

MICROBIAL BIOTECHNOLOGY

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Lecture-01

Lec 1: Introduction and principles of microbial biotechnology

Welcome to my course on microbial biotechnology. In this module, Module 1, we are going to study the introduction and principles of microbial biotechnology. So, the module is divided into various lectures, and this particular lecture is divided into four different sections. In the first section, we will study the introduction to microbial biotechnology. In the second section, we will study the principles of microbial biotechnology.

And then, in the third, we will study the contributions of microbial biotechnology. And in the last section, we will study some of the emerging concepts and issues in microbial biotechnology. So, let us start with the introduction to microbial biotechnology. Microbial biotechnology is a multidisciplinary science. Various people define it in various ways.

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For our purpose, we will define it as a multidisciplinary field that integrates principles from microbiology, molecular biology, genetics, biochemistry, and engineering to exploit the metabolic and genetic capabilities of microorganisms for various applications. Lately, the applications of artificial intelligence, synthetic biotechnology and biology have brought new vigor to the discipline. This, too, we will discuss towards the end of this lecture. As you can see in this particular figure, microbiology is a multidisciplinary subject, and it is receiving contributions of knowledge from various domains on one side, which includes some of the basic science subjects and some engineering subjects, and together they are

used for developing technologies for application in various fields like industry, agriculture, medicine, and the environment.

CLIMATE CONSIDERATIONS AND ENVIRONMENTAL MANAGEMENT

Pollutant Degradation: Microbial biotechnology provides solutions for mitigating climate change by developing microbes capable of degrading pollutants and toxins from industrial activities and climate-related disasters.

Carbon Sequestration: Engineered microbes can capture and store atmospheric carbon dioxide, addressing a key driver of climate change.

Sustainable Agriculture: Microbial biotechnology enhances soil health and fertility, promoting climate-resilient crops and reducing the reliance on chemical fertilizers, which contribute to greenhouse gas emissions.



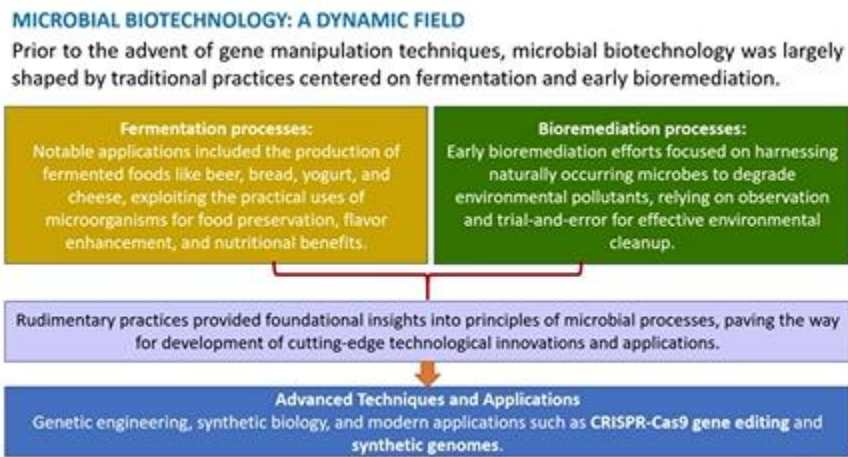
So briefly, we can tell that microbial biotechnology is an applied field that focuses on utilizing microbes for industrial, medical, agricultural, and environmental processes. Making it essential for advancements in biotechnology and related disciplines. Now, let us examine the scope and objectives of the two different subjects: microbiology and microbial biotechnology. Firstly, if we start with the objectives, you can see that the objectives of both subjects are different. Microbiology, being a basic fundamental science, tries to expand the understanding of the basics of microbes, their behavior, and impact.

While microbial biotechnology, which is more of an applied discipline, tries to leverage this understanding of microbiology to create new technologies or improve existing processes and solve real-world problems. Now, when it comes to the scope and focus, microbiology is primarily concerned with the study of microorganisms, including their physiology, classification, ecology, and pathology. It aims to understand the fundamental biological processes and interactions of different microbes. While microbial biotechnology applies the core principles of microbiology, then other subjects like genetic engineering, as we have discussed in the earlier diagram, to develop technologies and processes that harness microbes for practical applications such as producing bioproducts in agricultural, medical, industrial, and technological contexts. Now, the approach for these two subjects is also a little bit different. Microbiology uses observational and experimental methods to study microorganisms. While microbial biotechnology employs genetic manipulation, metabolic engineering, and process optimization to develop and implement microbial technologies. Although this course is focused on microbial biotechnology, we'll be discussing a lot about the fundamental aspects of microbiology and some related

disciplines so that we can understand how that knowledge is harnessed for its application in microbial biotechnology.

So once again, let us try to understand microbial biotechnology in a broader way. It is a multidisciplinary field, as we have already told you. It is also a very dynamic field. So it has evolved over time. Microbial biotechnology is not a new discipline if we look into its historical development.

