(4):826.
43. Thompson H, Onning G, Holmgren K, Strandler H, Hultberg M. Fermentation of Cauliflower and White Beans with Lactobacillus plantarum – Impact on Levels of Riboflavin, Folate, Vitamin B12, and Amino Acid Composition. *Plant Foods Hum Nutr*. 2020;75:236–42.
44. Zhao Q, Tang S, Fang X, Wang Z, Jiang Y, Guo X, et al. The Effect of Lactiplantibacillus plantarum BX62 Alone or in Combination with Chitosan on the Qualitative Characteristics of Fresh-Cut Apples during Cold Storage. *Microorganisms*. 2021;9(11):2404.

45. Anjum N, Maqsood S, Masud T, Ahmad A, Sohail A, Momin A. Lactobacillus acidophilus: Characterization of the Species and Application in Food Production. *Crit Rev Food Sci Nutr*. 2014;54(9):1241–51.
46. Giraffa G, Chanishvili N, Widyastuti Y. Importance of Lactobacilli in Food and Feed Biotechnology. *Res Microbiol*. 2010;161:480–7.
47. Hill C, Guarner F, Reid G, Gibson GR, Merenstein DJ, Pot B, et al. Expert consensus document. The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nat Rev Gastroenterol Hepatol*. 2014;11(8):506–14.
48. Rosano GL, Ceccarelli EA. Recombinant Protein Expression in Escherichia coli: Advances and Challenges. *Front Microbiol*. 2014;5:172.
49. Schatz A, Bugie E, Waksman SA. Streptomycin, a substance exhibiting antibiotic activity against gram-positive and gram-negative bacteria. 1944. *Clin Orthop Relat Res*. 2005;437:3–6.
50. Koch WL. Erythromycin. *Analy Prof Drug Subst*. 1979;8:159–77.
51. Enna SJ, Bylund DB, , . XPharm : the comprehensive pharmacology reference (Internet). Elsevier Science; 2008.
52. Sehgal SN. Sirolimus: its discovery, biological properties, and mechanism of action. *Transplant Proc*. 2003;35(3):7–14.
53. Haki GD, Rakshit SK. Developments in industrially important thermostable enzymes: a review. *Bioresour Technol*. 2003;89(1):17–34.
54. Chakraborty A, Gupta S. Bioengineered natural products in wound healing. *Wound Med*. 2016;14:1–8.
55. Westers L, Westers H, Quax WJ. Bacillus subtilis as cell factory for pharmaceutical proteins: a biotechnological approach to optimize the host organism. *Biochim Biophy Acta (BBA) - Mol Cell Res*. 2004;1694(1-3):299–310.
56. Babasaki K, Takao T, Shimonishi Y, Kurahashi K. Subtilosin A, a new antibiotic peptide produced by Bacillus subtilis 168: isolation, structural analysis, and biogenesis. *J Biochem*. 1985;98(3):585–603.
57. Gopinath V, Nampoothiri K. Encyclopedia of Food Microbiology. In: Batt C, Tortorello ML, editors. Corynebacterium glutamicum. Academic Press; 2014. p. 504–17.
58. Gohil N, Bhattacharjee G, Singh V. Microbial Cell Factories Engineering for Production of Biomolecules. In: An introduction to microbial cell factories for production of biomolecules. Academic Press; 2021. p. 1–19.
59. Gupta SS, Mishra V, Mukherjee MD, Saini P, Ranjan KR. Amino acid derived biopolymers: Recent advances and biomedical applications. *Int J Biol Macromol*. 2021;188:542–67.
60. Zago A, Chugani S. Pseudomonas. In: Schaechter M, editor. Encyclopedia of Microbiology. Academic Press; 2009. p. 245–60.
61. Hasan J, Haque P, Rahman MM. Protease enzyme based cleaner leather processing: A review. *J Cleaner Prod*. 2022;365:132826.
62. Chart H. Medical Microbiology. In: Greenwood D, Barer M, Slack R, Irving W, editors. Klebsiella, enterobacter, proteus and other enterobacteria: Pneumonia; urinary tract infection; opportunist infection. Elsevier; 2012. p. 290–7.
63. Mulrooney SB, Hausinger RP. Sequence of the Klebsiella aerogenes urease genes and evidence for accessory proteins facilitating nickel incorporation. *J Bacteriol*. 1990;172(10):5837–43.
64. Lee MH, Mulrooney SB, Renner MJ, Markowicz Y, Hausinger RP. Klebsiella aerogenes urease gene cluster: sequence of ureD and demonstration that four accessory genes (ureD, ureE, ureF, and ureG) are involved in nickel metallocenter biosynthesis. *J Bacteriol*. 1992;174(13):4324–30.
65. Farrugia MA, Wang B, Feig M, Hausinger R. Mutational and Computational Evidence That a Nickel-Transfer Tunnel in UreD Is Used for Activation of Klebsiella aerogenes Urease. *Biochemistry*. 2015;54(41):6392–41.
66. Raghavan PUM, Vivekanandan M. Bioremediation of oil-spilled sites through seeding of naturally adapted Pseudomonas putida. *Int Biodeterioration Biodegradation*. 1999;44(1):29–32.
67. Vinothini C, Sudhakar S, Ravikumar R. Biodegradation of petroleum and crude oil by Pseudomonas putida and Bacillus cereus . *Int J Curr Microbiol App Sci*. 2015;4(1):318–29.

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