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BIOSHIELD

WORKSHOP REPORT

WORKSHOP OBJECTIVES

The subsequent phase of data collection centres around 1 local-level worksho organization conducted with academicians, industry representatives, associate partners and students. Workshops include discussion and brainstorming session regarding biotechnology response to global climate change.

Overview

- To specify the effects of global climate change and increasing disasters threatening biological life on the Earth, especially agricultural product yield.
- To clarify in which areas industrial and agricultural biotechnology has developed solutions so far and what their efficiency on a global scale is
- To reveal future research and industrial and agricultural solution/remediation areas that can be developed through biotechnology
- To contribute to developing innovation in Biotech higher education towards upskilling students by delivering a curriculum



PROGRAMME FLOW

01	Opening Welcome and presenting workshop objectives
02	Session 1

	Overview of Climate Change and Its Global Impact - Climate Change and Disasters' Effects on Agricultural Productivity
03	Session 2 Current Biotechnology Applications in Climate Change and Climate Change-Oriented Disaster Mitigation
04	Session 3 Promising Research Areas in Biotechnology and Role of Biotechnology in Disaster Resilience
05	Session 4 Discussion for Regional Variations in Climate Change Effects - Case Studies - Experiences
06	Evaluation Participants' Opinions on Workshop Organization
07	Closing Participants' Opinions on Workshop Organization

DATA COLLECTION METHOD

Data Collection Process includes document preparation for workshops, questionnaire preparation, stakeholder communication, workshop facilitation, quality evaluation survey design and implementation.

Participant Profiles

The eligible departments for biotechnology professionals: biology, chemistry, genetics, energy, biochemistry, molecular biology, ecology, geography, eco- remediation

The sector representatives can be from the following sectors by technique: genetic engineering, molecular breeding, molecular diagnostics and tissue culture.

Workshop Materials

We, all partners, contribute to developing workshop organization materials, presentations, and resources.

Know-how Exchange

Participants will exchange their know-how about climate change and resulting disasters, its effects on agriculture, current applications, and emerging research areas.

Workshop questions will guide participants to share their know-how, creative ideas and offers.

Workshop Outcomes

Case studies and recommendations will be generated during the workshops.

Data Analysis

Data analysis includes demographic information about participants, themes created from the answers to the questions, highlights from each session, and quality evaluation results.

Participant Profiles

Participant Profiles	Academician	Sector	Associated Partner	Student
Number / Percentage	5/25	9/45	0	6/30

Participant Age

Age Range	18-25	26-35	36-45	46+
Number / Percentage				

Gender

Gender	Female	Male
Number / Percentage	6/30	14/70

After the general discussion on the consequences of climate change and its impact on agriculture, participants were divided into five groups. During the group sessions, they explored various aspects of biotechnology education, agricultural sustainability, and the role of innovation in preparing students for climate-related challenges. Each group addressed three questions and presented their findings, often sparking broader discussions.

Group 1 (4):
Martin – doctoral student, Agriculture and assistant: microbiology, project office, Tina – teacher: plant breeding, Vid – undergraduate student, Agronomy, Manfred – teacher: integrated and organic plant production
Group 2 (3):
Nejc – researcher, National Laboratory of Health, Environment, and Food, working extensively on soil microbiomes and plant holobiomes in connection to plant breeding for stress conditions, Luka – company Micronatura: production of effective microorganisms, Kaja – postgraduate student, Geography
Group 3 (3):
Metka – teacher: plant genetics, tissue culture, Mario – teacher: phytopathology, entomology, phytomedicine, Irina – undergraduate student, Organic farming
Group 4 (6):
Primož – spin-off company RGA (Research Genetics and Agrochemistry) and teacher: plant breeding, Andrej – teacher: phytopathology, entomology, phytomedicine, climate modeling, Drago and Vasja – Company Cornus: greenhouse vegetable seedling production, Alojz – Company Corteva Agrosience™ – distributor of plant protection products, biostimulants, N-stabilizers, and diazotroph products, Matjaž – undergraduate student, Agronomy
Group 5 (4): Anita – Company ŽIPO Lenart, 860 ha farm: no-till and regenerative agriculture, Tilen – postgraduate student, Geography, Zala – postgraduate student, Geography, Andrej – Company Karsia: advising in agriculture, distributor of fertilizers and plant protection products (also for integrated and organic production)

Data Analysis

Session 1: **Overview of Climate Change and Its Global Impact - Climate Change and Disasters' Effects on Agricultural Productivity, Improving Biotechnology Education for Climate Change Mitigation**

Questions of Session 1	Themes	Sub-themes	Excerpts of participants
Discussion After the Presentation on the Consequences of Climate Change Globally, in the EU, and in Slovenia	Climate Change and Agriculture Soil Health and Sustainable Management	- Longer growing seasons: opportunities and risks (droughts, extreme weather) - Changes in soil and water retention capacity - Role of soil microbiome in nutrient cycling and fertility - Carbon sequestration and conservation agriculture (reduced tillage, cover crops) - Maintaining plant cover to improve water retention and prevent erosion	**Primož**: Climate change also brings certain advantages, as we have observed a longer growing season in our region compared to 20 years ago. This creates an opportunity to increase cereal yields, as their organogenesis phase is extended, allowing for the development of longer ears with more spikelets and flowers. Winter cereals, in particular, are a crop group that, due to their growth cycle and development dynamics, still largely avoid drought—an issue that has been increasingly problematic in recent years. For some other crops, adjusting agronomic practices—such as modifying sowing dates—could help mitigate the effects of changing climatic conditions. **Mario:** Changes in soil conditions have become extreme. Climate change is significantly altering soil's water-holding capacity. Regarding the observed decrease in precipitation levels, in Slovenia—particularly in our region and the eastern part of the country, where most cereal production takes place—we still receive around or slightly less than 1,000 mm of annual rainfall. Compared to many other countries, this is still a luxury. In some places, only 350–450 mm of rain falls per year, yet they still manage to produce 12 tons/ha of maize with minimal irrigation. Such high yields are primarily due to excellent water retention in the soil. Thus, in our case, the key factor that needs to change is improving soil's capacity to retain water. There is still a lack of awareness regarding the need for more