Prior to the advent of gene manipulation techniques, microbial biotechnology was largely shaped by traditional practices centered on fermentation and early bioremediation. And we can see here how these two processes have evolved over time. For example, in the fermentation process by traditional methods, We, already have household items that we use daily, such as fermented foods like yogurt, wine, beer, bread, and cheese. These exploit the practical uses of microorganisms for food preservation, flavor enhancement, and nutritional benefits.



We have to understand that these kinds of traditional microbial biotechnology do not use any genetically engineered or genetically modified microorganisms. If we speak about early bioremediation processes, they particularly focused on harnessing naturally occurring microbes to degrade environmental pollutants, relying on observation and trial and error for effective environmental cleanup. Now, these old traditional methods, which in many ways are rudimentary, actually provided a lot of foundational insights into the principles of microbial processes. And paved the way for the development of cutting-edge technologies, innovations, and applications. So, due to these developments in different aspects, we have today very advanced techniques for different applications.

So, some of the advancements are genetic engineering, synthetic biology, and modern applications of gene editing technologies like CRISPR-Cas9, as well as the possibilities of making synthetic genomes. Let us now discuss some of the traditional microbial biotechnology methods and the various products that are produced by these processes. So, for example, in the case of traditional fermentation, it is one of the earliest known applications of biotechnology, particularly microbial biotechnology, and its origin traces back thousands of years. These traditional fermentation processes utilize the natural metabolic activities of microorganisms such as bacteria and yeast to transform raw materials into valuable products.

Traditional Fermentation

Microbial fermentation is one of the earliest applications of biotechnology, with its origins tracing back thousands of years. This process utilizes the natural metabolic activities of microorganisms, such as bacteria and yeast, to transform raw materials into valuable products.

Pakhala is called panta bhat in Bengal, poita bhat in Assam, bisiya bhat in Bihar and Jharkhand, and kanji in Tamil Nadu.



Pakhala is a traditional Odia dish made by soaking leftover rice in water for mild fermentation over night.

Sudhakar Panigrahi, CC BY-SA 4.0
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So, some of the simple products, for example, this is a traditional rice dish called Pakhala. This is prepared by soaking leftover rice in water for mild fermentation overnight. So, this is also a way of utilizing leftover food so that there is less food wastage. And these similar kinds of fermented rice are also found in West Bengal, where it is called Panta Bhat, and in Assam, where it is called Poita Bhat and other states like Bihar and Jharkhand, where it is called Basiyabhat, and also in South India, Tamil Nadu, where it is known as Kanji. Now modern research is trying to find out many of the beneficial effects of these kinds of fermented rice, and it has been reported to help in maintaining gut health to a large extent. Now there are other products of traditional fermentation like beverages, beer, So, here the cereals are fermented by yeast to produce these alcoholic drinks, and this is one of the oldest known biotechnological practices, and many ancient civilizations, including the Sumerians and Egyptians, mastered the art of brewing. Yeast ferments sugar into ethanol and carbon dioxide, resulting in beer with various flavors and alcoholic content.

So, another very old technology, but which is still used on a mass scale, is the making of bread, where yeast fermentation is used in bread making. This is also another ancient process. Here, yeast causes the dough to rise, creating a light and airy texture. Traditional

methods involve the natural fermentation processes. These were optimized over centuries for better bread quality.

Classic Fermentation Processes:

Brewing Beer: The fermentation of cereal grains by yeast to produce beer is among the oldest biotechnological practices. Ancient civilizations, including the Sumerians and Egyptians, mastered the art of brewing. Yeast ferments sugars into ethanol and carbon dioxide, resulting in beer with various flavors and alcohol content.

Making Bread: Yeast fermentation in bread-making is another ancient practice. Yeast causes the dough to rise, creating a light and airy texture. Traditional methods involved natural fermentation processes that were optimized over centuries for better bread quality.



Beer vats (large vessels used for fermenting and storing beer) at Budweiser brewery, Ceske Budejovice, Czech Republic.
User: (BT shared) Brando at: via wikipedia, CC BY-SA 4.0
<https://commons.wikimedia.org/wiki/File:18.jpg>, via Wikimedia Commons

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So, here in this picture, you can see these very large vessels used for fermenting and storing beer in a brewery in Jatjai Kriptak Liv. Now, there are other kinds of fermented foods which are produced by these traditional methods of microbial biotechnology. For example, the production of yogurt and cheese, the fermentation of milk, to produce yogurt and cheese is a significant development in food biotechnology whereby the shelf life of milk can be increased and the food products can be stored for a long time. In such cases, bacteria like lactobacillus and streptococcus are used to ferment lactose in milk, producing yogurt, while different bacterial and fungal cultures contribute to the flavor and texture of cheese.

