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BIOSHIELD

Novel Biotechnological Solutions in Climate Change Mitigation

2024-1-EL01-KA220-HED-000251373

HIGHER EDUCATION COURSE CURRICULUM

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Abbreviations

BIOSHIELD	Acronym of the project "Novel Biotechnological Solutions in Climate Change Mitigation"
CC BY-NC 4.0	Creative Commons Attribution Non-Commercial 4.0 International license
GHGs	Greenhouse Gases
EU	European Union
ETS	EU Emissions Trading System
NECPs	National Energy and Climate Plans
UNFCCC	The United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel on Climate Change
SDGs	Sustainable Development Goals
FBS	Fetal Bovine Serum
EM or EMs	Effective Microorganism Consortia or Effective Microorganisms
GIS	Geographic İnformation Systems
EACEA	The European Education and Culture Executive Agency
OECD	The Organisation for Economic Co-operation and Development
PPT	PowerPoint Presentation
SPSS	Statistical Package for the Social Sciences (software for data analysis)
NDVI	Landsat Normalized Difference Vegetation Index
DEM	Digital Elevation Models
UN	United Nations
EFSA	European Food Safety Authority
ANOVA	Analysis of Variance
SD	Standard Deviation
TWI	Topographic Wetness Index
CRISPR	Clustered Regularly Interspaced Palindromic Repeats
LST	Land Surface Temperature
LULC	Land Use/Land Cover
CRS	Coordinate Reference System
FAO	Food and Agriculture Organization
QGIS	Quantum Geographic Information System

Glossary

MODULES	WORD	EXPLANATION
MODULE 1		
1	Cultured Meat	Also known as lab-grown or cell-based meat, it is produced by cultivating animal cells in a controlled, sterile environment aiming to develop tissues that replicate the texture and taste of conventional meat without raising or slaughtering animals.
2	Cellular Agriculture	A field combining cell biology and biotechnology and engineering to produce agricultural products (meat, dairy, eggs) from cell cultures or fermentation rather than traditional farming.
3	Tissue Engineering	The application of principles from developmental biology and engineering to develop biological tissues by combining cells, scaffolds, and biochemical factors in vitro—here to create meat tissue.
4	Bioreactor	A vessel or system that provides optimal conditions (nutrients, oxygen, temperature, pH) for cell growth and tissue development, essential for tissue engineering - in this case scaling cultured meat production.
5	Fetal Bovine Serum (FBS)	A complex nutrient-rich supplement derived from the blood of bovine fetuses, commonly used as a supplement in cell culture media to provide growth factors and proteins necessary for cell proliferation.
6	Scaffolding	A three-dimensional structure, often made from various materials, that supports the attachment, growth, and organization of cells into tissue-like formations- in the case of cultured meat has to be edible
7	3D Bioprinting	A technology used to deposit layers of living cells and materials to fabricate complex tissue structures- enabling the creation of meat with defined architecture and texture.
8	Carbon Footprint	The total amount of greenhouse gases (mainly CO_2) generated by actions, particularly livestock farming in this context.
9	Stem Cell	A type of undifferentiated cell that can both self-renew and differentiate into one or more specialized cell types. In cultured meat production, stem cells are used as a starting point to grow muscle and other tissues.
10	Microbiome	The community of microorganisms (bacteria, yeast, etc.) living in a particular environment, along with their genetic material (genomes) and the suite of metabolites and biochemical compounds they produce within a specific environment or host; here, used in starter culture production.
11	Starter Cultures	Microorganisms used to initiate fermentation in food production (e.g., yogurt, cheese, fermented vegetables).
12	Agro-Waste	Agricultural waste like fruit peels, husks, and food by-products; here explored as sustainable substrates in microbial fermentation.

13	Circular Economy	An economic model aimed at minimizing waste and using efficiently the resources by designing regenerative and restorative products and systems.
14	Biomass Production	The process of producing microbial mass in fermentation systems—critical for industrial applications.
15	Bioprocess Design	The planning and structuring of biological processes (like fermentation) to optimize production.
16	Sustainable Growth Media	Environmentally friendly alternatives to traditional nutrient solutions used in microbial cultivation.
17	European Green Deal	A comprehensive policy initiative launched by the European Commission in December 2019 with the overarching goal of making Europe the first climate-neutral continent by 2050.
18	Wet Lab/Dry Lab	Wet labs involve experimental, hands-on biology; dry labs focus on data analysis and simulations.
MODULE 2		
1	One health	One health is a collaborative, transdisciplinary approach that recognizes the interconnectedness of human, animal, and environmental health, aiming to achieve optimal health and well-being for all three (https://www.who.int/health-topics/one-health#tab=tab_1)
2	Food system	Food system indicates the interconnection of processes and actors involved in the production, processing, distribution, consumption and disposal of food. It also incorporates the biological, economic, social and environmental elements that affect and are affected by these activities (https://knowledge4policy.ec.europa.eu/publication/food-systems-definition-concept-application-un-food-systems-summit-paper-scientific_en).
3	Sustainable food system	Sustainable food system: A sustainable food system is one that delivers food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised (https://www.fao.org/sustainability/en/)
4	Food supply chain	Food supply chain corresponds to the sequence of processes encompassing the manufacturing and the distribution of food, from the farm to the consumers, including farming, harvesting, processing, packaging, transportation, storage, distribution, retail and consumption. An effective food supply chain is pivotal to ensure safe, affordable and available food while preserving sustainability.
5	Biorefinery	Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat). (IEA Bioenergy Task 42 Biorefinery, www.IEA-Bioenergy.Task42-Biorefineries.com)
6	Bioeconomy	Bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes

		and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services (https://knowledge4policy.ec.europa.eu/glossary-item/bioeconomy_en)
7	Clean label products	Clean label products: are food and beverage products characterized by the application of natural ingredients with functional properties, minimal processing and the absence of artificial additives, preservatives, and colors (Alexandri, M., Kachrimanidou, V., Papapostolou, H., Papadaki, A., & Kopsahelis, N. (2022). Sustainable food systems: The case of functional compounds towards the development of clean label food products. *Foods*, *11*(18), 2796. https://doi.org/10.3390/foods11182796)
MODULE 3		
1	Plant holobiont	The biological system consists of a host (plant) and its symbionts, which engage in continuous exchange of information and genetic material, leading to the development of a metabolome and hologenome that adapt and persist in response to environmental factors.
2	Microbiome (plant microbiome)	A diverse kind of microorganisms associated with a higher organism (human, animal or plant).
3	Diazotrophic microorganisms	Diverse nitrogen-fixing microorganisms that contribute significantly to biological nitrogen fixation on Earth, playing a crucial role in enhancing agricultural yields by optimizing soil fertility and promoting crop growth.
4	Biological nitrogen fixation	The process of converting atmospheric nitrogen into accessible forms, such as ammonia, through symbiotic interactions between rhizobia and leguminous plants, as well as through free-living bacteria and certain actinomycetes. This process enables plants to utilize nitrogen, which is essential for their growth and development.
5	Effective Microorganisms (EM)	A microbial inoculant containing beneficial microorganisms (*e.g.* photosynthetic bacteria, lactic acid bacteria, yeasts, actinomycetes, and fermenting fungi) that can stimulate plant growth and improve soil fertility.
6	Microbial consortia	Associations of symbiotically living microorganisms from various species that interact based on functional complementarity, each fulfilling distinct roles within the community.
7	Biofertilizers	Bacterial or fungal inoculants applied to plants to enhance nutrient availability and utilization, and open new routes of nutrients acquisition by plants. , or as microbial biostimulants that improve plant nutrition efficiency. Products containing living microorganisms that enhance nutrient availability for plants.
8	Biostimulants	Any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop

		quality traits, regardless of its nutrients content.
9	Biopesticides	Products derived from living organisms (plants, bacteria, fungi, viruses, or other microbes) or their natural metabolites. They help control pests, diseases, and weeds in an environmentally friendly way, often by inhibiting pathogens, deterring insects, or competing with harmful organisms.
10	Root exudates	Low-molecular-weight organic compounds released by plant roots, which serve as a principal source of soil organic carbon and are part of the rhizodeposition process. These exudates include essential metabolites, such as amino acids, sugars, organic acids, and secondary metabolites that attract and nourish microbes.
11	Microbial inoculant	Biological agents that can improve nitrogen availability and fixation in agroecosystems, potentially enhancing sustainable fertilization practices. Their ecological impacts, including effects on nitrogen dynamics and the resident microbial community, must be thoroughly evaluated before widespread application.
12	Colonization (microbial)	The process by which microorganisms attach to plant surfaces (e.g., roots, leaves) and establish themselves, sometimes also entering internal tissues. It often involves specialized structures or molecules that enhance adherence and allow microbes to resist environmental challenges.
13	Field variability	The measure of dissimilarity or difference in soil, crops, management, pests, varieties, yields, elevation, soil water and soil nutrients in space and time across a field.
14	Scalability	The ability to expand microbial applications from controlled experiments to large-scale farming.
15	Climate-smart farming	An approach that guides the transformation of agri-food systems towards green and climate-resilient practices. It promotes agricultural methods that increase productivity and resilience while reducing environmental impacts under climate change.
16	Holistic approach (in plant production)	A systems-based view that considers plants, their associated microbes, soil, and the surrounding environment as interconnected components of a single functional unit. This perspective emphasizes harnessing and enhancing natural plant-microbe-soil interactions to support healthy, resilient, and productive crops.
17	Abiotic factors	The non-living physical and chemical components of the environment that influence the growth, survival, and distribution of organisms. Examples include pH, temperature, moisture, light, substrate type, ventilation, and air pollution. These factors significantly affect biological processes, microbial colonization, and ecosystem dynamics.
18	Biotic factors	The living components of an ecosystem that influence the growth, survival, and interactions of organisms. They include plants, animals, microbes (bacteria, fungi, yeast), and other living organisms such as pests, pollinators, or competitors. These factors shape ecological relationships and biological processes within ecosystems.
19	Geographic information system (GIS)	A computer-based tool that helps us collect, analyze, and visualize data on maps.
20	Spatial data	Data with coordinates that tells us where things are located on Earth.
21	Spatial modeling	A way of using maps and data to simulate or predict patterns and processes across space.

22	Weighted overlay	A method in GIS where different map layers are combined and given importance (weights) to make a decision or find the best location.
23	Remote sensing	Collecting data about the Earth's surface from a distance, usually with satellites or drones.
MODULE 4		
1	Carbon Sequestration	The process of capturing and storing atmospheric carbon dioxide to mitigate climate change.
2	Photosynthetic Efficiency	A measure of how effectively plants convert light energy into chemical energy during photosynthesis.
3	Carbon Capture and Utilization	Technologies that capture carbon dioxide emissions and reuse them in various applications, such as biofuels or synthetic materials.
4	Root Architecture	The spatial configuration of a plant's root system, including root length, branching, depth, and density.
5	Woody Plants	Perennial plants with hard, fibrous stems, such as trees and shrubs, often used in forestry and long-term carbon storage.
6	Controlled Environment	Laboratory or greenhouse conditions where variables such as temperature, light, and CO_2 concentration are regulated for research.
7	Soil Carbon Storage	The amount of carbon stored in soil as organic matter, contributing to ecosystem stability and climate mitigation.
8	Environmental Biotechnology	A branch of biotechnology focused on solving environmental problems, such as pollution or carbon emissions.
MODULE 5		
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Introduction

General aims of the curriculum

Especially since 1980s, our world has been facing unprecedented environmental issues, including climate change, pollution, and ecosystem degradation. Those challenges impact biodiversity, human health, and our planet's well-being (Dasgupta and Robinson, 2022). As the biotechnology industry expands, it is vital to redirect its potential to address these issues. (OECD, 2011). Despite the progress in environmental biotechnology, its full potential remains untapped (Yong, et al., 2021). A disconnection exists between biotechnology innovations and their practical application in solving environmental problems; hence closing this gap holds a great potential to unlock transformative solutions for our environment.