	Water and Nutrient Management Economic and Policy Perspectives	- Efficient use of water in agriculture and soil's role in water retention - Excessive nitrogen fertilization: environmental and economic impact - Alternative fertilization approaches: microbiome-based solutions, biological nitrogen fixation - Cost-effectiveness of sustainable practices for farmers - Role of policymakers in promoting climate-resilient agriculture - Integration of scientific research into advisory and policy frameworks	efficient water management and better utilization. A prolonged growing season—by a month or even a month and a half—can indeed be an opportunity, but only if we have control over water availability. One potential solution is conservation agriculture, an approach we have recently been working on intensively at our faculty. The core principle of this method is eliminating plowing. Despite the well-documented benefits of conservation farming and its widespread adoption—several large farms in our region already manage their land, this way—agricultural advisors and policymakers at the Ministry of Agriculture still fail to recognize its importance and advantages. **Luka:** Yes, and on those farms, water retention is not an issue because they maintain living, undisturbed soils. **Mario:** Exactly. We know how much water is required to produce 1 ton of maize, and we also understand the region's rainfall patterns. The issue is not water availability in Slovenia—it is preventing unnecessary water loss. **Luka:** Everything mentioned is true, but we still, even I, do not fully understand what exactly causes these changes. However, we do know that temperature and CO_2 levels are rising. Some new models even show that these increases are stabilizing. Ultimately, higher CO_2 levels also present an opportunity for most plants (especially C3 plants). Of course, there are challenges, but I believe the solution lies in the soil—its structure, humus content, and microbiome. You see, plants can grow without soil, but soil cannot exist without plants. This means that soil needs plants more than plants need soil. Therefore, soil is the first and most crucial factor in coping with the consequences of climate change. It plays a key role in successful and sustainable production, water retention, and

			plant nutrient supply. Healthy soil metabolism directly influences plant responses. From this perspective, agriculture is a solution for increased CO_2 levels, not just a contributor. **Primož:** Long-term trials (>30 years) conducted in two regions of Slovenia (western and northeastern) show that increasing carbon levels in the soil is very difficult, but they can be degraded very quickly—much faster than any other soil property. This is why maintaining an adequate soil microbiome is crucial, as it plays a key role in nutrient release. However, we know very little about the microbiome, and even the limited knowledge we have is not considered when creating fertilization plans. These plans are still developed purely mathematically, which leads to major inefficiencies. Unlike, for example, the International Plant Nutrition Institute (Canada), which emphasizes the importance of understanding how much of a given nutrient is removed with the yield and how much a plant can absorb—an approach that includes the role of the microbiome. Thus, we need to change our way of thinking. **Silva:** Thank you for your insights and for emphasizing the importance of soil and the soil microbiome. This aligns directly with our focus and objectives in designing the learning module for this project. **Mario:** I would add that, in my estimation, 50–60% of EU studies still contain significant gaps in the understanding of soil carbon and organic matter. There is a prevailing dogma that soil carbon sequestration is simply the accumulation of dead, decomposed organic matter—humus. However, this is a misconception. For plant and microbial life, the most crucial factor is the continuous metabolic carbon flow, which stimulates rapid

			microbial population growth. This is a fundamental concept that students often do not learn or fail to fully grasp by the time they complete their agronomy studies. **Silva:** What exactly disrupts these natural processes in the soil? **Mario:** Microbial activity is disrupted by soil tillage, the application of soluble mineral fertilizers, pesticides, and the restriction of organic matter input—because we want perfectly clean fields, free of any weeds. This is unnatural for the ecosystem. At our department, we have been conducting long-term trials in permanent crops—orchards and vineyards. The growth space between plants in the rows is in our experiments all year-round covered with different plant species, and we have demonstrated that the more plant diversity there is in a vineyard, the better the water and nutrient efficiency for grapevines. Vineyard owners, who dogmatically remove all vegetation between rows, struggle to understand this, but we show them the benefits: grapevines have more available water because they do not lose 30% of water immediately after a downpour, erosion is reduced (which is a major issue in our steep vineyards), and vines develop deeper root systems—7–8 meters instead of just 2 meters. Such a deep root system is possible—I have seen grapevines develop even deeper roots—up to 30 meters—in the Cuenca region of Spain, where landslides have exposed a 30-meter soil profile. And yet, with only surface rocks, vineyards still produce 30 tons/ha without irrigation. In contrast, shallow root systems mean large soil volumes remain unutilized. What I am saying is that in agriculture, we have completely ignored natural processes that could ensure sustainability.

			If we consider the average nutrient uptake by crops and account for soil depth—whether 0.5 meters, 1 meter, or deeper—we can calculate that we have nutrient reserves in the soil for hundreds of years. And yet, we continue fertilizing instead of enabling microbial activity to make these nutrients available to plants. **Primož:** That is true. When it comes to phosphorus and potassium fertilization, farmers focus only on maintaining a "C-level" of soil reserves without considering the microbiome. It is also crucial to understand plant growth dynamics—when a crop develops its maximum root system, when flowers are formed ontogenetically, etc. Understanding these aspects helps mitigate extreme weather conditions. **Luka:** Fertilization is certainly one of the key areas where we still have a lot of untapped potential. It seems that much of the knowledge we had about fertilization before the introduction of synthetic nitrogen and NPK fertilizers has been forgotten. **Mario:** Let's not forget about nitrogen oxides, which are even more potent greenhouse gases than CO_2. **Luka**: Excessive nitrogen fertilization, unfortunately, is a reality in many places, leading to pollution. Aggressive soil cultivation results in carbon depletion, and at the same time, we disrupt metabolic processes in the soil that could otherwise aid nutrient uptake. I'm also referring to diazotrophs, which could naturally supply plants with nitrogen for free powered by sunlight. We need to adapt to these natural processes. The solution I see is conservation tillage, regenerative agriculture, and diversified crop rotation (including legumes).