These processes were developed through empirical knowledge and have been refined over generations. There are also other fermented foods across the world known to various cultures and civilizations. For example, you have fermented vegetables like sauerkraut and kimchi. And these have been the staple foods in countries like Korea and Germany. Here also, lactic acid does the fermentation of the sugars.

Fermented Foods:

Yogurt and Cheese: The fermentation of milk to produce yogurt and cheese is a significant development in food biotechnology.

Bacteria such as *Lactobacillus* and *Streptococcus* are used to ferment lactose in milk, producing yogurt, while different bacterial and fungal cultures contribute to the flavor and texture of cheese.

These processes were developed through empirical knowledge and have been refined over generations.



A close-up photo of Feta Cheese
(Irita Antonevica, 2017)

Assorted Fresh Fruits with Yogurt
(Barth, 2021)

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[Images by pixelf.com (free to use)] 30

For example, in the case of sauerkraut, the sugar is fermented from cabbage, and this helps in preserving and enhancing the nutritional value of these vegetables. So, these traditional fermentation techniques contributed to the development of probiotic foods, promoting the health and nutrition of consumers. Another area we have mentioned is early bioremediation efforts or technologies. Here, microorganisms were used for environmental cleanup, and this particularly took shape in the latter half of the 20th century. Here, you can see that petroleum is getting spilled into the sea, and this petroleum can be degraded by microbes like *Alkanivorax*.

Fermented Foods:

Sauerkraut and Kimchi: Fermented vegetables like sauerkraut and kimchi have been staple foods in various cultures.

Lactic acid bacteria ferment sugars in cabbage or other vegetables, preserving them and enhancing their nutritional value.

These traditional fermentation techniques contributed to the development of probiotic foods, promoting gut health and nutrition.



Delicious Sauerkraut
(Irita Antonevica, 2017)

Sliced Radish Kimchi
(makafood, 2021)

[Images by pixelf.com (free to use)]

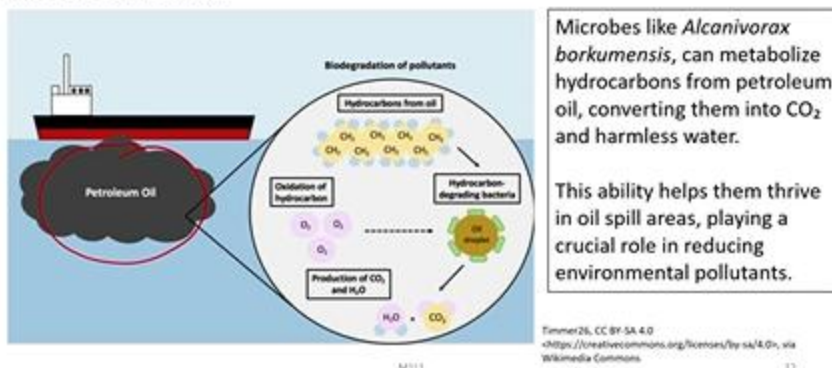
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They particularly metabolize the hydrocarbons and convert them into carbon dioxide and water, which are harmless. This finally helps these microbes thrive in these oil spill areas, and it plays a crucial role in reducing environmental pollutants. In the 1980s, these became very important areas of research, particularly for the technology development of oil spill cleanup. This happened because of the environmental challenges caused by oil spills.

Early Bioremediation

The use of microorganisms for environmental cleanup began to take shape in the latter half of the 20th century.



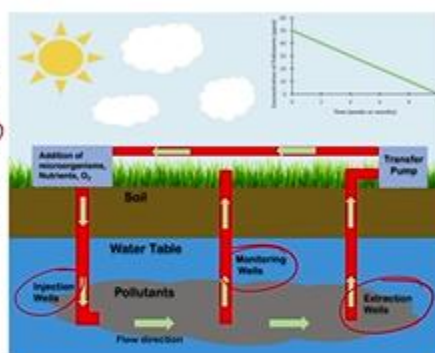
Here, you can see in these pictures that there are certain wells. For example, there is an injection well, a monitoring well, and an extraction well. The monitoring well helps us look into the inside of the wells to observe various happenings. Here, you can see again that the oil is getting spilled and contaminating the groundwater. Now, this groundwater is not suitable for human consumption. So this has to be made free from these oil spills. So, in this case, naturally occurring microorganisms, along with nutrients and oxygen, are injected into these wells, and they end up in the oil spill, where these microorganisms carry out the degradation of these pollutants. And then, this extraction well helps us in pumping out the byproducts of these reactions, and they are again pumped back into the oil well.

Early Bioremediation (1980s):

Oil Spill Cleanup: The concept of bioremediation emerged in response to environmental challenges such as oil spills.

Early techniques involved using naturally occurring or added microorganisms to break down hydrocarbons into less harmful substances.

Fig. In Situ Bioremediation involves injecting gases, nutrients, or microbes into soil to remove pollutants, often from leaks or buried wastes contaminating groundwater. Injection, monitoring, and extraction wells recirculate water until pollutants decrease. Injected O_2 detoxifies pollutants, converting them to CO_2 and water.