It is well known that environmental pollutants threaten ecosystems and human health whereas traditional in-situ bioremediation is costly and limited. However, biotechnology practices provide alternative solutions through which a serious progress can be possible in mitigating climate change. For example, biotechnology enhances microbe-based pollutant degradation, offering faster, cost-effective solutions for site cleanup, ecosystem restoration, and public health protection (Borchert E, Hammerschmidt K, Hentschel U and Deines P, 2021). Besides, precise and timely data is crucial for effective environmental management, but conventional methods demand expertise and resources. However, biosensors provide accessible, efficient alternatives (Kadadou et al., 2022). They enable frequent and wide-scale sampling, enhancing data accuracy and response capabilities, essential for understanding and addressing environmental challenges. Urgent action is needed to reduce greenhouse gas emissions and achieve negative emissions for climate change mitigation. Biotechnology can enhance natural carbon capture. Crop modification and enzymatic pathway optimization can effectively capture and store carbon, contributing to a sustainable future.

BIOSHIELD curriculum directly addresses high-priority environmental challenges, including pollution, climate change, and biodiversity loss through its modules. More specifically, the modules are tailored to the needs of students with a biotechnology background, prospering to enhance sensitivity on climate change mitigation practices and project their knowledge into innovative solutions for global-level benefit.

Hence, the specific objectives of the BIOSHIELD curriculum are determined as follows.

- Reveal the future research and industrial and agricultural solution/remediation areas that can be developed through biotechnology,
- Foster university-industry collaboration for innovative approaches to combat climate change and disasters.
- Enable biotechnology students to connect data with practical and transversal skills for biotechnology in the context of climate change and disaster mitigation and adaptation.
- Enrich students' learning experience with educational technologies tailored to the BIOSHIELD course delivery process for sustainable practices.
- Equip students for their future careers through professional guidance.

Design thinking and Blended Learning

Climate change is a reality threatening life on Earth and one of the most complex and urgent global challenges of our time. It requires innovative and multidisciplinary responses, particularly from fields like biotechnology. Given the potential to provide sustainable solutions—from genetic modification of crops to microbial carbon capture and waste treatment—biotechnology plays a critical role in addressing climate-related issues. However, unlocking this potential demands technical knowledge, creative problem-solving and the ability to think systemically and empathetically as a whole.

In this context, the BIOSHIELD project has developed a HE course curriculum designed specifically for biotechnology students, incorporating the Design Thinking approach to equip students with the skills needed to develop real-world solutions to climate change. Design Thinking encourages problem-based, user-centered, and creative thinking, fostering an educational environment where students actively explore and generate solutions rather than passively absorb information.

Furthermore, the BIOSHIELD curriculum adopts a blended learning model, integrating instructional videos that can be used both in-class and as preparatory materials. This flexibility allows students to learn at their own pace while maximizing classroom time for interactive activities such as discussions, hands-on wet-lab experiments, and project-based learning. This blended approach strengthens the connection between theory and practice, especially in laboratory settings such as for:

- Investigating the carbon capture capabilities of microorganisms,
- Developing drought-resistant plant varieties through plant biotechnology,
- Exploring waste valorization using microbial and enzymatic systems.

Such activities empower students to work on real-life environmental problems while gaining scientific and technical skills.

Design Thinking methodology plays a vital role in helping students to approach complex environmental challenges with innovative and human-centered solutions. Through this process, students:

- Empathize – Realise the needs of communities, ecosystems, or systems affected by climate change.
- Define the problem – Clearly articulate complex climate-related challenges.
- Ideate – Generate innovative ideas through brainstorming and creative thinking.
- Prototype – Transform ideas into tangible models or designs.
- Test and iterate – Evaluate the effectiveness of solutions; refine them based on feedback or results.

The BIOSHIELD curriculum has been designed in a way to include 5 abovementioned phases of Design Thinking, offering a forward-thinking educational model that supports biotechnology students in becoming solution-oriented scientists and innovators in the fight against climate cha

Climate Change

Basic Information About Climate Change, Modeling of Climate Data and Programming

Climate change refers to long-term alterations in temperature, precipitation, wind patterns, and other elements of the Earth's climate system. These changes are primarily driven by human activities, especially the burning of fossil fuels, deforestation, and industrial processes that increase the concentration of greenhouse gases (GHGs) in the atmosphere.

To understand and predict climate change, scientists use climate models. These models simulate the interactions of the atmosphere, oceans, land surface, and ice. Climate modeling involves complex mathematics and physics and is implemented using computer programming, typically in languages such as Python, R, or MATLAB. These models help researchers analyze past climate behavior, forecast future climate scenarios, and inform policy decisions.

European Regulations

In response to the growing climate crisis, EU have implemented a range of environmental and climate-related regulations. The EU Green Deal is a major regulatory initiative aimed at making Europe climate-neutral by 2050. Key legislation includes:

- The EU Climate Law, which enshrines the 2050 climate neutrality goal.
- The Effort Sharing Regulation, which sets national targets for emission reductions.
- The EU Emissions Trading System (ETS), a cap-and-trade system for major industrial emitters.

Member states are also required to develop National Energy and Climate Plans (NECPs) to meet EU targets.

International Agreements, Conventions, Plans, Guidelines etc.

Several international frameworks guide global climate action. The most significant include:

- The United Nations Framework Convention on Climate Change (UNFCCC): Established in 1992, it provides a foundation for international climate negotiations.
- The Kyoto Protocol (1997): The first international agreement to set binding emission reduction targets for developed countries.
- The Paris Agreement (2015): A landmark accord where countries committed to limiting global warming to well below 2°C, preferably 1.5°C, above pre-industrial levels.
  Intergovernmental Panel on Climate Change (IPCC) Guidelines: Provide standardized methods for greenhouse gas inventories.
- Sustainable Development Goals (SDGs), Goal 13: Climate Action, also align with climate strategies

Module 1 - Resilience Through Food and Microbiome Innovations

Problem 1 – Advancing Cultured Meat: A Sustainable Solution for Climate Change

Learning Objectives

The course takes a scientific problem-solving approach to understanding how cultured meat can help combat climate change. Using design thinking, the students will tackle real scientific challenges in cellular agriculture, such as tissue engineering, optimizing nutrient supply, improving bioreactor efficiency, and scaling up production.

By the end of the course, the students will be able to:

- Understand the scientific foundations of cultured meat production.
- Analyze the key scientific challenges in cellular agriculture.
- Apply a problem-solving framework to scientific challenges.
- Develop innovative solutions for improving cultured meat production.
- Critically assess the environmental impact of cultured meat.
- Design and present a scientific research proposal.

Contents

Introduction

- ✓ Livestock farming is a driver of climate change, responsible for methane emissions, deforestation, excessive water use, and biodiversity loss.
- ✓ Cultured meat has been proposed as a sustainable alternative, but it still faces scientific, economic, and social barriers.

The course combines:

- ✓ Understanding cultured meat production.
- ✓ Investigating climate problems related to livestock.
- ✓ Developing solutions to improve synthetic meat as a climate-friendly alternative.

Learning Resources

- Scientific video presentations
- Classroom notes
- Textbook chapters
- Review articles/Original articles
- Newspapers, short videos from media

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

- The lecturer will provide information to the students regarding the modules planned for the semester, the objectives of the course and the expected learning outcomes.
- The tasks assigned to students throughout the semester will be clearly defined within the scope of the course, along with a detailed timeline of activities.
- Students will also receive information on how to access additional resources on the subject (University library, online resources, etc.).
- An outline of the topic of each module will be introduced to the students.
- The students will be divided into groups of 4 or 5.
- Each group will decide on the problem they will work on.

Duration: 3x45 minutes

Teaching-Learning Methods

- Questions - Answer
- Discussion

Week 2. Emphasize Understanding the problem

In-Class Activity

- Introduction to climate challenges in conventional meat production.
- Environmental impact: carbon footprint, land use, and water consumption.
- The role of cellular agriculture in sustainable food systems.
- The biological basis of cellular agriculture: muscle cell proliferation and differentiation.
- Stem cells and stem cell technology for the production of cultured meat.

Duration: 3x45 minutes

Out of Class Activity

- Students study material provided by the instructors.
- Students prepare a short video for the general public introducing cultured meat and the potential impact it may have (5 min each group).

Duration: 3x45 minutes

Teaching-Learning Methods

- Study of scientific literature
- Directed discussion
- Instructor presentations

Week 3. Defining the Scientific Challenges

In-Class Activity

- Growth media optimization: reducing reliance on fetal bovine serum (FBS)

- Engineering scalable, cost-effective bioreactors
- Ensuring structural integrity: scaffolding and tissue architecture

Duration: 2x45 minutes

Out of Class Activity

- Students discuss and try to frame the most pressing scientific problems.
- Students choose one key scientific problem.
- Students prepare a poster to present (10 min each group).

Duration: 3x45 minutes

Teaching - Learning Methods

- Study of scientific literature
- Directed discussion
- Brainstorming
- Instructor presentations

Week 4. Define - Explore potential solutions

In-Class Activity

- Students present their posters and start discussing potential solutions (Alternative growth factors and serum-free media, Advances in 3D bioprinting and tissue engineering for meat texture, Scaling up cell culture: overcoming density and metabolic waste challenges).
- Brainstorming on scientific innovations.

Duration: 2x45 minutes

Teaching-Learning Methods

- Directed discussion
- Instructor presentation
- Cooperative learning

Week 5: Ideate

Out-Class Activity

- Students watch videos on the approaches and methodologies used in cultured meat production.
- Each group designs an in-depth presentation on the challenge they will try to address.

Duration: 3x45 minutes

Teaching-Learning Methods

- Cooperative learning
- Flipped classroom
- Experimental learning

Week 6-7-8 Ideate

Out-Class Activity

- Groups will prepare a project proposal with research objectives, methods, data analysis, and budget in line with the ideas/challenges discussed.

In-class Activity

Duration: 3 x (3x45) minutes

- Groups discuss their progress with the PhD student/Postdoc researcher.

Teaching-Learning Methods

- Cooperative learning
- Experimental learning

Week 9-10-11: Prototype

Out-Class Activity

- Groups work on their projects. A PhD student/Postdoc researcher is assigned to help the groups.

Duration: 3 x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Week 12-13. Assessment

Out-Class Activity

- Groups work on the project and on the report of their activities. Then, the groups complete their report and upload it.