			We also need to reduce the impact of certain pesticides on the soil, minimize heavy machinery passes on fields, especially at inappropriate times, and ensure that soils are not left bare—we need to use cover crops more extensively. Additionally, we must incorporate suitable crop species and varieties into the rotation. With these measures, Slovenia could view changing climate conditions not just as a challenge but also as an opportunity—just as some northern countries, such as Canada, Russia, and Ukraine, are doing. **Mario:** Here's an interesting point. German researchers wrote a book about soil life and the role of earthworms in 1 m^3 of soil, describing their ecosystem services. One of the authors linked last year's severe floods in Germany—and most problems caused by heavy rainfall—to low soil biological activity. In his opinion, if agricultural soil contained just 20% more earthworms, the problems would have been significantly less severe. The soil's infiltration capacity would have been higher, meaning that much of the water would have remained within the soil ecosystem instead of rapidly running off into waterways and causing flooding. The book provides calculations that support this claim. Of course, urbanization, transport, and other human interventions in agricultural ecosystems also play a role. Several decades ago in Slovenia, we extensively modified watercourses, draining and straightening them into rapid-flow channels. Now we realize this was a mistake, and in many places, we are trying to restore rivers to their natural state, slowing down water runoff and effectively preserving water in the landscape.

			Today, even urban planners are seeking ways to retain rainwater, channeling it gradually into drainage systems instead of allowing immediate runoff into rivers. Globally, we can link extreme rainfall events with disasters—whether in Spain, California (Sierra Nevada), Brazil, or South Africa. The pattern is the same: glaciers are disappearing, and in spring, these areas face massive water surpluses, but nothing retains the water—it quickly drains away. This is followed by summer droughts. Then, in autumn, when crops should be harvested, mini monsoons occur. This disrupts the natural rhythm of plants and soil microbiomes. **Tina**: But the fact remains that farmers must produce enough food under changing climate conditions—not just in quantity, but also to generate sufficient income. **Luka**: From an economic perspective, the efficiency of production is crucial. When calculating profitability, all costs must be considered. **Martin**: The goal is to maximize profit with the lowest possible costs. Regarding fertilization and pesticide application, it is necessary to consider not just input costs, but also the costs associated with their application. These costs are not insignificant, yet they are often overlooked.
Q1: What are the specific skills and knowledge gaps in current biotech education related to climate change mitigation? Q2: What knowledge and	Modernizing Biotechnology Education	- Updating curricula with relevant and practical knowledge. - Bridging the generational gap between educators and students. - Expanding microbiology content to include soil, plant,	**Group 1** pointed out that the knowledge delivered to students is often outdated and lacks relevance, which is particularly problematic in the rapidly evolving field of biotechnology. They emphasized that the core issue lies not only in the content itself but also in the didactic approaches of university professors and the generational gap between educators and students. Another key topic discussed was the perception of the agricultural profession. Students in agriculture should recognize that farmers are not merely food producers but also key actors in ensuring food security, landscape architects,

skills should the students acquire?		and human microbiomes. - Increasing hands-on learning through university farms and field projects. - Encouraging critical thinking, problem-solving, and interdisciplinary approaches. - Strengthening the connection between research, industry, and real-world applications.	and environmental stewards. Additionally, they should graduate as well-informed consumers, capable of distinguishing between healthy food, industrially processed food, and generic food products. The group stressed the need for a stronger focus on alternative and more sustainable food production systems, particularly those that emphasize environmental responsibility. Industrialized agriculture often prioritizes synthetic pesticides, fertilizers, and short-term profit, whereas more ecologically harmonious methods minimize environmental degradation. Graduates should adopt a holistic perspective on agroecosystems and food production, with a particular emphasis on soil health, which plays a crucial role in sustainable agriculture. To ensure the long-term functionality of soils, students should gain knowledge about crop selection, optimal crop rotations, mulching, weed management, intercropping, and the role of organic matter in nutrient cycles, including carbon. The discussion also highlighted the importance of rethinking crop choices in response to changing climate conditions, as traditional and indigenous varieties may no longer be the most suitable. Looking further south from Slovenia may provide better-adapted varieties. In terms of educational methodology, there was strong support for incorporating more project-based learning, as well as problem-based and flipped learning approaches. The idea that students should engage with materials independently before class and be prepared for in-depth discussions was widely endorsed. The group emphasized the need for students to think critically, identify solutions to real-world problems, and be able to justify and defend their perspectives in classroom discussions. A major shortcoming of the current
	Applied and Project-Based Learning		
	Economic and Entrepreneurial Skills	- Strengthening agricultural economics and financial sustainability education. - Encouraging entrepreneurship and business thinking in biotechnology.	

	Digitalization and Innovation	- Integrating AI, bioinformatics, and ICT tools into education. - Adapting teaching methods to meet the expectations of digital-native students.	system is an overemphasis on rote memorization and factual knowledge, with too little attention given to practical, applied thinking. **Manfred** shared insights from his own teaching experience, explaining that in his Organic Crop Production course, students are divided into small groups and tasked with solving real-world agricultural challenges on the university estate (University Agricultural Center). They observe field conditions, analyze them, propose multiple solutions, and collectively decide on the most promising approach. They must then justify their decisions in a debate with their peers. He believes that the university farm is still underutilized as a teaching tool and offers a valuable opportunity for students to explore biotechnological applications, as agronomy is a practical and applied science. **Matjaž**, a student, strongly supported this hands-on approach, explaining that it changes how students perceive theoretical knowledge. By engaging directly with practical challenges, they can better understand the relevance and utility of what they learn. He also emphasized the value of requiring students to justify their decisions, as this deepens their understanding. Irina (student) voiced a critique regarding the absence of microbiology in some curricula, despite its fundamental importance in biotechnology. She pointed out that microbiology is not only essential for food fermentation applications, such as wine, yogurt, cheese, and silage making, but also for understanding soil microbiomes and the biotechnological solutions related to them. She stressed the interconnectedness of soil, plant, animal, and human gut microbiomes and the necessity of including this knowledge in education to develop a more holistic understanding of biological systems. **Luka** agreed, noting that while there is still much to discover about beneficial microorganisms, the knowledge that has already been established should be