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So that, any residual pollutants can be further degraded by these microorganisms. So, in brief, this kind of technique is known as in situ bioremediation, which means we are doing the bioremediation on the site of the oil spill. This involves injecting gases, nutrients, or microbes into the soil to remove pollutants, which basically takes care of oil spills from

leaks or buried waste that contaminate the groundwater. Then, the injected oxygen helps in detoxifying the pollutants and converting them into carbon dioxide and water with the help of the microorganisms. There are certain challenges and limitations, of course, in this entire process, which occur due to our limited knowledge of the microbial capabilities on the one hand and the environmental variability on the other hand.

But now, with research, we have been able to make these processes much more efficient. For example, there are now much more efficient strains and efficient processes due to which the biodegradation utilizing microbes has become cost-effective and beneficial. With regards to oil spill pollutant degradation, we have to discuss the initiatives and pioneering work by Professor Anand Mohan Chakrabarty, who is often considered as the superbug superhero. So, in 1971, Professor Chakrabarty developed the first genetically engineered oil-eating bacterium, which we call the superbug, particularly from the species *Pseudomonas putida*.

So, this particular genetically engineered *Pseudomonas* was capable of degrading two-thirds of the hydrocarbons found in typical oil spills more efficiently, paving the way for modern bioremediation technologies. So, for his pioneering work, Professor Chakrabarty is considered one of the most brilliant microbiologists, and he was the first to secure the US patent on a living organism back in 1981. His groundbreaking achievement paved the way for the legal ownership of genetically engineered organisms, sparking a wave of biotech innovation and commercialization. We'll be speaking about the IP issues in one lecture, probably in module number 12, where we'll discuss Professor Chakrabarty's work in more detail.

Prof. Ananda Mohan Chakrabarty: The Superbug Superhero!

In the year 1971, Prof. Chakrabarty developed the first genetically engineered "oil-eating bacterium", a "superbug" (*Pseudomonas putida*) capable of degrading two thirds of hydrocarbons found in typical oil spills more efficiently, paving the way for modern bioremediation technologies.

Prof. Chakrabarty, considered as one of the most brilliant microbiologist, secured the first-ever U.S. patent on a living organism back in 1981. His groundbreaking achievement paved the way for the legal ownership of genetically engineered organisms, sparking a wave of biotech innovation and commercialization.



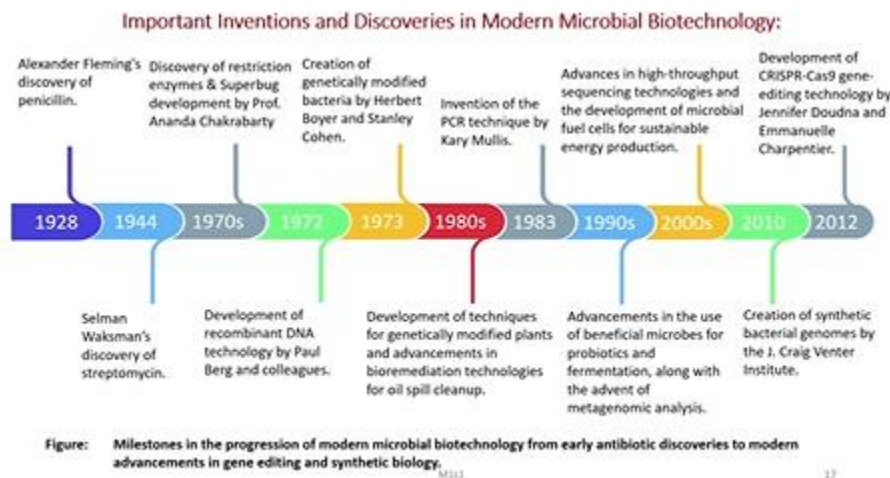
Prof. Ananda Mohan Chakrabarty
(4 April 1938 – 10 Jul 2020)

https://commons.wikimedia.org/wiki/File:Ananda_Mohan_Chakrabarty_-_Kolkata_2009-11-08_3037.JPG#filelinks

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Another advancement in the area of microbial biotechnology is that of antibiotics. In fact, the modern era of microbial biotechnology is said to have begun with the discovery of antibiotics by Sir Alexander Fleming. So, in 1928, Alexander Fleming discovered penicillin. This was the first antibiotic produced by any mold, particularly in this case, *Penicillium notatum*. And this breakthrough revolutionized medicine by providing an effective treatment for bacterial infections.

Now, let us look into some other important discoveries and inventions, which played a role in shaping modern microbial biotechnology. So, as mentioned, the work by Alexander Fleming in 1928 is considered a pioneering event in the history of microbial biotechnology. This was followed by another similar discovery of streptomycin by Waksman. Then, we already discussed the superbug developed by Professor Chakraborty in the 1970s.