In-class Activity

Duration: 2 x (3 x45) minutes

- Groups present the results of their project followed by the discussion/evaluation of the course

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Problem 2 – Microbiome-based strategies for sustainable manufacturing challenges in the starter culture industry: A circular approach to climate resilience

Learning Objectives

The course takes a scientific problem-solving approach to understanding how food and agro-waste can be used as sustainable alternative to growth mediums for conventional starter cultures cultivation. Using design thinking, the students will tackle real scientific challenges in cell biomass production, improvement of bioreactor efficiency, scaling-up production and circular economy approaches.

By the end of the course, the students will be able to:

- ➢ Understand the environmental and economic challenges of food and agro-waste disposal and its link to climate change.
- ➢ Assess the potential of food and agro-waste as a source of nutrients for starter cultures cultivation.
- ➢ Analyze current barriers and future opportunities in sustainable starter cultures development.

Contents

Introduction

- ✓ Agricultural by-products and food wastes constitute an issue of vital importance to global good environmental governance, directly linked with environmental, economic, and social impacts.
- ✓ On the other hand, they offer a sustainable alternative as growth mediums to conventional starter cultures cultivation.
- ✓ Promotion of circular economy in accordance with European Green Deal.

The course combines

- ✓ Food and agro-waste management & circular economy approaches
- ✓ Starter cultures production challenges

Learning Resources

- Scientific video presentations
- Classroom notes
- Textbook chapters
- Review articles / Original articles
- Newspapers, short videos from media

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

Duration: 3x45 minutes

- The lecturer will provide information to the students regarding the modules planned for the semester.

- The tasks expected from the students throughout the semester will be defined within the scope of the course.
- Students will also receive information on how to access additional resources on the subject (University library, online resources, etc.).
- The topic of each module will be introduced to the students.
- The students will be divided into groups of 4 or 5.
- Each group will decide on the problem they will work on.

Teaching-Learning Methods

- Question – Answer
- Discussion

Week 2. Emphasize

Out-Class Activity

- Food and agro-waste management & circular economy approaches for starter cultures production challenges: Each group presents the food and agro-waste they are going to work with, as sustainable alternative for growth mediums to conventional starter cultures cultivation and uploads a poster before the in-class activities.

In-Class Activity

Duration: 3x45 minutes

- Oral presentation of the posters (10 min each group).
- Through discussion on the posters the challenges of using food and agro-waste as sustainable alternative for growth mediums to conventional starter cultures cultivation become apparent.
- Groups receive literature on food and agro-waste as sustainable alternative for growth mediums to conventional starter cultures cultivation and their impact in promotion of circular economy in accordance with European Green Deal.

Teaching-Learning Methods

- Directed discussion
- Brainstorming
- Instructor presentation

Week 3. Define

Out-Class Activity

- Groups work on the literature and prepare a 5 min video presenting the challenges of their project, which is then uploaded.
- Each group watches the videos of the other groups and prepares for in-class discussion.

In-class Activity

Duration: 3 x45 minutes

- Discussion on the videos presented; each group answers to questions on their work.

- Design sustainable bioprocesses for starter cultures cultivation using food and agro-waste as sustainable alternative for growth mediums. Instructor gives examples.
- Wrap up - groups take notes with main points.

Teaching-Learning Methods

- Directed discussion
- Flipped classroom
- Instructor presentation
- Cooperative Learning

Week 4. Define

Out-Class Activity

- Each group is asked to write a newspaper article on sustainable production of starter cultures using food and agro-waste as sustainable alternative for growth mediums.

In-Class Activity

Duration: 3x45 minutes

- How do we design a sustainable bioprocess for starter cultures cultivation using food and agro-waste as sustainable alternative for growth mediums?

Teaching-Learning Methods

- Directed discussion
- Instructor presentation
- Cooperative learning

Week 5: Ideate

Out-Class Activity

- Students watch videos on the methodology used to design for starter cultures cultivation using food and agro-waste as sustainable alternative for growth mediums.
- Each group designs an in-depth presentation of a sustainable process for industrial starter cultures production using food and agro-waste as sustainable alternative for growth mediums.
-

In-class Activity

Duration: 3x45 minutes

- Each group presents the industrial process of starter cultures production using food and agro-waste as sustainable alternative for growth mediums.
- Challenges and technical issues are discussed.
- Groups discuss ideas/challenges on the development of industrial bioprocesses that foster sustainability.

- Ideas are presented following by group discussion; each group focuses on one idea to work as a research proposal.

Teaching-Learning Methods

- Cooperative learning
- Flipped classroom
- Experiential learning

Week 6-7 Ideate

Out-Class Activity

- Groups prepare a project proposal with research objectives, methods, data analysis, and budget in line with the ideas/challenges discussed.

In-class Activity

Duration: 2 x (3x45) minutes

- Groups discuss their progress with the PhD student /Postdoc researcher.

Teaching-Learning Methods

- Cooperative learning
- Experimental learning

Week 8-9-10-11: Prototype

Out-Class Activity

- Groups work on their projects. A PhD student/Postdoc researcher is assigned to help the groups.

In-class Activity (Wet & Dry Lab)

Duration: 4 x (3x45) minutes

- Pilot scale starter cultures production using food and agro-waste as sustainable alternative for growth mediums (hands-on laboratory work).
- Kinetic parameters determination and assessment of process sustainability (dry laboratory).

Teaching-Learning Methods

- Experiential learning
- Cooperative learning

Week 12-13. Assessment

Out-Class Activity

- Groups work on the evaluation of the results of their project and on the report of their project activities. Then, the groups complete their report and upload it.

In-class Activity

Duration: 2 x (3 x45) minutes

- Groups present the results of their project

- Discussion/evaluation of the course
- Teaching-Learning Methods
- Cooperative learning
- Directed discussion

Module 2 - Sustainable Food systems: Biotechnology and Renewable Resources for Clean Label Products

Problem 1 – Food Sustainability: Emerging Approaches to Mitigate Protein Shortages

Learning Objectives

The course will introduce the concept and framework of Sustainable Food Systems, as part of the Sustainable Development Goals (SDGs) adopted by the United Nations (UN) to mitigate current unsustainable practices in food manufacturing and the impact on climate crisis. Through the adoption of design-thinking principles, students will engage in holistic thinking to consider the health, social, economic and environmental dimensions of food systems. In this context, students will explore emerging approaches towards the production of nutritious and environmentally benign food products. Likewise, the course will emphasize particularly on shifting protein consumption as a means to promote environmental sustainability and human health.

By the end of the course, students will be able to:

- ➢ Understand the complexity of food systems and the interconnections of sub-systems.
- ➢ Conceive the totality of food systems and the dimensions of sustainability: health, economic, social and environmental.
- ➢ Understand the FAO's framework for food systems including food security and nutrition.
- ➢ Acknowledge the emerging alternative protein sources, including microbially produced proteins, insect proteins and plant-based proteins, among others.
- ➢ Scrutinize state-of-the-art research and propose innovative solutions to integrate alternative protein sources in food systems.
- ➢ Assess the social, economic and environmental aspect of alternative protein sources.
- ➢ Design and present a scientific research project/case study.

Contents

Introduction

- ✓ Food systems include all stages from manufacturing, packaging and transportation of food.
- ✓ Current food systems include primarily unsustainable food production and consumption, along with environmental degradation and intensified global hunger. Enhancing the resilience of food systems necessitates the evaluation of changes in all dimensions (health, society, economy and environment) along with their interaction.
- ✓ Biotechnology offers a lever to find sustainable solutions to combat malnutrition, hunger along with

waste management though the generation of alternative protein sources for food and feed.

The course combines:

- ✓ Understanding the different dimensions of sustainable food systems
- ✓ Microbial (bacterial, yeast and fungal) proteins, edible insects as protein sources, microalgae and plant proteins.
- ✓ Exploitation of agro-industrial waste to extract and/or produce alternative protein sources.
- ✓ Development of integrated solutions for alternative protein sources in the bio-economy framework.

Learning Resources

- Scientific video presentations
- Review and research articles
- Book chapters
- Lecture notes
- Podcasts and short articles

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

- The lecturer will inform the students with respect to the planned modules and the activities of the semester (in class and out of class), the objectives of the course and the expected learning outcomes.
- Students will also be instructed on how to acquire information and implement the available supplementary resources (online resources, books, reviews and scientific papers, etc.).
- The lecturer will outline and explain the tasks assigned to the students through the semester and how these conform with the scope of the course, along with a scheduled timeline of activities.
- The students will be divided into groups and each group will select the topic they will work on.

Duration: 3x45 minutes

Teaching-Learning Methods

- Questions and Answers
- Discussion

Week 2. Emphasize/Understanding the problem

In-Class Activity

- Introduction to food supply chain and the interconnection of sub-systems and how climate crisis challenges the resilience of food systems and vice-versa.
- Introduction to the sustainability of food systems including the health, economic, social and environmental dimensions.
- The environmental stress of animal-based food and feed products

- The different sources and role of alternative protein sources in food sustainability.
- Students get informed about participatory role-play activities to understand how potential disruptions affect the resilience of food systems. Students (or groups) will be assigned roles related to different dimensions/stakeholders of the food system (e.g. farmers, government-policy makers, food industries, consumers, environmentalists etc.) and will be introduced with a disruption (e.g. pandemic). Each student or group will discuss their decision making based on the different goals and provide arguments. At the end all students will discuss the impact of this incident on food access and sustainability.

Duration: 3x45 minutes

Out-Class Activity

- Students study the educational video shared by the instructors.
- Students research the literature on the resilience of food systems and prepare sticky notes that will be used for the educational game.

Teaching-Learning Methods

- Flipped learning through pre-class study of the video material
- Lecturer presentations
- Educational role-play and directed discussion
- Instructor presentations

Week 3-4. Defining the Scientific Challenges

In-Class Activity

- Identifying the challenges related to alternative protein sources (organoleptic characteristics, consumers' acceptance, cost and scale-up potential, nutritional value, regulation and labeling).
- The role of renewable resources (including agro-industrial waste and by-products) as onset materials for alternative proteins.
- Current EFSA framework on alternative protein sources.
- Role play game: Students will be assigned with a stakeholder role including: policy maker, an alternative protein startup founder (e.g. insect protein), a traditional livestock farmer, an academic, a vegan/vegetarian advocate, a nutritionist etc. Each "stakeholder" will elaborate a position statement regarding the implementation of the specific alternative protein source including the challenges, obstacles, regulations, nutrition aspect and environmental impact.

Duration: 2 x (3x45) minutes

Out-Class Activity

- Students identify and discuss the prevailing challenges with alternative protein sources.
- Students select one alternative protein source that will associate with their subsequent project.

Teaching - Learning Methods

- Study of scientific literature

- Directed discussion
- Role play game and co-operative learning
- Instructor notes

Week 5: Ideate

Out-Class Activity

- Students conduct research on the biotechnological tools and approaches on alternative protein production.
- Students prepare sticky notes with questions and a short presentation of the topic they will engage.