			actively integrated into teaching. He emphasized that beneficial microbes, such as lactic acid bacteria, are found across different microbiomes and that some microorganisms can transition between pathogenic and beneficial roles depending on environmental conditions. As an example, he mentioned *Fusarium* species, which can be used in biotechnology for nanoparticle synthesis. He argued that students do not need to memorize every detail but should understand the key concepts behind these biological processes. **Martin** pointed out a major gap in economic education, particularly in environmental economics, where financial indicators intersect with environmental impacts. **Drago, Alojz** and **Luka** further emphasized the importance of focusing on economics, business models, and financial sustainability in agriculture. They argued that students should be equipped with the skills to maximize profitability with minimal financial input and that agronomy, in many ways, is the application of economic principles to biology. **Nejc** added that there is insufficient student involvement in project-based work, which would facilitate the practical application of theoretical knowledge. He stressed that this is important not only at master's and doctoral levels but also in undergraduate education. Martin (assistant, doctoral student) also highlighted the need for proper and cautious use of artificial intelligence in agricultural sciences. **Tina** reiterated the importance of fostering innovation and ensuring that young professionals are equipped with strong teamwork and communication skills, both in their native language and in English. **Luka** suggested that, given the expectations of the new generation of students, universities should consider incorporating more ICT tools into education.

			Alojz concluded the discussion by emphasizing that younger generations have different learning styles and expectations, and as educators and employers, older generations must be willing to adapt to some extent to support the professional development of future agricultural and biotechnological experts.

Data Analysis

Session 1 – HIGHLIGHTS

1 – Climate change extends growing seasons but also increases drought and extreme weather risks. Adaptation depends on water management, soil fertility, and conservation agriculture.

2 – Healthy soils with diverse microbiomes improve nutrient cycling, water retention, and resilience. Maintaining soil carbon is essential for long-term sustainability.

3 – Overuse of synthetic fertilizers contributes to pollution. Alternative solutions include microbiome-based fertilization and biological nitrogen fixation.

4 – Stronger collaboration between researchers, policymakers, and farmers is needed to integrate scientific knowledge into agricultural practices.

5 – Biotechnology education must be updated with practical, interdisciplinary learning, including microbiology, digital tools, and real-world problem-solving.

Data Analysis

Session 2: **Current work of biotechnology on climate change**

Questions of Session 2	Themes	Sub-themes	Excerpts of participants
Q3: What are the key gaps in biotechnology research for climate change mitigation?	Soil Microbiome, Carbon Sequestration, and Nutrient Efficiency Climate-Resilient Crops and Breeding Innovations	- Enhancing microbial contributions to carbon storage and soil health - Developing microbial biofertilizers and inoculants for better nutrient uptake - Underutilized potential of CRISPR and precision breeding - Adoption of biotech solutions in sustainable farming	**Group 1:** One of the gaps is the role of the soil microbiome in carbon sequestration. While soil health was emphasized, less is known about how biotechnology can enhance microbial activity to improve carbon retention and reduce greenhouse gas emissions. Another gap concerns biotechnological solutions for improving water and nutrient efficiency. With increasing drought stress, research on microbial inoculants, microbial biofertilizers, and biostimulants to enhance nutrient uptake and soil water-holding capacity remains insufficient. Likewise, the potential of stress-resilient crops through CRISPR, synthetic biology, and precision breeding is underexplored, despite climate shifts demanding faster adaptation. The integration of biotechnology with sustainable farming also requires more research. While conservation agriculture was highlighted, the role of biotech innovations in supporting no-till farming, cover cropping, and agroecological systems is not well understood.
Q4: Which technologies for analyzing climate data	Digital Tools and Climate Data	- Remote sensing, IoT sensors, and climate modeling	**Group 2:** If agronomists and biotechnologists are expected to utilize and develop climate-smart solutions, they need tools to measure their effectiveness. Several technologies are proving invaluable, like remote sensing, including satellite imagery and drones, providing real-time insights into crop health, nutrient status of plants, and land-use changes. Internet of Things (IoT) and sensor

are currently most useful in biotechnology and agriculture, and how can they be integrated into educational programs?		- Bioinformatics and GIS for data-driven decisions	networks allow continuous monitoring of temperature, humidity, CO_2 levels, and other key environmental factors, helping track climate-related stressors. Climate models and simulations play an important role in predicting long-term trends and their impacts on agriculture. To make these technologies useful for students, they need hands-on experience, not just theory. This means working directly with climate sensors, running models, and interpreting real-world data. Bioinformatics, data analysis, and GIS tools should be part of the curriculum so students can process and visualize climate and agricultural datasets.
Q5: What are the most appropriate indicators for assessing the impact of biotechnological solutions on reducing greenhouse gas emissions in agriculture?	**Assessing Biotech Impact** Ecosystem Services and Long-Term Sustainability	- Economic viability (yield, costs, profitability) - Environmental indicators (soil health, resource efficiency, emissions) - Carbon footprint and sustainability metrics - Biodiversity, water retention, and regenerative practices	**Group 2:** Assessing the impact of biotechnological solutions on greenhouse gas emissions in agriculture requires a combination of environmental, economic, and agronomic indicators. Yield, production costs, and profitability remain key economic factors, ensuring that sustainable practices are not only environmentally beneficial but also viable for farmers. Reduced reliance on synthetic fertilizers and pesticides is another critical metric, as these inputs contribute significantly to greenhouse gas emissions and environmental degradation. From an agronomic perspective, indicators should include plant nutritional status, nutrient and water use efficiency, and improvements in soil health. Enhanced soil quality—measured through parameters like pH, soil-moisture regime, soil structure, and biological activity (e.g., soil respiration rates or CO_2 efflux)—can provide valuable insights into the long-term sustainability. **Silva:** additionally, analysis tools, such as simple, online and free accesed calculators of footprint (e.g. SPI – Sustainable Process Index®) and carbon calculators (e. g. Farm Carbon Calculator, Fertilisers Carbon Footprint Calculator) and are valuable for quantifying emissions reductions and overall sustainability improvements.