Around the same time, the discovery of restriction enzymes happened, which helped us in cutting out desirable genes from organisms. And then, other developments like vectors and ligases helped us in doing recombinant DNA work. So, by around 1972, the development of recombinant DNA technology by Polberg and colleagues is another important milestone in this historical journey. The creation of genetically modified bacteria by Howard Boyer and Stanley Cohen in 1973 is no less than a science fiction and an important event in this journey. Then, we have other important developments like the development of techniques for genetically modified plants.

Although these are not directly related to microbial biotechnology, it is a microbe, *Agrobacterium tumefaciens*. On which these technologies are based. So, these are some of the most important progress in this field. Then, one of the most cutting-edge technologies, which has so many different kinds of applications, is that of polymerase chain reaction

developed by Kary Mullis in 1983. And then, this has now evolved to many different forms, including RT-PCR, which is used extensively in the detection of infectious diseases like COVID.

And then, we have the advancements in the use of beneficial microbes for probiotics and fermentation, along with the advent of metagenomic analysis in the 1990s, advances in high-throughput sequencing technologies, and the development of microbial fuel cells for sustainable energy production, which happened around 2000. Then, the creation of synthetic bacterial genomes by the J. Craig Venter Institute in 2010 was almost like playing God, trying to create life forms, of course, not totally from scratch. In this case, genes and constructs were stitched together from different sources. But anyway, this was one of the most remarkable achievements of this century.

And of late, the genome editing technologies by Jennifer Doudna and Emmanuelle Charpentier are revolutionizing the field of microbial biotechnology. So now with this introduction and background, let us try to understand the various principles involved in the field of microbial biotechnology. Mostly we will be discussing the microbial diversity, the genetic manipulation, the fermentation technologies, bioprocess engineering, metabolic engineering, biotransformation, environmental applications, microbial production systems, quality control and safety, and finally the sustainability. So we have already mentioned that microbial biotechnology leverages microorganisms to develop products, number one, and processes, number two. And offer solutions across various industries like agriculture, medicine, and environmental management.

And in these, several principles guide the application of microorganisms to solve complex problems and create innovative solutions across various fields. So, let us study the microbial diversity and how it is important in microbial biotechnology. To exploit the vast diversity of microorganisms ranging from bacteria, fungi, viruses, and also archaea to discover and utilize unique metabolic pathways and enzymes, it is very important to have an idea of the diversity of these microorganisms. The second most important aspect is genetic manipulation, where we have two important technologies.

One is that of gene cloning, where we insert specific genes into microorganisms to produce desired products. For example, the production of insulin and several other vaccines is saving millions of lives today. Then genome editing technologies, one of which is CRISPR-Cas9. Then there are two other technologies, ZFN and TALEN. So, these technologies

enable us to make precise changes in the microbial genomes for enhanced traits or functionalities.

Genetic Manipulation:

Gene Cloning: Inserting specific genes into microorganisms to produce desired products (e.g., insulin, vaccines).

Gene Editing: Techniques like CRISPR/Cas9 to make precise changes in microbial genomes for enhanced traits or functionalities.

Fermentation Technology:

Using microbial fermentation processes to produce chemicals, pharmaceuticals, biofuels, and food products. Optimizing conditions (temperature, pH, oxygen levels) for maximum yield and efficiency.

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Next is the fermentation technology, where we use microbial fermentation processes to produce chemicals. Pharmaceuticals, biofuels, and food products. By optimizing the conditions, we can maximize the yield and efficiency. So, we can see that microbial biotechnology offers a huge range of solutions regarding industrial production. In bioprocess engineering, we focus on designing and operating reactors.

For scaling up. For example, to produce insulin for the entire world, we need the help of bioprocess engineering, where we can use microorganisms cultivated in huge fermenters to grow and produce targeted products, such as insulin or certain vaccines. This requires scaling up from lab to industrial production and is one of the most important aspects of this particular technological process. Another method is the principle of metabolic engineering, which is used to modify microbial metabolic pathways to enhance the production of target compounds or degrade pollutants.

Today, with the power of genome editing, we can modify these metabolic pathways in a much more efficient way compared to what we could achieve with simple gene cloning technologies some decades ago. In these kinds of approaches, we try to balance the metabolic flux to optimize product yield and reduce byproducts. Biotransformation is another important principle. Here, we use microbes to catalyze chemical reactions. Converting substrates into valuable products, such as drug synthesis, environmental detoxification, etc.

And now, the principles of environmental applications are also very important, and we have already spoken about the traditional bioremediation process where microbes are used to clean up the environment from contaminants like oil spills. It is also possible to clean up environmental pollution which contains heavy metals. Then, other important pollutants today are the biopesticides which are used for raising crops. So, after the crop is harvested, these residues remain in the soil or go into the water bodies. So, we can use microorganisms or their products as natural pest control agents in agriculture, which we know as biopesticides. Another important principle is that of microbial production systems.