In-Class Activity

Duration: 3x45 minutes

- Students present and discuss their ideas to the group using also the sticky notes.
- The lecturer guides the discussion when needed and the most suitable ideas are selected for further implementation.

Teaching-Learning Methods

- Questions and Answers
- Discussion

Week 6-7-8 Ideate

Out-Class Activity

- At this stage, based on the most suitable ideas previously selected, students will prepare a project/case study including state-of-the-art and research objectives, beyond the state-of-the art innovation and the impact of their approach to address the problem.

In-Class Activity

Duration: 3 x (3x45) minutes

- Groups discuss their progress with the assigned researcher.
- Opinion from instructors and/or experts on the field will be sought after to advise the students on their proposal.

Teaching-Learning Methods

- Discussion
- Questions and Answers
- Presentation

Week 9-10-11: Prototype

Out-Class Activity

- Groups engage in the appropriate preparations for their projects. A researcher and/or an instructor is assigned to help the groups.

In-Class Activity

- Students conduct meetings with the instructor to monitor and discuss the progress of their projects.

Duration: 3 x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Questions and Answers
- Cooperative learning

Week 12-13. Assessment

Out-Class Activity

- Groups finalize the preparations for their projects and their report and upload them.

In-Class Activity

Duration: 2 x (3 x45) minutes

- Groups of students present their project. An event could be simulated (e.g. a workshop) to include time management and encourage questions and answers from their colleagues.
- Discussion/evaluation of the course.

Teaching-Learning Methods

- Discussion
- Cooperative learning

Problem 2 – Waste to Treasure: Biorefinery and Upcycling Strategies in the Bioeconomy Era

Learning Objectives

The course will elaborate on the design of biorefinery concepts to generate value-added products, highlighting the importance of clean label products, within the concept of Bioeconomy. The exhaustion of finite resources and climate crisis confers an issue of paramount importance, as corroborated by the enactment of European legislations and SDGs. Circular Bioeconomy will foster resource efficiency, reduce carbon footprint and enhance sustainability, by implementing the concept of valorizing agro-industrial waste and by-product streams to formulate diversified bio-based products. Food availability and access, economic and environmental resilience are strongly interconnected, thus the exploitation of renewable resources through biorefinery development is a key driver to mitigate these concerns. In line with the above, students will be trained in the current and rising approaches on the fractionation and bioprocessing of waste and by-product streams to deliver valuable products.

By the end of the course, students will be able to:

- Acknowledge the pivotal role of Bioeconomy to mitigate climate crisis and the interlinkages with sustainable food systems, environmental and economic resilience.
- Understand the significance of biorefineries to enact the Bioeconomy strategy.
- Familiarize with biomass/waste fractionation processes and microbial bioconversions.
- Understand the production and the end applications of several bio-based compounds and products.
- Review state-of-the-art research and suggest pioneering solutions to valorize waste and by-product streams.
- Assess the social, economic and environmental aspect of biorefineries.
- Design and present a scientific research project/case study.

Contents

Introduction

- ✓ Waste and by-products derive from all stages of the food supply chain and contribute to climate crisis and environmental concerns.
- ✓ The valorization of agro-industrial waste and by-products confers a pivotal role towards food, economic and environmental resilience.
- ✓ Biorefineries are an economically viable solution to implement the Circular Bioeconomy framework.
- ✓ Green extraction techniques, chemical and enzymatic methods and microbial bioconversions can be implemented to generate valuable products.

The course combines:

- ✓ Understanding the design and development of a biorefining process.
- ✓ Green extraction techniques of value-added compounds from agro-industrial waste and by-product streams.
- ✓ Implementation of microbial bioconversions for the production of diversified end products.

✓ The development of clean-label products through waste and by-product valorization.

Learning Resources

- Scientific video presentations
- Review and research articles
- Book chapters
- Lecture notes
- Podcasts and short articles

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

- The lecturer will inform the students with respect to the planned modules and the activities of the semester (in class and out of class), the objectives of the course and the expected learning outcomes.
- Students will be also instructed how to acquire information and implement the available supplementary resources (online resources, books, reviews and scientific papers, etc.).
- The lecturer will outline and explain the tasks assigned to the students through the semester and how these conform with the scope of the course, along with a scheduled timeline of activities.
- The students will be divided into groups and each group will select the topic they will work on.

Duration: 3x45 minutes

Teaching-Learning Methods

- Questions and Answer
- Discussion

Week 2. Emphasize/Understanding the problem

In-Class Activity

- Introduction to Bioeconomy and Circular Economy and the connection with sustainable food systems and clean label products.
- Overview of the problems stemming from the depletion of finite-fossil resources and the linear economy model.
- Outline of the pivotal role of valorizing agro-industrial waste as renewable resources to generate value-added products.
- Students get informed about participatory role-play activities on Biorefinery design and select biomass type and target products.

Duration: 3x45 minutes

Out-Class Activity

- Students study the educational video shared by the instructors.

- Students research the literature related with Bioeconomy and the role of biorefinery development towards value-added products.

Teaching-Learning Methods

- Flipped learning through pre-class study of the video material
- Lecturer presentations
- Educational role-play and directed discussion
- Instructor presentations

Week 3-4. Defining the Scientific Challenges

In-Class Activity

- Identifying the challenges and potential bottlenecks related to biorefinery development.
- The importance of agro-industrial waste and by-product streams as renewable resources to formulate value-added products.
- Role play game to understand Biorefinery design: Students will be assigned a role including a farmer, a policy maker, an academic, a startup founder, an owner of food manufacturing company etc. Each “stakeholder” will elaborate a position statement regarding the implementation of biorefineries in waste reduction, including the challenges, obstacles, regulations, economic and environmental impact.

Duration: 2 x (3x45) minutes

Out-Class Activity

- Students identify and discuss the fundamental hurdles associated with biorefinery development.
- Students select a biomass type and potential (bio)processes that will be utilized in their subsequent project.

Teaching - Learning Methods

- Study of scientific literature
- Directed discussion
- Educational game and co-operative learning
- Instructor notes

Week 5: Ideate

Out-Class Activity

- Students conduct research on the biotechnological tools, focused on microbial bioconversions and environmentally benign approaches for the holistic exploitation of renewable resources.
- Students prepare sticky notes with questions and a short presentation of the topic they will engage.

In-Class Activity

- Students present and discuss their ideas to the group using the sticky notes.

- The lecturer guides the discussion when needed and the most suitable ideas are selected for further implementation.

Duration: 3x45 minutes

Teaching-Learning Methods

- Question-Answer
- Discussion

Week 6-7-8 Ideate

Out-Class Activity

- At this stage, based on the most suitable ideas previously selected, students will prepare a project/case study including state-of-the-art and research objectives, beyond the state-of-the art innovation and the impact of their approach to address the problem.

In-Class Activity

Duration: 3 x (3x45) minutes

- Groups discuss their progress with the assigned researcher.
- Opinion from instructors and/or experts on the field will be sought after to advise the students on their proposal.

Teaching-Learning Methods

- Discussion and presentation
- Questions-Answer

Week 9-10-11: Prototype

Out-Class Activity

- Groups engage in the appropriate preparations for their projects. A researcher and/or an instructor is assigned to help the groups.

Duration: 3 x (3x45) minutes

Teaching-Learning Methods

- Experimental and cooperative learning
- Questions and Answers

Week 12-13. Assessment

Out-Class Activity

- Groups finalize the preparations for their projects and their report and upload them.

In-Class Activity

Duration: 2 x (3 x45) minutes

- Groups of students present their project. An event could be simulated (e.g. a workshop) to include time management and encourage questions and answers from their colleagues.
- Discussion/evaluation of the course.

Teaching-Learning Methods

- Discussion
- Cooperative learning

Module 3 - From Micro to Macro: Soil Microbiome for Climate-Smart Farming

Problem 1 - Harnessing microbiome for sustainable plant production

Learning Objectives

By the end of this module, students will be able to:

- Explain the concept of the plant holobiont and the ecological roles of plant-associated microbiomes in plant health, nutrient uptake, and stress resilience, emphasizing their contribution to sustainable crop production.
- Describe the ecological and functional roles of diazotrophic microorganisms and effective microorganism (EM) consortia in biological nitrogen fixation, soil quality, and plant productivity.
- Analyze the environmental, physiological, genetic, and agronomic factors that influence microbiome assembly, colonization, and function, with particular focus on diazotrophs and EMs in the plant-soil system.
- Evaluate microbiome-based applications in agriculture, including biofertilizers, biostimulants, and biopesticides, and critically assess the challenges of translating microbiome research into practice, including field variability, regulatory barriers, and scalability.
- Discuss the broader implications of microbiome management for food security, climate resilience, environmental conservation, and the achievement of sustainable development goals.

Contents

- ✓ The plant holobiont and microbiome ecology: structure and function of plant-associated microbiomes; holobiont concept; roles in plant health, stress resilience, and sustainability.
- ✓ Beneficial microbial groups: ecological and functional roles of diazotrophs and effective microorganisms (EMs) in nitrogen fixation, soil improvement, plant nutrition, and stress mitigation.
- ✓ Factors affecting microbiome dynamics: influence of environmental, genetic, physiological, and agricultural factors on microbiome assembly, colonization, and stability.
- ✓ Microbiome-based agricultural applications – biofertilizers, bio-stimulants, and biopesticides: mechanisms, case studies, and practical integration into farming systems (including the conduction of a pot experiment under controlled conditions)
- ✓ Challenges and prospects: efficacy, field variability, regulation, and future directions for microbiome use in sustainable crop production.

Learning Resources

- Selected scientific original research and review articles covering the plant microbiome, diazotrophic microorganisms, and effective microbial consortia, as well as case studies of microbiome-based agricultural applications

- Laboratory protocols and technical manuals for microbial media preparation, cultivation, and inoculation procedures relevant to the practical work
- Datasheets and application instructions for commercial EM and diazotrophic products used in student experiments
- Lecture slides, video content, and other instructional materials to support flipped learning and in-class activities
- Classroom notes taken during lectures and discussions

All essential learning resources will be provided via the Moodle platform.

Teaching and Learning Process

Week 1: Introduction to the Project, the Module, and the Central Problem

In-Class Activity

Duration: (2 × 45 minutes)

- Introduction to the BIOSHIELD project, its structure, and the module From Micro to Macro: Soil Microbiome for Climate-Smart Farming, with emphasis on the role of microbiomes in climate-resilient agriculture
- Presentation of the course Harnessing Microbiome for Sustainable Plant Production, including its structure, learning objectives, and expected outcomes
- Overview of the applied methodologies: flipped learning, design thinking, and problem-based learning
- Screening and group discussion of the short introductory video on the plant microbiome and its relevance to sustainable agriculture (prepared within the project)
- Introduction to key concepts: plant holobiont, soil microbiome, diazotrophic microorganisms, and effective microorganisms (EMs), and their role in sustainable crop production
- Formation of student working groups (4-5 students), promoting diversity in background and perspective
- Group discussion and initial brainstorming on sub-problems related to microbiome application in sustainable plant production (e.g. nutrient efficiency, drought stress, degraded soils)
- Distribution of the digital starter pack via Moodle, including introductory reading materials (reviews on plant microbiomes and their role in sustainable agriculture), a short video, infographic resources, and visual examples of microbiome-based agricultural products (e.g. product fact sheets or promotional visuals)

Out-Class Activity

- Students read review articles from the digital starter pack provided via Moodle, focusing on core concepts such as the plant holobiont, microbiome-plant interactions and microbial consortia

- Each student writes a short reflection (100–150 words) addressing: insight they found particularly interesting or surprising and question(s) they would like to explore further
- Students are invited to browse online for real-world examples of microbial inoculants or products (e.g. biofertilizers, EM formulations) and upload one example (name and short description)
- Students, working in groups, create the initial version of a shared visual poster (on large-format paper or digital board) illustrating how microbiomes support plant growth and sustainability. This will serve as the foundation for an evolving concept map that will be expanded and refined throughout the module.