			Beyond these measurable factors, biotechnological solutions also contribute to broader ecosystem services, which should be considered in impact assessments. Innovations that support biodiversity conservation, soil fertility restoration, and water retention can enhance agricultural resilience to climate change. Similarly, technologies that promote carbon sequestration—whether through improved plant-microbe interactions or regenerative soil practices—play a crucial role in mitigating emissions.

Data Analysis

Session 2 – HIGHLIGHTS

1 – Soil microbiomes play a key role in carbon sequestration and nutrient efficiency.

2 – CRISPR and biotechnology-assisted breeding offer untapped potential for climate-resilient crops.

3 – Remote sensing, IoT, and climate modeling enhance data-driven decision-making.

4 – Carbon calculators and sustainability metrics improve and visualize impact assessments.

5 – Biotechnological solutions must support both environmental sustainability and economic viability.

Data Analysis

Session 3: **Promising biotechnology areas and applications in response to climate change**

Questions of Session 3	Themes	Sub-themes	Excerpts of participants
Q6: What is the key industry demands for biotech professionals in this field?	Technical & Interdisciplinary Skills Practical & Soft Skills	- Bioinformatics, climate modeling, lab techniques - Regulations, sustainability, and biotech applications - Problem-solving, communication, entrepreneurship	**Group 2:** The biotech industry increasingly seeks professionals with a strong interdisciplinary skill set, combining biotechnology, agronomy, and environmental science. Employers value practical experience in bioinformatics, climate modeling, and data-driven decision-making for developing sustainable agricultural solutions. Another key demand is hands-on expertise in laboratory techniques, along with a solid understanding of regulatory frameworks and sustainability policies in EU and global climate strategies. Beyond technical skills, critical thinking, problem-solving, communication, and cross-disciplinary collaboration are essential. Industry partners emphasize the need for real-world exposure through internships, collaborative projects, and industry-driven research. To meet these demands, biotech education should prioritize applied research, digital literacy, and entrepreneurship.
Q7: How can we integrate interdisciplinary approaches, such as system thinking and ecological economics, into biotech	Comprehensive Biotechnology Education Risk and Long-Term Impact	- Broad exposure to solutions - Ongoing teacher training - Ecological and health risks - Sustainability vs. short-term gains	**Group 3**: Education must take a broader, holistic approach, ensuring that biotechnology and its solutions are widely presented. Students should be exposed to various biotechnological innovations, as the field is rapidly evolving and will continue to generate new solutions. For this reason, teachers must also stay updated and maintain expertise in emerging technologies. It was emphasized that every technology has its limitations or "dead ends." Some biotechnological solutions may initially seem highly promising, but once implemented, they may fail to deliver the expected benefits. A biotech innovation might improve certain physical, chemical, or economic parameters, yet its

education for climate adaptation and mitigation?	Economic and Market Barriers Policy and Incentives	- Corporate control over innovation - Consumer acceptance of GMOs - Carbon sequestration policies - Funding for sustainable practices	biological and toxicological effects on ecosystems and human health may not have been sufficiently examined. Therefore, before the widespread adoption of any new technology, it is crucial to assess potential biological risks. A prime example is genetically modified organisms (GMOs), where conflicting research findings have led to debates. Evaluating biotech solutions requires systems thinking and long-term perspectives, particularly in assessing their environmental benefits and potential future restoration costs if unintended consequences arise. Any projected economic gain from a biotechnological innovation should be considered over an extended period, factoring in all possible side effects. An example was provided from a visit to a major multinational biotech company in the U.S., where researchers developed a genetically modified plant combining C3, C4, and CAM photosynthetic pathways—three metabolic routes naturally incompatible. Despite the plant's promising efficiency, the company has kept it in laboratory testing because the full ecological impact of its release remains unknown. Unlike the EU, where GMO regulation is stricter, the U.S. is generally more open to introducing genetically engineered crops into production. Economic considerations also play a crucial role in determining whether a biotechnological innovation reaches the market. A case was shared from the same U.S. biotech company, where farmers own 51% of the company's shares. Their researchers developed hybrid maize varieties capable of yielding 19 tons of dry grain per hectare. However, majority-owner farmers decided against releasing these hybrids, as doing so would reduce their competitive advantage over other maize producers. This decision was based entirely on economic rather than technological reasons. Another example is genetically modified apples developed by the same company. Despite greater public acceptance of GM crops in the U.S.

			compared to Europe, consumer studies showed strong resistance to GM apples, even among Americans who otherwise accept GM soy. The discussion also highlighted that some technologies may appear costly or ineffective in the short term but provide significant long-term benefits. When evaluating a biotech solution, it is essential to consider its impact on ecosystem services rather than focusing solely on immediate economic returns. Education should also integrate knowledge of legislation and agricultural subsidy policies. For example, carbon sequestration is a major topic in current agricultural policy, and large companies are increasingly required to report their environmental impact indicators. There is a possibility that, in the future, corporations aiming to improve their sustainability ratings will financially support farmers implementing carbon sequestration techniques. This concept represents environmental economics at the corporate level, but on a broader scale, it underscores the importance of preventing environmental degradation, as restoration efforts are always significantly more expensive.
Q8: Which emerging biotech fields (e.g., synthetic biology, CRISPR-based crop editing, microbial biofertilizers) hold the most promise for climate	Holistic Biotech Approaches and Soil Microbiome Considerations Practical Training & Industry Collaboration	- Combining CRISPR and soil microbiome technologies - Adapting crops and microbes for climate resilience - Limited lab resources at universities - Joint projects with industry for	**Group 3**: The discussion emphasized that different biotechnological solutions have varying applicability across different crops and agroecosystems. Rather than focusing on any particular technology, the group suggested integrating multiple approaches into a chain of solutions. For example, CRISPR-based crop editing could be combined with soil microbiome technologies, allowing simultaneous adaptation of both the plant and its microbial environment. This could result in crops that are more resilient to multiple stresses occurring across different seasons. The group stressed the importance of holistic thinking, as solutions suitable for rice may differ significantly from those for potatoes or other crops. **Silva** (moderator) asked whether soil microbiomes should always be considered when developing biotechnological solutions.