Particularly, we are interested in cell-free systems where we use extracts or purified enzymes from microbes rather than the whole microbial cell for industrial processes, avoiding the need to cultivate live organisms. And then, there are also whole cell systems where we employ live microbes for continuous production or degradation processes. Then comes the quality control and safety principles. To ensure the safety, consistency, and efficacy of microbial products through rigorous testing and compliance with regulatory standards, we need to address potential risks associated with genetically modified organisms as well as microbial pathogens. Finally, the principle of sustainability is supreme to all of these because whatever processes we develop, to minimize waste and energy consumption, we should always try to maximize the efficiency and economic viability of these applications. And therefore, we need to promote the use of renewable resources and eco-friendly practices.

Microbial Production Systems:

Cell-Free Systems: Using extracts or purified enzymes from microbes for industrial processes, avoiding the need to cultivate live organisms.

Whole-Cell Systems: Employing live microbes for continuous production or degradation processes.

Quality Control and Safety:

Ensuring the safety, consistency, and efficacy of microbial products through rigorous testing and compliance with regulatory standards.

Addressing potential risks associated with genetically modified organisms (GMOs) and microbial pathogens.

Let us now discuss the contribution of microbial biotechnology. Particularly, the advancements of biotechnology and its impact on related disciplines, its use in human and animal healthcare, and finally, the integration of the various disciplines. First, the contributions of microbial biotechnology.

So, we can see that the advancements in biotechnology have helped us in industrial applications. Particularly, it has revolutionized the production process through engineered microbes, such as those that produce enzymes, biofuels, and also today, bioplastic production is becoming a very important area. Next is the pharmaceuticals. Here, the production of antibiotics, vaccines, and therapeutic proteins is facilitated, along with the improvement of drug efficacy and, finally, affordability by cutting down costs. Then, other things are like biotechnology innovations.

Particularly, the advancements in gene editing, synthetic biology, and several other biotechnological fields are driving the advancements in microbial biotechnology. So, the impact of microbial biotechnology spans across industrial processes, environmental sustainability, and healthcare, offering innovative solutions to global challenges and improving the quality of life for humans and animals alike. In the case of environmental science, we have enhanced environmental management through bioremediation and waste treatment. In agriculture, it supports sustainable practices like providing inputs such as biofertilizers, biopesticides, and microbial inoculants.

In the case of the food industry, it contributes by improving food quality and safety through fermentation and preservation technologies. And its impact on human health includes the advances in microbial biotechnology, contributing to the development of novel vaccines, probiotics, and therapeutic agents. For example, recombinant DNA technology enables the production of human insulin and growth hormones, significantly impacting treatment for diabetes and growth disorders. So, if we consider the old method of insulin production, it was basically prepared from the calf thymus, for which young calves had to be sacrificed. So, for producing a few grams of insulin requires the sacrifice of thousands of calves. Now, along with it, if we calculate the cost of land required to raise those calves and their parents, So the cost is high, and the viability actually reduces. So, thanks to advancements in recombinant DNA technology, which now enables us to produce human insulin in large amounts in a small factory. Now, when it comes to animal health, the impact is somewhat similar.

Impact on Related Disciplines:

- iv. **Human Health:** Advances in microbial biotechnology contribute to the development of novel vaccines, probiotics, and therapeutic agents. For example, recombinant DNA technology enables the production of human insulin and growth hormones, significantly impacting treatment for diabetes and growth disorders.
- v. **Animal Health:** Develops veterinary vaccines, probiotics, and antibiotics that improve animal health and productivity. Microbial biotechnology helps in creating vaccines that protect livestock from diseases and enhances the nutritional quality of animal feed.

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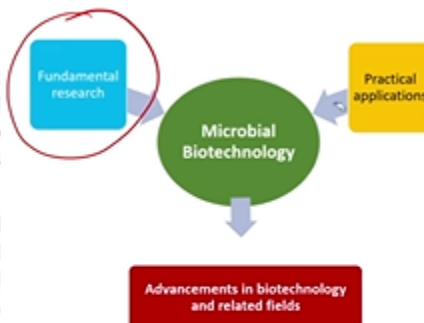
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The animals also benefit from the development of vaccines, probiotics, and antibiotics. Which improve their health as well as their productivity, and microbial technology helps in creating vaccines that protect livestock from diseases and enhances the nutritional quality of the animal feed. Now, let us discuss the integration of disciplines vis-a-vis microbial biotechnology. So, we can see that microbial biotechnology is Impacted by fundamental research and is always dictated by practical applications.

So, the interaction of these two, through the integration of various disciplines, finally leads to advancements in biotechnology and other related fields. So, if you take a few examples, like that of genetics and molecular biology, Here, you utilize gene editing and recombinant DNA technologies to modify organisms for various applications, some of which we have already discussed, including designing metabolic pathways. And then, if we look into other disciplines like biochemistry and chemical engineering, which involve the biochemical manipulation of microbes and optimization of the production processes. So, this helps us in cutting down the cost of products.