Teaching-Learning Methods

- Instructor-led teaching and video-based learning
- Flipped learning
- Brainstorming, discussion, and guided reflection
- Collaborative group work
- Exploratory learning

Week 2: Empathize I - Understanding Microbiome-Environment Interactions

In-Class Activity

Duration: (3 × 45 minutes)

- Recap of Week 1 insights and shared observations
- Interactive lecture on environmental, biological, and management-related factors influencing plant-microbiome interactions (e.g. plant genotype, soil type, temperature, moisture, light, inoculation method)
- Group activity and discussion: classification of influencing factors (abiotic, biotic, and technical/management-related), followed by an exploration of real examples of microbiome applications in agriculture — what might go wrong, and why might microbial biostimulants or biofertilizers not deliver the expected effects promised by commercial products
- Short expert input (recorded or live): “What do microbial products need to work effectively in real-world settings?”

Out-Class Activity

- Students read scientific articles on microbiome-environment interactions (available on Moodle)
- Each student selects one factor (e.g. light intensity, temperature, root exudates, soil pH) and writes a short summary (max. 150–200 words) on how it may affect plant-microbiome interactions
- Working in groups, students contribute their selected factor and key insights to a shared visual poster (on large-format paper or digital board), expanding the visual concept from Week 1. Teaching-Learning Methods

- Interactive lecture
- Group discussion and analysis
- Field-based insight – practitioner or researcher perspective on real-world application of microbial products (case-based reasoning)
- Flipped learning
- Collaborative concept mapping

Week 3: Empathize II – Exploring Practical Challenges and User Perspectives

In-Class Activity

Duration: (3 × 45 minutes)

- Group presentations – students present their shared visual poster and explain the individual factors they investigated, summarizing their potential impact on plant-microbiome interactions
- Joint mind-mapping activity (on board or digital whiteboard): identifying practical challenges in the real-world application of microbial products (e.g. variability, environmental conditions, farmer acceptance)
- Simulation exercise: each member of the group takes the role of a stakeholder (e.g. farmer, agronomist, researcher, product developer) and reflects on concerns, needs, and constraints related to microbial product use
- Moderated discussion: linking literature-based understanding to practical limitations and uncertainties in microbiome-based interventions
- Introduction to the idea that students will later formulate a research question for their own pot experiment

Out-Class Activity

- Students read and watch selected resources (e.g. scientific articles, practitioner interviews, video case studies, or posts from biotech companies) on the real-world use of microbial products in agriculture
- In their groups, students reflect on the challenges and needs related to the use of microbial products and link these to the factor they previously investigated. Based on this, they update their shared visual poster by adding a challenge section that highlights potential barriers or uncertainties in practical applications

Teaching-Learning Methods

- Group presentations
- Collaborative mind mapping
- Role-play simulation
- Moderated discussion

- Flipped learning
- Visual synthesis through poster development

Week 4: Define - Framing the Research Question

In-Class Activity

Duration: (2 × 45 minutes)

- Recap of Week 3 outcomes and discussion of recurring themes or challenges
- Guided short lecture: what makes a good research question? (criteria: focused, testable, relevant, feasible)
- Group work: students review the individual factors and challenge sections on their shared poster, collaboratively draft a focused research question related to microbiome application (e.g. *"Does individual factor as temperature, soil pH, water availability, or light condition etc. affect the efficiency of diazotrophic or EM inoculants on X plant species?"*), and exchange their draft question with other groups or the teacher for structured feedback based on clarity, relevance, and feasibility
- Discussion on the next steps: how to move from question to experimental plan

Out-Class Activity

- Each group finalizes and submits their research question or problem statement via Moodle, incorporating feedback received during in-class peer/teacher review
- Students search for one or more relevant scientific articles that explore a similar research question or examine the same factor (e.g. temperature, soil pH, inoculation method) and prepare a short annotation (3-5 sentences) explaining its relevance to their planned investigation
- Groups begin collecting preliminary ideas and constraints for their future experiment: what variables could be tested, which materials would be needed, and what practical limitations (time, space, equipment) they might face

Teaching-Learning Methods

- Guided discussion
- Short lecture
- Collaborative question formulation
- Peer and teacher feedback
- Flipped learning
- Literature-based analysis

Week 5: Ideate - Designing the Experimental Approach

In-Class Activity

Duration: (3 × 45 minutes)

- Short lecture: key elements of experimental design (independent/dependent variables, controls, replication, feasibility)
- Group discussion: examples of microbiome-related experiments (e.g. inoculant comparisons, growth conditions, plant-microbe responses)
- Group activity: development of an experimental concept based on the finalized research question
- Structured worksheet: each group fills out a simplified planning template provided by teacher (e.g. hypothesis, variables, materials, expected outcome, timeline)
- Peer exchange: groups briefly present their experimental concept and receive feedback from peers and/or the teacher
- Brainstorming potential risks and how to address them (e.g. contamination, non-germination, variation in environmental conditions)

Out-Class Activity

- Each group refines their experimental plan in written form (max. 1–2 pages)
- Students explore available lab and greenhouse resources and check feasibility with the teacher (materials, timing, space)
- Groups submit their finalized plan via Moodle for instructor review and approval before moving to the next stage (Prototype/Experiment)

Teaching-Learning Methods

- Short lecture
- Group brainstorming
- Experimental planning
- Peer feedback
- Flipped and resource-guided learning
- Risk identification and mitigation

Weeks 6-13: Prototyping and Testing - Conducting and Analyzing the Experiment

Week 6: Prototype I - Experiment Setup

In-Class Activity

Duration: (3 × 45 minutes)

- Final instructor feedback on experimental plans

- Setup of pot experiment (substrate, labeling, sowing or transplanting seedlings, inoculation)
- Introduction to measurement protocols and observation templates
- Instructions for organizing and storing raw data

Weeks 7-12: Prototype II-VII - Experiment Ongoing

In-Class Activity

Duration: (2 × 45 minutes)

- Group progress updates and informal presentations
- Peer exchange of challenges and observations
- Troubleshooting sessions with the teacher when necessary

Week 11-12: Test I - Mid-Experiment Reflection and Data Review

In-Class Activity

Duration: (2 × 45 minutes)

- Overview of basic statistical concepts, methods and tests (mean, SD, homogeneity of variance, normality of distribution, ANOVA, PostHoc tests)
- Hands-on activity: analyzing preliminary data in SPSS statistical program
- Group reflection: What significance / trends are we seeing? What might they mean?

Out-Class Activity (weeks 6–12)

- Monitoring experiment: watering, environment checks
- Record observations (germination, initial development, post-transplant development)
- Regular data collection (e.g. height, leaf number, photosynthesis)
- Photographing plant progress
- Completion of observation logs (template-based)
- Uploading raw data, images and summaries of preliminary findings (graphs, tables) to Moodle

Teaching-Learning Methods (weeks 6–12)

- Hands-on experimental work
- Guided data collection and documentation
- Inquiry-based learning
- Reflective observation and troubleshooting
- Group collaboration and peer exchange
- Instructor facilitation and ongoing mentoring

Week 13: Test II - Final Data Collection and Analysis

In-Class Activity

Duration: (2 × 45 minutes)

- Final measurements (e.g. harvest, biomass, root length, nodulation)
- Supervised session for organizing raw data and entering into SPSS
- Comparative statistics (e.g. t-test, ANOVA, PostHoc tests)

Out-Class Activity

- Each group performs statistical analysis with support from teacher
- Graphs and summary tables created for presentation
- Interpret results and prepare scientific conclusions

Teaching-Learning Methods

- Instructor-guided measurement and data handling
- Collaborative data entry and analysis
- Supported use of statistical software (SPSS program)
- Data interpretation through group discussion
- Visual synthesis (graphs, tables)

Week 14: Evaluate - Preparing the Final Presentation

In-Class Activity

Duration: (2 × 45 minutes)

- Discussion: how to communicate scientific findings clearly and convincingly
- Review of effective presentation formats (poster vs. PPT – structure, clarity, visuals)
- Group work: outlining the final story – research question, methods, key results, conclusion, limitations
- Peer exchange: feedback on draft layout, clarity of graphs, logic of interpretation
- Instructor input: final tips on scientific tone, visual design, time management for oral delivery

Out-Class Activity

- Groups finalize their presentation (PPT or poster), integrating data, visuals, and interpretation
- Design of visual elements (charts, tables, images, key phrases) for maximum clarity and impact

Teaching-Learning Methods

- Guided discussion and modeling
- Group synthesis and scientific storytelling
- Peer feedback and iterative improvement

- Visual communication strategies

Assessment: Final presentation (Week 15)

In-Class Activity

Duration: (2 × 45 minutes)

- Final group presentations (poster or PPT, 15–20 minutes) in front of teachers and invited expert(s)
- Q&A session following presentation with feedback from peers, teachers, and the expert
- Final comments from the invited expert (agronomist, microbiologist, or industry partner)
- Short individual or group reflection: What did we learn? What surprised us? How would we improve next time?