adaptation and resilience, and how can these be integrated into the curriculum?	Curriculum Updates	hands-on learning - Interdisciplinary focus (agronomy, genetics, ecology) - Climate modeling & simulations in biotech education	The participants unanimously agreed, emphasizing that supporting natural soil processes is essential for sustainable agriculture. Without considering the role of soil microbiomes, effective long-term solutions cannot be developed. Regarding practical training for students in advanced biotechnologies, the ideal scenario would be hands-on experience at universities. However, due to financial limitations and the lack of cutting-edge laboratory equipment in many institutions, collaboration with biotechnology companies was suggested as a potential solution. The group acknowledged, however, that industry partnerships can be difficult to establish, especially when companies are protective of their proprietary technologies. **Danijel** (moderator) asked if there were alternative ways for students to gain practical experience besides industry placements. The group suggested joint university-industry projects that actively involve motivated students, providing them with exposure to real-world applications of biotechnology. Regarding curriculum reform, the group strongly advocated for greater interdisciplinarity. They stressed that a solid understanding of agronomy fundamentals is crucial before students can grasp advanced topics such as gene manipulation, gene expression, and regulatory mechanisms. Without knowledge of environmental and agronomic factors affecting plant growth, biotechnology applications remain incomplete. Therefore, the curriculum should integrate expertise from soil science, microbiology, chemistry, biology, plant physiology, ecology, and economics to provide a comprehensive foundation. Additionally, the group highlighted the importance of environmental sciences, climate modeling, and simulation in biotechnology education. These areas are

			essential for assessing long-term impacts and ensuring that biotech solutions align with climate adaptation strategies.
Q9: What infrastructural needs (lab equipment, digital resources, field stations) must be addressed to support hands-on learning in biotech relevant to climate challenges?	Essential Infrastructure Digital Technologies Field-Based Learning Challenges and Solutions	- Soil analysis tools, growth chambers, climate sensors - GIS, climate models, digital twins - Experimental fields, demonstration farms - EU funding, underutilized equipment, specialization, research commercialization	**Group 3**: To effectively measure the impact of biotechnological solutions on the environment, proper equipment is needed for soil analysis—including all soil quality parameters, identification, and quantification of microorganisms. This includes both beneficial microbes and known pathogens. Additionally, well-equipped growth chambers and devices for measuring photosynthetic activity in plants are necessary. Monitoring greenhouse gas emissions and climate factors requires various sensors, while analyzing and predicting their effects demands spatial data—GIS systems and agricultural climate models for simulating the impact of climate change on plants and soils. Digital twins would also be beneficial. Beyond controlled lab settings, field-based demonstration trials and experimental stations, including test fields and livestock facilities, are essential. However, given the reality of Slovenia's tertiary education funding, much of this infrastructure remains unattainable. **Manfred** (teacher) acknowledged this challenge but pointed out that Slovenian research and educational institutions applied for national and EU grants earlier this year. Over the next five years, significant financial resources will be allocated to strengthening various agricultural fields, including plant breeding, organic farming, agricultural digitalization, and animal welfare. As part of this initiative, institutions have requested funding for the acquisition of sensor-based monitoring systems and high-tech growth chambers capable of simulating diverse climatic conditions. **Nejc** (National Laboratory of Health, Environment, and Food) emphasized that while research laboratories in Slovenia are relatively well-equipped, some equipment remains underutilized. This is either because potential users are

			unaware of its availability or because analyses are prohibitively expensive due to the lack of accreditation for specific tests. Accreditation, in turn, is often too costly given Slovenia's limited sample numbers. A possible solution could be increased commercialization and the establishment of spin-off companies, alongside greater investment in skilled personnel. More than infrastructure, investment is needed in research projects and human capital. He also highlighted the issue of university professors being spread too thin—often teaching five or more subjects—arguing that a greater degree of specialization would allow for deeper expertise and more time for research. **Manfred** agreed, noting that as a small country, Slovenia could benefit from greater centralization and specialization. This aligns with the objectives of the funding proposal he mentioned—the development of competence and demonstration centers across different regions of Slovenia.
Q10: What specific skills related to digital tools (e.g., bioinformatics, climate modeling) should be included in the biotechnology curriculum to			**Group 4:** To get students ready for climate challenges, biotech education should include key digital skills like bioinformatics for analyzing genetic data and microbiomes, statistical tools for working with climate and biological data, and climate modeling to predict environmental impacts on crops and ecosystems. Tech like digital phenotyping and sensors help track how plants react to stress, while AI can optimize biotech processes, predict yield stability, and support smarter decision-making in agriculture. On top of that, strong science communication skills are essential so students can share their findings with policymakers, industry, and the public. The best way to build these skills? Hands-on experience with real-world data, collaboration with industry and research institutions, and project-based learning. This way, students don't just learn about digital tools, they actually use them to drive biotech innovation and climate adaptation.

prepare students for climate-related challenges?			

Data Analysis

Session 3 – HIGHLIGHTS

1 – Interdisciplinary expertise in biotechnology, agronomy, and environmental science is crucial.

2 – Practical experience in bioinformatics, climate modeling, and lab techniques is in high demand.