Integration of Disciplines:

- i. **Genetics and Molecular Biology:** Utilizes gene editing and recombinant DNA technologies to modify microorganisms for various applications.
- ii. **Biochemistry and Chemical Engineering:** Involves biochemical manipulation of microbes and optimization of production processes.



Briefly, microbial biotechnology bridges fundamental research with practical applications, contributing to advancements in biotechnology and related fields.

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And also make the production in large volumes, which is scaling up of the products, along with ensuring that the products are safe and they comply with the regulatory guidelines of various authorities. So, in brief, microbial biotechnology bridges fundamental research with practical applications and contributes to advancements in biotechnology and related fields. Now, with this background, we will be discussing some of the emerging hot topics, and some of these are already making an impact in the field of microbial biotechnology. So, we have discussed a lot about gene editing, which is revolutionizing biotechnology. Also, in the future, artificial intelligence is going to play a big role, similarly synthetic biology, and one of the most important problems of our time is that of climate change.

So, microbial biotechnology is also going to help us mitigate some of the climate change challenges. So, if we look into the various research that is happening, we can see that people are now interested in accurate microbial genome editing technologies on one hand, and then also they are interested in using artificial intelligence for microbial biotechnology and use of synthetic biology for microbial community design. So, these are some of the important developments which are setting the agenda for the future. So, we can see that microbial biotechnology is advancing rapidly, which is driven by the innovations in genome editing, artificial intelligence, and synthetic biology, and climate change is demanding eco-friendly solutions



to emerging challenges. In this context, these tools are unlocking new possibilities in medicine, agriculture, industry, and environmental sustainability. So, we'll discuss briefly how these innovations and climate considerations are shaping the future of the discipline. For example, in the case of genome editing, which we have already discussed to some

extent in the earlier slides, one of the advantages of these genome editing technologies, the CRISPR-Cas9 system, is the precision and customization. So, these tools allow precise modifications to microbial genomes, unlike the old technologies of gene cloning.


So, this has enhanced the ability to address climate change-related issues. For instance, we can use engineered microbes to design carbon capture or degrade pollutants in the environment much more efficiently. Another issue is that of biocontainment and biosafety. So today, we are interested in developing microbes known as climate-resilient strains. Even if there is some change in the climate, the temperature goes high or low, these microbial strains will still be equally efficient in producing the products we are interested in.

GENOME EDITING

Precision and Customization:
CRISPR/Cas Systems: Gene editing tools like CRISPR/Cas9 allow precise modifications to microbial genomes, enhancing their ability to address climate change-related issues. For instance, engineered microbes can be designed to capture carbon dioxide or degrade pollutants more efficiently.

Biocontainment and Biosafety:
Climate-Resilient Strains: Gene editing can create strains with built-in safety mechanisms, ensuring that genetically modified organisms do not adversely affect ecosystems as they are deployed to tackle climate-related challenges.

Functional Genomics:
Climate Adaptation: Gene editing can reveal and modify microbial traits that enhance resilience to climate-induced stresses such as temperature fluctuations, drought, and salinity, contributing to more robust microbial applications in agriculture and environmental management.

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So, this can be created with gene editing and built-in safety mechanisms. Ensuring that genetically modified organisms will not adversely affect ecosystems as they are deployed to tackle climate-related challenges in the field. The third most important aspect is that of functional genomics, where a lot of focus is on climate adaptation, where gene editing can reveal and modify microbial traits that enhance resilience to climate-induced stresses such as temperature fluctuations, drought, and salinity. Contributing to more robust microbial applications in agriculture and environmental management. Another important discipline bringing a lot of promise to microbial biotechnology is that of artificial intelligence, particularly in the area of data analysis and prediction.

When it comes to climate modeling, it's a very complex subject, and artificial intelligence can analyze vast datasets from climate studies. And microbial interactions to predict how microbes will respond to climate change, enabling the development of more effective strategies for using microbes in climate mitigation and adaptation. In this regard, one important aspect is that of the melting permafrost due to climate change, where it is thought

that as this permafrost melts a lot of unknown microbes that were trapped in the past will actually get released into the environment. So, from that aspect, artificial intelligence will help us in dealing with these unknown microbes, some of which may be harmful and some of which may be beneficial.

Data Analysis and Prediction:

ARTIFICIAL INTELLIGENCE

Climate Modeling: AI can analyze vast datasets from climate studies and microbial interactions to predict how microbes will respond to climate change, enabling the development of more effective strategies for using microbes in climate mitigation and adaptation.

Optimized Environmental Solutions:

Enhanced Bioremediation: AI-driven optimization of microbial bioremediation processes can improve the efficiency of microbes in degrading pollutants, thus addressing the environmental impacts of climate change, such as increased frequency of oil spills and chemical pollution.