Teaching-Learning Methods

- Oral presentation and scientific communication
- Peer learning through observation and questioning
- Expert feedback
- Group reflection and self-assessment

Problem 2 – Exploring Environmental Factors of Soil Microbiomes with GIS

Learning Objectives

By the end of this module, students will be able to:

- Describe geographic information systems (GIS) and its components
- Understand the applicability and usefulness of GIS in biotechnology
- Get familiarized with basic data types, data formats, data sources for environmental experts
- Use basic tools and procedures for simple spatial analysis
- Suggest solutions to environmental problems identified with GIS
- Understand soil microbiomes and their importance in ecosystem and agriculture
- Identify and analyze environmental factors influencing soil microbiomes
- Evaluate the potential impacts of climate change on soil microbiomes
- Apply basic GIS techniques for studying soil microbiomes distribution
- Develop GIS-based solutions for studying and improving soil microbiomes
- Assess the usefulness and limitations of GIS approach for studying soil microbiomes

Contents

- ✓ GIS techniques: analysis, modeling, mapping…
- ✓ GIS data: satellite images, lidar, field sampling, online resources…
- ✓ Environmental factors influencing soil microbiomes: land cover, soil moisture, soil pH…
- ✓ Climate change impacts: drought, flood, erosion…

Learning Resources

- Scientific papers
- Textbooks
- Lecture notes, presentations
- Video tutorials
- Case studies
- Online reports

Teaching and Learning Process

Week 1: Introduction to the Project, the Module, and the Central Problem

In-Class Activity

Duration: (2 × 45 minutes)

- Welcome and overview of the BIOSHIELD project and the Design Thinking + Flipped Learning approach

- Weekly journey presentation highlighting milestones, deliverables and assessment checkpoints
- Setting expectations about learning outcomes, teamwork etiquette and an innovation mindset
- Resource-toolkit walk-through of beginner GIS readings, explainer videos, open-data portals and free-software downloads
- Interactive poll on students' current understanding of soil microbiomes and GIS, followed by a whole-class discussion
- Live demonstration of an online interactive soil map to spark curiosity
- Team formation: students organise into interdisciplinary groups of 4-5 balancing biology, GIS curiosity, communication and entrepreneurship skills

Out-Class Activity

- Explore the curated starter pack (introductory GIS article, soil-microbiome explainer video, example interactive map) and record three insights and one question
- Install QGIS, following the step-by-step guide in the toolkit
- Create a personal concept-map sketch linking "GIS → environmental layer → soil microbiome" and upload it to the shared workspace
- Collaborate within teams to synthesise key learnings and draft a list of critical questions for the next session

Teaching-Learning Methods

- Frontal Method - Initial orientation and explanation of structure
- Flipped Learning - Independent exploration of materials before deeper discussions
- Discussion and Brainstorming - Student-generated questions seed subsequent problem finding
- Teamwork - Early team-building fosters collaborative innovation
- Hands-on Learning - Videos and online platforms serve as interactive learning tools

Week 2: Evaluate - Empathize - Understanding the Problem - What environmental factors influence soil microbiomes and why does it matter?

In-Class Activity

Duration: (2 × 45 minutes)

- Expert insights: guest lecture illustrating soil-microbiome responses to drought, flooding and erosion
- Team question generation: groups refine critical questions about how land cover, pH, moisture, temperature and texture influence microbiomes
- Mind-mapping exercise on a shared whiteboard to visualise relationships among environmental factors
- Card-sorting activity: categorise sample data layers (e.g., NDVI, precipitation) as direct, indirect or contextual influences

- Questionnaire design: draft at least five open-ended interview questions for farmers, scientists or land managers

Out-Class Activity

- Conduct at least one stakeholder interview per team (online or in person) to gather qualitative data on environmental influences
- Transcribe interview highlights and tag key themes in a shared spreadsheet
- Capture interview-location coordinates and create a simple point layer in QGIS or Google My Maps
- Summarise interview insights, highlight surprising findings or recurring themes and post them on the shared board

Teaching-Learning Methods

- Frontal Method – Structured expert lecture for concept introduction
- Literature Review and Inquiry – Pre-read materials inform interview questions
- Brainstorming – Collaborative design of meaningful questionnaires
- Interviews – Direct stakeholder interaction deepens contextual understanding

Week 3: Define - Identifying the Core Challenge - How is GIS useful for studying soil microbiomes?

In-Class Activity

Duration: (2 × 45 minutes)

- Introduction to GIS fundamentals: spatial layers, raster versus vector data and the hardware-software-data-people framework
- Case studies: mapping plant-disease spread, visualising soil salinity, locating carbon-farming hotspots
- Live annotation of case-study maps: students mark observed patterns and discuss implications
- Concept-check quiz to reinforce terminology
- Team discussion: link interview insights to GIS capabilities using a whiteboard grid connecting questions to spatial analyses
- Draft a problem statement with the template “We observe X affecting Y; therefore we will use GIS to investigate …”

Out-Class Activity

- Locate and screenshot a Sentinel-2 image, a soil-pH raster and a land-cover shapefile for the study region
- Upload screenshots with one-sentence descriptions to the team folder
- Complete a sandbox exercise: load all layers in QGIS, set the correct CRS and save the project file
- Refine and submit the team problem statement for lecturer feedback

Teaching-Learning Methods

- Frontal Method - Concise lecture establishes foundational GIS knowledge
- Case Study Review - Real-world examples demonstrate application
- Exploratory Learning – Independent navigation of GIS platforms
- Collaborative Definition – Teams articulate meaningful challenges

Week 4: Ideate - Developing Solutions - What data sources and GIS techniques are useful to study soil microbiomes?

In-Class Activity

Duration: (2 × 45 minutes)

- Data-acquisition demonstration: download a Sentinel-2 tile, inspect metadata and perform quality checks
- Hands-on GIS techniques: create a slope layer from a DEM and overlay it with land-cover data to identify steep croplands
- Quick-fire comparison of true-colour versus false-colour composites to illustrate vegetation indices
- Team presentations: outline the challenge, candidate GIS layers and planned analysis approach
- Peer-feedback carousel: teams leave constructive comments and data-source suggestions on each poster
- Develop a shared data-quality checklist covering completeness, resolution, currency and licence

Out-Class Activity

- Watch micro-lessons on buffering, re-projection and basic map styling; complete a short self-quiz
- Mini-lab: buffer 500 m around sample points and calculate mean soil-moisture values using provided datasets
- Fill out a solution-blueprint table listing each layer, source URL, relevance, GIS technique and expected output
- Draft a storyboard wireframe for a StoryMap or WebMap illustrating the user journey

Teaching-Learning Methods

- Frontal Method - Targeted demonstrations of essential workflows
- Hands-on Exploration – Immediate application of techniques
- Peer Learning – Structured feedback drives improvement
- Video-Based Self-Learning – Multimedia supports flexible skill acquisition

Week 5: Prototype - Creating Solutions - Which specific GIS products and services can be developed for studying and improving soil microbiomes?

In-Class Activity

Duration: (2 × 45 minutes)

- Import selected layers, clean data and run analyses such as hotspot analysis, terrain modelling or correlation mapping
- Maintain an error-log board where teams crowd-source solutions to common issues
- Mid-session show-and-tell: share an intermediate map for peer and lecturer feedback
- Continue team work: design a draft visualisation or dashboard highlighting environmental factors affecting soil microbiomes
- Document metadata for at least two layers (source, scale, projection) using the provided template

Out-Class Activity

- Build a minimum viable product (thematic map series, predictive model or interactive web map)
- Conduct a usability test: another team interprets the map and provides feedback on clarity
- Apply a self-assessment grid to rate data quality, output clarity and practical usability; note remaining gaps
- Create a concise README describing the prototype, data sources and reproduction steps

Teaching-Learning Methods

- Hands-on Application – Real GIS data management, analysis and visualisation
- Problem-Solving through Doing – Technical challenges become learning opportunities
- Team Collaboration – Collective effort produces functional prototypes
- Iterative Design Thinking – Emphasis on testing and refinement

Week 6: Test - Presenting Findings - What do the developed GIS products and services reveal and how can they be used for studying and improving soil microbiomes?

In-Class Activity

Duration: (2 × 45 minutes)

- Team presentations: demonstrate the prototype, data sources, techniques, key findings and practical applications
- Peer review and discussion: constructive feedback on clarity, analytical quality and real-world relevance
- Entrepreneurial mini-pitch clinic: deliver a 2-minute investor-style pitch outlining the problem, GIS solution, value proposition and next steps

Out-Class Activity

- Incorporate feedback to enhance technical accuracy and visual clarity
- Polish the pitch deck or storyboard (problem → solution → benefits → users) and record a practice pitch video

Teaching-Learning Methods

- Presentation and Public Speaking - Development of communication skills
- Peer Evaluation - Learning through constructive critique
- Hands-on Refinement – Iterative improvement based on feedback
- Critical Reflection – Integration of technical, scientific and societal perspectives

Assessment: Evaluating Findings - What worked well in the GIS analysis, what were the challenges and how can it be refined?

In-Class Activity

Duration: (1 × 45 minutes)

- Final evaluation workshop: guided reflection on successes, challenges, mitigation strategies and ideas for future refinement
- Celebration of achievements: gallery walk where teams display final outputs (maps, dashboards, pitch decks) and share insights

Out-Class Activity

- Complete the final team report summarising project outcomes, lessons learned and future recommendations
- Write an individual reflection on personal growth in GIS skills, microbiome understanding, teamwork and entrepreneurial thinking

Teaching-Learning Methods

- Self-Assessment and Critical Reflection – Deepened learning and personal growth
- Peer Learning and Knowledge Sharing

Module 4 - Biotechnology for Carbon Capture and Utilization

Problem 1 – Enhancing Photosynthetic Efficiency in Crop Plants for Increased Carbon Sequestration

Learning Objectives

Students will be able to;

- Understand the composition of atmospheric carbon dioxide and its role in the global carbon cycle.
- Understand the process of photosynthesis and its implications in enhancing carbon sequestration in crop plants.
- Understand the diverse applications of biotechnology in optimizing carbon capture and utilization in agriculture.
- Evaluate the advantages and disadvantages of employing biotechnological strategies to improve photosynthetic efficiency.
- Examine the limitations and challenges associated with improving photosynthetic performance for increased carbon capture.
- Analyze the environmental impact of enhanced carbon sequestration in agricultural systems.
- Develop innovative biotechnological approaches to boost carbon sequestration through improved crop plant efficiency.
- Familiarize with current legislation and policies regarding carbon capture and utilization in crop production.

Contents

- ✓ Photosynthetic Processes in Crop Plants
- ✓ Underutilized Atmospheric Carbon Dioxide
- ✓ Environmental Impact of Enhanced Carbon Sequestration

Learning Resources

- A detailed video outlining advanced techniques in improving photosynthetic efficiency in crops. The video, along with supplementary documents, provides insights into biotechnological innovations, the process of carbon capture, and quantitative data on carbon sequestration outcomes.
- Articles, books, and lecture notes that delve deeper into biotechnology for carbon capture and utilization, as well as the environmental and regulatory aspects associated with these advancements, Textbook chapters

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

- The lecturer will introduce the modules planned for the semester, focusing on biotechnology for carbon capture and the specific challenge of enhancing photosynthetic efficiency in crop plants.
- The course tasks and expectations throughout the semester will be outlined.
- Students will receive guidance on accessing additional resources (university library, online databases, etc.).
- The key topics and objectives of each module will be presented.
- Students will be divided into groups, and each group will choose a specific problem.

Duration: 3x45 minutes

Teaching-Learning Methods

- Question-Answer and discussion

Week 2. Emphasize

Out of Class Activity

- A prepared video and additional digital resources will be shared with the students.
- Students are required to:
- Comprehend the biological and biotechnological processes behind photosynthesis and its enhancement in crop plants.
- Understand the diverse applications of biotechnology in increasing carbon sequestration.
- Recognize the advantages and disadvantages of current approaches to enhance photosynthetic efficiency.
- Assess the environmental impact of improved carbon capture through enhanced photosynthesis.
- Familiarize themselves with the limitations and challenges in current methodologies and the regulatory framework associated with these innovations.
- Students will independently investigate the literature and digital resources on biotechnological strategies for improving photosynthetic performance.

In-Class Activity

- Students will share articles, books, and digital resources with their group members.
- Groups will discuss the issue based on the gathered literature.
- Each group is encouraged to envision themselves working in a cutting-edge agricultural biotechnology firm dedicated to pioneering solutions for enhanced photosynthetic efficiency.
- As a group, they will discuss and develop a comprehensive description of the challenges and opportunities in increasing carbon sequestration via improved photosynthesis (using a designated worksheet).