3 – Regulatory knowledge ensures biotech innovations align with EU and global policies.

4 – Soft skills like problem-solving, communication, and teamwork are essential.

5 – Industry collaboration through internships and applied research strengthens career readiness.

Data Analysis

Session 4: **Region-specific solution approaches**

Questions of Session 4	Themes	Sub-themes	Excerpts of participants
Q11: How should we design a biotechnology curriculum to align with EU policies, such as the European Green Deal and the Sustainable Development Goals (SDGs)?	Sustainable Agriculture Climate-Smart Biotech Bioeconomy Transition	- Biofertilizers, biopesticides - Climate-resilient crops - Emission reduction - C sequestration - Bioplastics, biofuels - Circular economy	**Group 4:** To align the biotechnology curriculum with UN and EU policies, it is crucial to integrate biotechnological innovations that support climate resilience, sustainable agriculture, and the transition to a bioeconomy. The curriculum should emphasize interdisciplinary approaches, combining biotechnology, environmental sciences, and digital tools to equip students with the skills needed for climate change adaptation and mitigation. A key focus should be on biotechnological solutions for sustainable agriculture, such as biofertilizers and biopesticides as alternatives to chemical inputs, as well as the development of genetically improved crops with enhanced resistance to drought and climate extremes. Additionally, integrating climate-smart technologies, such as bioengineering for emission reduction and microbial processes for carbon sequestration, would strengthen students' understanding of biotechnology's role in addressing global environmental challenges. The transition to bioeconomy could also be reflected in the curriculum by incorporating biotechnological approaches for producing bioplastics, biofuels, and biomaterials, alongside principles of circular economy and resource efficiency. This approach directly supports several SDGs and reinforcing the role of biotechnology in sustainable food systems, environmental protection, and climate resilience.
Q12: How can universities and industry	University-Industry Collaboration	- Joint curriculum & guest lectures - Practical workshops	**Group 4:** To effectively integrate biotechnology, climate science, and policy, universities should work more closely with industry partners than they do today.

work together to develop interdisciplinary programs that combine biotechnology, climate science, and policy?	Student-Engaged Research Internships & Lifelong Learning Policy & Funding	- PUŠ projects as an example - Industry internships & micro-credentials - EU sustainability integration & joint funding	One possibility is for biotech companies, agro-industries, and other relevant organizations to collaborate in curriculum design. This could mean jointly developing courses, guest lectures from industry experts, and practical workshops that allow students to work on real-world industry challenges and apply theoretical knowledge to practical solutions. Another key element is research and innovation collaboration, encouraging student-engaged biotech projects that incorporate climate data analysis and environmental impact assessments. **Silva:** such initiatives are already being implemented in Slovenia under various frameworks, including PUŠ projects (Projects for Bridging Knowledge and Practice in the Workplace). These projects, lasting 3–5 months, bring together students from diverse disciplines, faculties, study programs, and academic levels to work under the mentorship of university teachers and industry professionals. The aim is to solve real-world challenges identified by companies, bridging the gap between academic knowledge and industry needs. Through participation, students not only enhance their field-specific expertise but also develop essential generic competencies such as problem-solving, teamwork, interdisciplinary collaboration, critical thinking, project management, and professional communication. Internships and lifelong learning also play an important role in bridging the gap between academia and industry. Mandatory internships in biotech firms, as well as micro-credential programs, would be important to ensure students continuously develop relevant, cross-disciplinary competencies. **Silva:** in Slovenia, universities are currently developing micro-credentials as part of the National Recovery and Resilience Plan (NOO - Načrt za okrevanje in odpornost). These educational programs are already in the pilot phase and aim to provide short, targeted lifelong learning experiences that address specific industry needs. Micro-credentials

			allow professionals and students to upskill and reskill in a flexible manner, keeping pace with advancements in particular fields. Also, policy and funding alignment is essential for embedding EU sustainability policies into biotech education. Universities and industries should seek joint funding opportunities to support research and hands-on learning initiatives, ensuring that educational programs remain aligned with climate action priorities.
Q13: How can we improve the transfer of research findings in biotechnology to industrial practice for more effective climate change mitigation? What are your suggestions, best practices?	Bridging Academia and Industry Commercialization of Innovations Practical Training & Knowledge Transfer Lifelong Learning & Policy Alignment	- Focus on applied research - Industry-driven student projects - Startups and spin-offs - Tech fairs for knowledge exchange - Industry-supported thesis work - Internships and open-access research - Micro-credentials for professionals - Nstional and EU sustainability-focused research	**Group 5:** A major challenge in transferring biotech research to industry is that too much of it remains within academia or research institutions—often focused on publication rather than real-world application. To bridge this gap, we need more applied research that directly addresses industry needs. Encouraging spin-off companies and startups based on university research is one way to push innovations into practice. Organizing technology fairs where academia and industry can connect is another practical solution. **Vasja:** a great example of effective collaboration is when businesses actively engage in research by allowing students to conduct their final thesis work on real industrial challenges. That is practice in our greenhouses. This not only benefits companies by providing fresh insights but also ensures that students gain practical, industry-relevant experience. **Silva:** PUŠ projects are another strong model, connecting students, academic mentors, and businesses in problem-solving teams. Similarly, lifelong learning, including new micro-credential programs, seems to be an important approach to helping professionals stay updated with the latest biotech developments. Industry internships, open-access research data, and better alignment with EU sustainability policies can also help make research findings more accessible and useful. The key is fostering a culture where biotech research isn't just for publishing papers—it needs to create tangible solutions that industries can implement.