Personalized Solutions:

Climate-Resilient Probiotics: Can AI tailor probiotic strains to individual needs and environmental conditions, enhancing agricultural productivity and soil health in the face of changing climate conditions!

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So, another issue is the optimized environmental solutions. Where artificial intelligence will be used for the optimization of microbial bioremediation processes to improve the efficiency of microbes in degrading pollutants, addressing the environmental impacts of climate change such as the increased frequency of oil spills and chemical pollution. Over and above these, one interesting aspect is that of personalized solutions. So, for example, the case of climate-resilient probiotics. Now there is a lot of hype in this field, and there are discussions about whether artificial intelligence-tailored probiotic strains to individual needs are a possibility and whether they can enhance agricultural productivity and soil health in the face of changing climatic conditions.

Another area contributing to microbial technology is synthetic biology, particularly the design and construction of novel biological systems with respect to climate-adapted microbes. Synthetic biology enables the creation of microbes with engineered traits for climatic adaptation, such as enhanced drought resistance or increased efficiency in carbon capture and storage. Then come the biological devices and systems where climate monitoring tools are very, very important. And here, synthetic biology can produce novel biosensors and biological devices that monitor climate-related parameters such as atmospheric carbon dioxide levels or soil moisture, providing real-time data for climate adaptation strategies.

Design and Construction of Novel Biological Systems:

Climate-Adapted Microbes: Synthetic biology enables the creation of microbes with engineered traits for climate adaptation, such as enhanced drought resistance or increased efficiency in carbon capture and storage.

Biological Devices and Systems:

Climate Monitoring Tools: Synthetic biology can produce novel biosensors and biological devices that monitor climate-related parameters, such as atmospheric CO₂ levels or soil moisture, providing real-time data for climate adaptation strategies.

Bioengineering and Systems Biology:

Integrated Solutions: Synthetic biology combined with systems biology can design microorganisms that perform complex functions like carbon sequestration or degradation of greenhouse gases, contributing to climate change mitigation efforts.

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And finally, the bioengineering and systems biology approaches are also going to be very, very important, where we are looking for integrated solutions through synthetic biology combined with systems biology. for designing microorganisms that perform complex functions like carbon sequestration or degradation of greenhouse gases, contributing to climate change mitigation efforts. Now, if you look into various climate considerations and environmental management overall, microbial biotechnology plays a very central role here. For example, in mitigating greenhouse gases, maintaining healthy soil and water, and there are also concepts of circular bioeconomy where the waste of one enterprise becomes the input for another enterprise, thereby closing the loop, and there will be no waste dumped, ensuring full utility of resources. This kind of approach is known as the circular bioeconomy.

CLIMATE CONSIDERATIONS AND ENVIRONMENTAL MANAGEMENT

Pollutant Degradation: Microbial biotechnology provides solutions for mitigating climate change by developing microbes capable of degrading pollutants and toxins from industrial activities and climate-related disasters.

Carbon Sequestration: Engineered microbes can capture and store atmospheric carbon dioxide, addressing a key driver of climate change.

Sustainable Agriculture: Microbial biotechnology enhances soil health and fertility, promoting climate-resilient crops and reducing the reliance on chemical fertilizers, which contribute to greenhouse gas emissions.



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And this would help create new enterprises and thereby create new products for new markets, as well as address social problems like unemployment. So, in this entire scenario, microbial biotechnology is going to play a crucial role because, by using waste from one

enterprise as inputs for another enterprise, we need to modify microbes utilizing various approaches like synthetic biology, gene editing, and artificial intelligence, which is going to help us in this entire process. Now, whatever microbial processes, the natural ones or engineered ones, we use in this entire process of adaptation to climate change or mitigating climate change, we have to ensure sustainable practices throughout the process. So, in the entire scenario, microbial biotechnology is going to play a crucial role. If we once again focus on pollutant degradation, which we have already discussed at length, we can see that microbial biotechnology provides solutions for mitigating climate change by developing microbes that are capable of degrading pollutants and toxins from industrial activities and climate-related disasters.

Carbon sequestration with engineered microbes is a possibility. This will reduce atmospheric carbon dioxide, one of the key drivers of climate change. Besides these, other greenhouse gases are also challenging, and microbial biotechnology can help us in mitigating many of such challenges. And one important aspect is that of making agriculture sustainable. With our increasing global population, the demand for food is increasing.

While the number of people who go hungry to bed every night is also similarly increasing, so there is a need for enhanced food production. But for days, we cannot go and claim more land by converting forest land into agricultural land. Because that will make the climate change challenge much more aggravated. So, for this, microbial biotechnology is going to play a key role by enhancing soil health and fertility. Promoting climate-resilient crops and reducing the reliance on chemical fertilizers will contribute to greenhouse gas emission mitigation.

So, with this, we come to the end of this first lecture. Thank you for your patient listening. Amen.