Duration: 3x45 minutes

Teaching-Learning Methods

- Brainstorming
- Discussion

Week 3. Define

Out of Class Activity

- Students are required to deepen their understanding of the biological processes and technological interventions aimed at enhancing photosynthetic efficiency in crop plants.
- They will evaluate the benefits and drawbacks of these approaches, analyze the environmental implications, and recognize the current limitations and regulatory aspects.
- Each group is tasked with researching and synthesizing literature on these topics.
- As a deliverable, each group will create a digital infographic or poster that addresses the challenges and potential of enhancing photosynthetic efficiency for increased carbon sequestration. This will be presented in class by Week 3.

In-Class Activity

- Groups will present their infographics/posters and explain the core problem related to enhancing photosynthetic efficiency.
- These presentations will provide a platform for discussion and further refinement of the identified issues among peers.

Duration: 3x45 minutes

Teaching - Learning Methods

- Presentation
- Discussion
- Question-Answer

Week 4. Ideate

Out of Class Activity

- Students are asked to explore various techniques and biotechnological strategies for enhancing photosynthetic efficiency in crop plants.
- They will study advanced methods in genetic modification, agronomic practices, and laboratory-scale systems designed to simulate and test photosynthetic improvements.
- Key topics include: measurement techniques for photosynthetic performance, experimental setups for controlled environment studies, and protocols to verify the fidelity of genetic interventions.
-

In-Class Activity

- Students will present their mind maps and explain the challenges and opportunities associated with improving photosynthetic efficiency.
- Groups will engage in discussions to further define the problem and identify potential research directions.

Duration: 3x45 minutes

Teaching - Learning Methods

- Discussion
- Question-Answer

Week 5. Ideate

Out of Class Activity

- At this stage, each student is asked to generate ideas for selecting the most effective methods to enhance photosynthetic efficiency, optimize photosynthetic rates, and characterize plant performance under varying environmental conditions.
- Students are encouraged to propose a broad range of ideas, including unconventional approaches, that could contribute to improved carbon capture in crops.

In-Class Activity

- Each student will present their ideas to the group and participate in a collaborative discussion.
- The instructor may guide discussions by emphasizing topics such as: The role of genetic innovations in boosting carbon sequestration, the impact of agronomic practices on photosynthetic performance, methods for accurately quantifying photosynthetic rates and key environmental parameters that affect photosynthetic activity.
- For each group, one or two ideas most suitable for further exploration and implementation will be selected.

Duration: 3x45 minutes

Teaching - Learning Methods

- Discussion
- Question-Answer

Weeks 6-7. Ideate

Out of Class Activity

- Students are asked to prepare a detailed project proposal addressing the enhancement of photosynthetic efficiency for increased carbon sequestration.
- The proposal should include clear research objectives, methodologies, data analysis plans, and a budget outline. (Refer to the Annex: Research Draft for all modules.)

- Students are also encouraged to seek expert opinions by communicating with professionals in agricultural biotechnology and plant physiology, as well as industry partners and research institutions. (This engagement is recommended for Week 6.)

In-Class Activity

- **Week 6:** Each group will update the instructor and classmates on the progress of their research proposal.
- **Week 7:** Each group will present their final proposal to the class.

Duration: 2 sessions of 3x45 minutes each

Teaching - Learning Methods

- Discussion
- Question-Answer
- Presentation

Weeks 8-11. Prototype

Out of Class Activity

- Students will prepare to conduct experiments aimed at enhancing photosynthetic efficiency in crop plants for increased carbon sequestration.
- They will procure the necessary materials and consumables (e.g., growth media, lighting systems, CO_2 sensors) and develop detailed experimental protocols.
- Project activities such as setting up controlled environment experiments and designing measurement methods for photosynthetic performance will be planned.
- Associated partners (e.g., agricultural research centers and biotechnological firms) will be contacted to support laboratory work and provide expert guidance.

In-Class Activity (Wet Lab)

- Students will optimize experimental conditions, carry out laboratory experiments, and prototype innovative methods to enhance carbon capture in crop plants.
- Activities include running controlled experiments, monitoring plant responses under varied conditions, and collecting data for further analysis.

Duration: 4 sessions of 3x45 minutes each

Teaching - Learning Methods

- Experimental Techniques
- Data Collection
- Data Analysis

Weeks 12-13. Testing

In-Class Activity

- Students will test their prototypes to evaluate the effectiveness of enhanced photosynthetic efficiency.
- The testing phase involves assessing plant performance, measuring carbon assimilation rates, and analyzing the overall efficiency of the prototype systems.
- Data collection and analysis will be critical to determining the reproducibility and success of the experimental interventions.

Duration: 2 sessions of 3x45 minutes each

Teaching - Learning Methods

- Experimental Techniques
- Data Collection
- Data Analysis

Week 14. Assessment

Out of Class Activity

- Students will present their project results or prototypes to experts from industry and academia, including silent partners. Feedback on the approaches used to enhance photosynthetic efficiency and carbon sequestration will be provided.

In-Class Activity

- Students will engage in self-evaluation based on their experimental outcomes and the expert feedback received.
- A reflective discussion session will allow students to assess their work, discuss challenges, and identify areas for future improvement.

Duration: 3x45 minutes

Teaching - Learning Methods

- Discussion

Problem 2 - Engineering Enhanced Root Architecture for Optimized Carbon Sequestration in Woody Plants

Learning Objectives

Students will be able to;

- Understand the structure, composition, and functions of woody plant root systems.
- Comprehend the developmental processes of roots and their critical role in carbon sequestration.
- Recognize the diverse applications of biotechnology in engineering enhanced root architecture.
- Evaluate the advantages and disadvantages of modifying root systems to improve carbon capture in woody plants.
- Analyze the environmental impact of engineered root systems and their influence on soil carbon storage.
- Assess the limitations and challenges in optimizing root architecture for maximized carbon sequestration.
- Propose innovative biotechnological approaches to engineer root systems for enhanced carbon capture.
- Familiarize themselves with relevant regulations and guidelines concerning genetic and biotechnological modifications in forestry.

Contents

- ✓ Woody Plant Root Development:
  Explore the fundamental processes involved in the formation, structure, and function of root systems in woody plants.
- ✓ Engineered Modifications for Enhanced Root Architecture:

Investigate cutting-edge biotechnological interventions aimed at modifying root systems to optimize carbon sequestration.

- ✓ Environmental Impact of Engineered Root Systems:
  Assess how engineered root architectures influence carbon storage, soil health, and ecosystem sustainability.

Learning Resources

- A comprehensive video that details the anatomy, growth processes, and biotechnological strategies to engineer enhanced root systems for improved carbon capture, accompanied by supporting documents.
- Articles, books, and lecture notes that cover advanced topics in plant physiology, genetic engineering in forestry, and the environmental implications of modifying root architecture.

Teaching and Learning Process

Week 1. Introduction

In-Class Activity

- The lecturer will provide an overview of the modules planned for the semester, with a special focus on engineering enhanced root architecture for optimised carbon sequestration in woody plants.
- The expected tasks and objectives for the semester will be clearly defined.
- Students will receive guidance on accessing additional resources, including the university library and online databases.
- The topic of each module will be introduced, highlighting the significance of advanced root system engineering in forestry and environmental biotechnology.
- Students will be divided into groups, and each group will decide on the problem they wish to tackle.

Duration: 3x45 minutes

Teaching - Learning Methods

- Question-Answer
- Discussion

Week 2. Emphasize

Out of Class Activity

- A prepared video and additional resources will be shared with the students.
- Students are required to:
- Comprehend the fundamental processes of woody plant root development and its importance in carbon sequestration.
- Understand the diverse biotechnological applications used to engineer root systems for enhanced carbon capture.
- Recognize the advantages and disadvantages of various approaches to modify root architecture.

- Assess the environmental impact of engineered root systems on soil carbon storage and ecosystem health.
- Acknowledge the limitations and challenges in current methods, including regulatory and ethical considerations in genetic modifications.
- Students will investigate the literature on root development and biotechnological strategies using the available resources.

In-Class Activity

- Students will share relevant articles, books, and digital resources with their group members.
- In groups, they will discuss the problem based on the literature.
- Students are instructed to envision themselves working in a leading forestry or environmental biotechnology firm dedicated to enhancing root systems for improved carbon sequestration.Each group is expected to provide a comprehensive description of the issue, considering all its dimensions (using Worksheet 1).

Duration: 3x45 minutes

Teaching - Learning Methods

- Brainstorming
- Discussion

Week 3. Define

Out of Class Activity

- Students will deepen their understanding of woody plant root development and the innovative biotechnological approaches for modifying root architecture.
- They are required to investigate literature on engineered root systems, assess both the advantages and limitations, and become familiar with the regulatory framework concerning genetic modifications in forestry.
- Each group will be tasked with creating a digital infographic or poster, addressing the challenges and potential solutions for engineering enhanced root architecture (to be presented in class by Week 3).

In-Class Activity

- Each group will present their infographics or posters, explaining the problem related to current limitations in root system engineering.
- An interactive discussion will follow, allowing students to share insights and further refine the problem definition.

Duration: 3x45 minutes

Teaching - Learning Methods

- Presentation
- Discussion
- Question-Answer

Week 4. Ideate

Out of Class Activity

- At this stage, each student is asked to generate ideas on how to engineer enhanced root architecture effectively to optimize carbon sequestration in woody plants.
- Students are encouraged to propose a variety of ideas, including unconventional approaches, that address factors such as increasing root biomass, optimizing root depth, and improving root-soil interactions.

In-Class Activity

- Each student will present and discuss their ideas within the group.
- The lecturer will provide guidance when necessary, drawing attention to issues like: The potential to increase carbon storage by modifying root growth patterns, the importance of balancing root function with overall plant health, innovative approaches to integrate traditional breeding with modern biotechnological techniques and economic and environmental considerations of engineered root systems.
- For each group, one or two of the most promising ideas will be identified for further development.

Duration: 3x45 minutes

Teaching - Learning Methods

- Discussion
- Question-Answer

Weeks 5-7. Ideate

Out of Class Activity

- In line with the ideas generated, students are asked to prepare a detailed project proposal addressing the engineering of enhanced root architecture for optimised carbon sequestration.
- The proposal should include clear research aims, methodologies, data analysis plans, and a budget outline (refer to the Annex: Research Outline for all modules).
- Students are encouraged to consult with experts in forestry, plant physiology, and environmental biotechnology to refine their proposals.
- Engagement with opinions from associate partners is recommended, particularly in Week 6.

In-Class Activity

- **Weeks 5 and 6:** Each group will update the lecturer and classmates on the progress of their research proposal.
- **Week 7:** Each group will present their final project proposal to the class.