Q14: How can we ensure the scalability and economic feasibility of biotechnological solutions for small-scale farmers? How can we scale-up biotechnological research/results from micro to macro level? How can we better align biotechnology research with regional and global policy frameworks for			**Group 5:** Scaling up biotechnological solutions for small-scale farmers isn't just about affordability, it's about awareness, mindset, and knowledge. Many small farms in Slovenia are not market-oriented businesses; instead, they are often run by part-time farmers, older generations, or individuals without an agricultural background. This means that even when effective biotechnological solutions exist, they might not be recognized or understood, let alone implemented. A key issue is the lack of holistic knowledge. Farmers need more than just technical instructions on how to use biofertilizers or microbial inoculants—they need to understand the broader picture. Why are these solutions beneficial in the long run? How do they contribute to soil health, resilience, and climate adaptation? Without this awareness, change happens too slowly. The role of agricultural advisory services is also crucial, yet not always up to speed with modern biotechnological advancements. While Slovenia is experiencing a generational shift among advisors, younger agronomists tend to be more familiar with these innovations and digital tools, but there's still a gap in how effectively this knowledge is transferred to farmers. Bridging this knowledge gap through farmer education, hands-on training, and better communication from advisors is essential. Sustainability awareness also plays a role. Climate change isn't just something that's happening somewhere else, it affects local farms directly. Yet, many farmers still hesitate to change their practices, either because they're unsure of the benefits or because they don't feel a sense of urgency. Encouraging a long-term perspective is key: understanding that investments in biotechnology may not bring immediate returns, but they help secure the farm's future viability. In short, making biotechnology work for small-scale farmers isn't just about developing new solutions—it's about helping farmers see why these solutions matter, ensuring advisors are well-informed, and fostering a mindset shift towards long-term

climate change?			sustainability. Without this, even the best innovations risk being on paper instead of in the field.
Q15: What role does public perception and acceptance of biotechnology play in its implementation for climate change mitigation? What are the potential ethical concerns related to the use of advanced biotechnological tools in addressing climate challenges, and	Misinformation and Awareness Regional Differences Ethical Concerns Trust and Policy consumer education.	– Public equates biotech with GMOs; need for better education – U.S. acceptance vs. EU skepticism; impact of regulations – Corporate influence, long-term ecological risks – Transparent research, stakeholder engagement	**Group 5:** Public perception plays a huge role in whether biotechnological solutions actually get used for climate change mitigation. While biotech offers great tools, whether they make it to the field depends a lot on how much people trust and understand them. One big issue is that many people don't fully understand what biotechnology actually is. For a lot of the public, "biotech" equals "GMOs," and GMOs equal something risky or unnatural. This oversimplification leads to resistance, even against other biotech innovations that could improve sustainability, reduce emissions, and help crops adapt to climate stress. Clearer communication and science-based education are key to shifting this mindset. Acceptance of biotechnological solutions, particularly genetically modified organisms (GMOs), is also highly dependent on geopolitical regions. In the U.S., consumers tend to be more open to genetically modified crops, while in the EU (especially in Slovenia), public opinion is overwhelmingly negative. Strict regulations and consumer opposition have slowed down the adoption of biotech in Europe, despite scientific evidence supporting its safety and benefits. Another problem is that most people only think of biotechnology as genetic engineering, when in reality, it includes a wide range of innovations—like microbial fertilizers, precision fermentation, and bio-based materials. There's a major need for better public awareness so that people understand biotech's full scope and potential. Then there are ethical concerns—who controls these technologies? How do they impact ecosystems in the long run? What happens when biotech is driven more by corporate profits than sustainability? Addressing these concerns through transparent research, open-access data, and responsible regulations can help build public trust.

how can they be addressed?			To improve acceptance, we need more conversations between scientists, farmers, policymakers, and consumers. When people feel like they have a say in how technologies are developed and used, they're more likely to support them. In the end, biotech can be a game-changer for sustainability, but only if the public understands and trusts it. That starts with better communication, education, and making sure that innovations align with real societal needs.

Data Analysis

Session 4 – HIGHLIGHTS

1 – Aligning biotech education with EU policies to support sustainability and climate resilience.

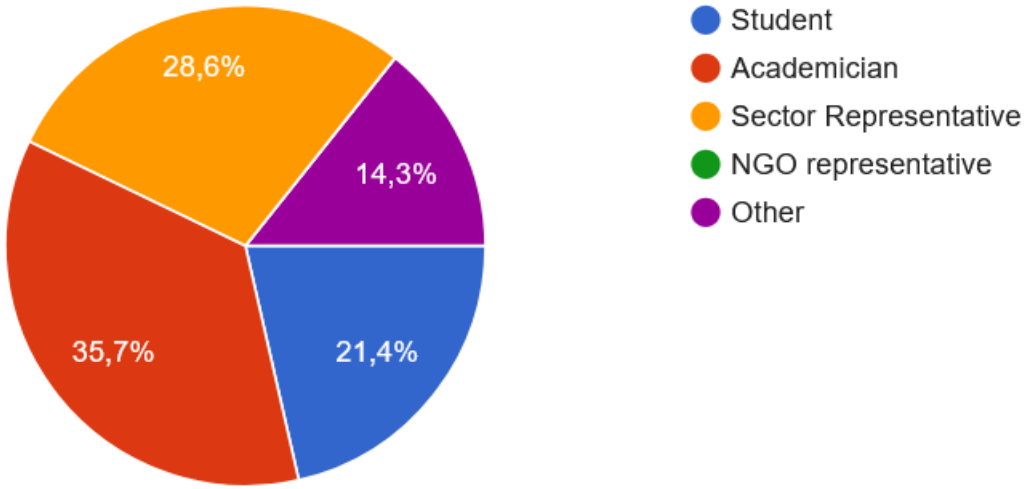
2 – University-industry collaboration to bridge research and real-world applications.

3 – Scaling biotech for small farms through knowledge transfer and advisory support.

4 – Addressing public perception with transparent communication and responsible innovation.

Quality Evaluation

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Questions	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q2				3 / 21,4%	11 / 78,6%
Q3				4 / 28,6%	10 / 71,4%
Q4				4 / 28,6%	10 / 71,4%
Q5				5 / 35,7%	9 (64,3%
Q6		2 / 14,3%	12 / 85,7%	×	×
Q7				2 / 14,3%	12 / 85,7%