Duration: 3 sessions of 3x45 minutes each

Teaching - Learning Methods

- Discussion
- Question-Answer

- Presentation

Weeks 8-13. Prototype & Testing

Out of Class Activity

- Students will prepare to conduct their project on engineering enhanced root architecture for optimized carbon sequestration in woody plants. This includes securing necessary materials (e.g., specialized soil substrates, growth media, imaging tools, and molecular reagents) and planning detailed experimental protocols.
- Associate partners, such as forestry research centers and environmental biotechnology firms, will be contacted to support the wet lab activities.

In-Class Activity (Wet Lab)

- Students will optimize experimental conditions, perform experiments aimed at modifying root architecture, and prototype innovative techniques to enhance carbon sequestration.
- They will obtain and analyze experimental results, integrating data collection and analysis to refine their approaches.
- Groups will test their prototypes

Duration: 6 sessions of 3x45 minutes each

Teaching - Learning Methods

- Experimental Techniques
- Data Collection
- Data Analysis

Week 14. Assessment

Out of Class Activity

- Students will present their project results or prototypes to experts from industry (including associate partners) and academia, receiving constructive feedback on their work.

In-Class Activity

- Students will assess their own work by reflecting on their experimental outcomes and incorporating expert feedback into their evaluation.
- A guided discussion will allow students to critically analyze the successes and challenges of their project and to identify areas for further improvement.

Duration: 3x45 minutes

Teaching - Learning Methods

-
- Discussion

Module 5 - Plant-based Solutions in Climate Change Mitigation

Problem 1 – Phytoremediation: Plants as environmental cleaners

Learning Objectives

The course takes a scientific problem-solving approach to understanding how plants can be used to clean up environmental pollutants. Using design thinking, students will tackle real scientific challenges in phytoremediation, such as optimizing plant selection, improving pollutant uptake, enhancing soil health, and scaling up phytoremediation processes.
By the end of the course, the students will be able to:

- Understand the biological mechanisms behind phytoremediation.
- Analyze key scientific and technical challenges in phytoremediation.
- Apply a problem-solving framework to environmental cleanup challenges.
- Develop innovative strategies for improving phytoremediation efficiency.
- Critically assess the environmental and socio-economic impact of phytoremediation.
- Design and present a scientific research proposal addressing a phytoremediation challenge.

Contents

- ✓ Pollution sources
- ✓ Environmental pollution and remediation methods.
- ✓ Phytoremediation as a green technology for environmental restoration.
- ✓ Advantages and limitations of phytoremediation strategies.
- ✓ Understanding the scientific basis of phytoremediation.
- ✓ Developing innovative phytoremediation solutions.

Learning Resources

- Scientific video presentations
- Classroom notes
- Review articles/Original articles
- Media resources

Teaching and Learning Process

Week 1- Introduction

In-Class Activity

- Overview of the course structure, objectives, and learning outcomes.

- Explanation of assignments and project timeline.
- Introduction to phytoremediation and its significance in environmental cleanup.
- Students form groups (4-5 members) and select a specific phytoremediation challenge.

Duration: 3x45 minutes

Teaching-Learning Methods

- Questions and answers
- Discussion

Week 2- Introduction and Emphasize: Understanding the Problem

In-Class Activity

- Introduction to types of pollutants and their environmental impact.
- Biological processes in phytoremediation: phytoextraction, phytostabilization, phytovolatilization.
- Factors affecting phytoremediation efficiency (soil pH, bioavailability, plant traits).

Duration: 3x45 minutes

Out-of-Class Activity

- Students study provided literature.
- Each group prepares a short video (5 min) for the general public explaining phytoremediation.

Duration: 3x45 minutes

Teaching-Learning Methods

- Study of scientific literature – Directed discussion – Instructor presentations

Week 3: Defining the Scientific Challenges

In-Class Activity

- Identifying key limitations in phytoremediation (e.g., plant uptake efficiency, environmental variability).
- Exploring innovations (e.g., genetically modified plants, microbial-assisted phytoremediation)

Duration: 2x45 minutes

Out-of-Class Activity

- Groups identify and frame a specific scientific problem.
- Each group prepares a poster presenting the problem (10 min presentation).

Duration: 3x45 minutes

Teaching-Learning Methods

- Study of scientific literature
- Directed discussion
- Brainstorming
- Instructor presentations

Week 4: Define - Explore Potential Solutions

In-Class Activity

- Group discussions on potential solutions (e.g., advanced plant breeding, bioaugmentation strategies)
- Brainstorming innovative phytoremediation approaches

Duration: 2x45 minutes

Teaching-Learning Methods

- Directed discussion
- Cooperative learning
- Instructor presentations

Week 5: Ideate

Out-of-Class Activity

- Students watch videos on advanced phytoremediation techniques.
- Groups design a presentation on their chosen challenge and potential solutions.

Duration: 3x45 minutes

Teaching-Learning Methods

- Cooperative learning
- Flipped classroom
- Experimental learning

Weeks 6-7-8: Ideate

Out-of-Class Activity

- Groups prepare a detailed experimental proposal.

In-Class Activity

- Progress discussions with a PhD student/Postdoc researcher.

Duration: 3x (3x45) minutes

Teaching-Learning Methods

- Cooperative learning
- Experimental learning

Weeks 9-10-11: Prototype

Out-of-Class Activity

- Groups develop experimental designs
- Course leader assists with troubleshooting.

Duration: 3x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Weeks 12-13: Assessment

Out-of-Class Activity

- Groups finalize project reports and submit them.

In-Class Activity

- Groups present their findings.
- Course evaluation and discussion of future research directions.

Duration: 2x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Assessment

Phytoremediation Approach Presentation
Each group will present a specific phytoremediation strategy (e.g., phytoextraction, phytostabilization, or phytodegradation).
Presentation (15 minutes) should include:

- Explanation of the chosen phytoremediation approach and its biological mechanisms.
- A step-by-step description of how the experiment will be set up (including plant selection, pollutant type, growth conditions, and measurement methods).
- Anticipated challenges and solutions.
- Evaluated on scientific depth, experimental design, problem-solving, and communication skills.

Problem 2 – Plant *in-vitro* cultures: Biotechnological approaches for sustainability

Learning Objectives

The course takes a scientific problem-solving approach to understanding how plant *in-vitro* cultures can contribute to sustainable agriculture, biodiversity conservation, and industrial applications. Using design thinking, students will address real scientific challenges such as optimizing culture conditions, improving regeneration efficiency, and applying advanced biotechnological tools.

By the end of the course, students will be able to:

- ➢ Understand the scientific foundations of plant in-vitro culture techniques.
- ➢ Analyze key challenges in plant tissue culture, micropropagation, and genetic transformation.
- ➢ Apply problem-solving frameworks to improve plant in-vitro culture systems.
- ➢ Develop innovative solutions for enhancing sustainability through biotechnology.
- ➢ Evaluate the environmental, economic, and social impacts of plant in-vitro culture.
- ➢ Design and present a scientific research proposal focused on plant in-vitro culture challenges.

Contents

- ✓ Plant in-vitro culture techniques: tissue culture, callus culture, micropropagation, and somatic embryogenesis.
- ✓ Role of plant biotechnology in sustainable agriculture and biodiversity conservation.
- ✓ Challenges and opportunities in plant in-vitro cultures for commercial and ecological applications.

Learning Resources

- Scientific video presentations
- Classroom notes
- Review articles/Original articles
- Media resources

Teaching and Learning Process

Week 1: Introduction

In-Class Activity

- Introduction to course structure, objectives, and learning outcomes.
- Explanation of assignments, project deliverables, and the timeline.
- Overview of plant *in-vitro* culture and its biotechnological applications.
- Formation of student groups (4-5 members) to address a specific *in-vitro* culture challenge.

Duration: 3x45 minutes
Teaching-Learning Methods

- Questions and answers

- Discussion

Week 2: Emphasize Understanding the Problem

In-Class Activity

- Introduction to plant tissue culture methods: organogenesis, somatic embryogenesis, and protoplast culture.
- Factors influencing in-vitro growth: media composition, plant growth regulators, and environmental conditions.
- Applications of plant in-vitro culture in sustainable agriculture (e.g., disease-free plant production, conservation of endangered species).

Duration: 3x45 minutes

Out-of-Class Activity

- Students review assigned literature on plant *in-vitro* techniques.
- Each group produces a 5-minute video for the general public explaining plant in-vitro culture and its sustainability benefits.

Duration: 3x45 minutes

Teaching-Learning Methods

- Study of scientific literature
- Directed discussion
- Instructor presentations

Week 3: Defining the Scientific Challenges

In-Class Activity

- Identifying key limitations in plant in-vitro culture (e.g., low regeneration efficiency, somaclonal variation).
- Exploring innovations (e.g., genetic transformation, synthetic seed technology, and automation of culture systems).

Duration: 2x45 minutes

Out-of-Class Activity

- Each group identifies a specific scientific challenge.
- Groups prepare a 10-minute poster presentation to frame the problem.

Duration: 3x45 minutes

Teaching-Learning Methods

- Study of scientific literature
- Directed discussion
- Brainstorming and Instructor presentations

Week 4: Define - Explore Potential Solutions

In-Class Activity

- Groups present posters and discuss potential solutions (e.g., optimizing media composition, developing stress-tolerant lines, improving somatic embryogenesis efficiency).
- Brainstorming session on biotechnological innovations to improve plant in-vitro culture.

Duration: 2x45 minutes

Teaching-Learning Methods

- Directed discussion
- Cooperative learning
- Instructor presentations

Week 5: Ideate

Out-of-Class Activity

- Students watch videos on cutting-edge approaches (e.g., CRISPR in plant tissue culture, automation technologies).
- Each group designs a presentation outlining their proposed solution and experimental setup.

Duration: 3x45 minutes

Teaching-Learning Methods

- Cooperative learning
- Flipped classroom
- Experimental learning

Weeks 6-7-8: Ideate

Out-of-Class Activity

- Groups prepare a comprehensive research proposal, including:
    - Research objectives
    - Experimental design and methodology
    - Data collection and analysis plan
    - Budget and resource needs

In-Class Activity

– Groups discuss progress with a PhD student/Postdoc researcher for feedback and guidance.

Duration: 3x (3x45) minutes

Teaching-Learning Methods

- Cooperative learning
- Experimental learning

Weeks 9-10-11: Prototype

Out-of-Class Activity

- Groups work on implementing their project plan, refining methodologies, and preparing for the final presentation.
- PhD student/Postdoc researcher provides technical assistance.

Duration: 3x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Weeks 12-13: Assessment

Out-of-Class Activity

- Groups complete and submit a final report detailing outcomes and future implications.

In-Class Activity

- Each group presents a 15-minute final project presentation, summarizing their challenge, methodology, results, and potential applications.
- Course reflection and evaluation of future directions in plant biotechnology.

Duration: 2x (3x45) minutes

Teaching-Learning Methods

- Experimental learning
- Cooperative learning

Assessment

The assessment evaluates students' ability to analyze complex scientific problems, develop innovative solutions, and communicate findings effectively.

Plant In-Vitro Approach Presentation

A 15-minute presentation where each group outlines a specific plant in-vitro culture approach and how they would set up the experiment.

Must include:

- Explanation of the approach (e.g., micropropagation, genetic transformation)
- Step-by-step experimental setup and anticipated challenges and troubleshooting strategies.

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