GEEK4FOOD

Glocal Ecosystems and Expanded Knowledge for green skills and capability in the Food Sector

D5.2

Report on training delivered

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CONTENT

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1. Executive summary

This deliverable reports on the implementation and delivery of the training activities carried out under Task 5.2 of Work Package 5 (WP5). While the design of the training modules was completed in WP4, Task 5.2 focuses on their actual deployment to higher education learners and participants from the agri-food sector. The deliverable outlines the methodology used for delivering the modules, describes the organisation of the training sessions, and presents how the WP4 training framework was operationalised in real learning environments.
The report details the GEEK4Food approach applied during the delivery phase, emphasising how the modules, developed based on skills needs identified in WP2 and competence gaps analysed in WP3, were implemented through online, blended, and on-site formats across partner institutions. The structure and duration of the modules are presented, along with adaptations made to local contexts to ensure accessibility and relevance for diverse learner groups.
The target group reached by the training is identified, followed by a summary of the modules delivered under Task 5.2 and the learning outcomes targeted. A mapping of content to competencies is provided to demonstrate alignment with the GEEK4Food competence model and the project's broader educational objectives.
In the Annexes, agendas, list of participants, content-mapping files, syllabi, and module content used during Task 5.2 delivery are included to illustrate the learning resources applied and to document the educational materials supporting the training activities.

2. Introduction

One of the project's central goals is to translate the educational and training modules developed in previous work packages into effective learning experiences that strengthen green skills among higher education learners and agri-food sector participants.
Task 5.2 represents the stage where the theoretical model created in WP4 becomes operational: the modules are delivered, tested, and experienced by real learners. Through this process, the project actively supports the development of the competences needed to advance sustainability within the agri-food system.
Green skills encompass the knowledge, abilities, and attitudes that enable individuals to contribute to environmental sustainability, resource efficiency, and the transition to greener value chains. In the context of the agri-food sector, these skills are especially important, as the sector faces increasing pressure to adopt more sustainable, circular, and innovative practices. The GEEK4Food project aims to address these needs by equipping learners with practical competences that not only raise awareness but also empower them to take informed action toward reducing environmental impact.
The training delivered under Task 5.2 builds on forward-looking educational planning. Rather than responding passively to existing challenges, the project anticipates future requirements and aligns

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its curriculum with the emerging demands identified in WP2 (market skills needs) and WP3 (competence gaps). By doing so, it ensures that the modules delivered under WP5 remain relevant, practical, and fit for purpose as the food sector moves toward greener and more sustainable models of production, processing, and consumption.

In this context, Task 5.2 contributes directly to preparing the next generation of graduates and agri-food professionals with the competencies needed to support a sustainable, resilient, and innovation-driven food system. The training delivered represents a bridge between the project's design phase and its real-world impact, demonstrating the applicability, coherence, and value of the WP4-developed modules when implemented in authentic learning environments across partner institutions.

3. Methodology

3.1 Task description as presented in the project work plan

Task 5.2, as defined in the project work plan, focuses on the implementation and delivery of the training modules created in WP4 to learners in higher education and the agri-food sectors. The emphasis of this task is on transforming the WP4-designed content, based on green, digital, and entrepreneurial competences, to concrete learning experiences that support the project's sustainability objectives. The training responds to the evolving needs of the agri-food sector by equipping learners with practical skills that reflect labour-market trends and competence gaps identified in WP2 and WP3.

The training modules delivered under T5.2 are not only designed to be learner-focused but also adaptive, ensuring relevance within dynamic and rapidly changing agri-food environments. Skills such as problem-solving, critical thinking, digital literacy, and sustainability awareness are central elements of the training, reflecting the increased need for professionals who can navigate the sector's green transition. The GEEK4Food competence model, drawing inspiration from European sustainability frameworks such as GreenComp, guides the structure of the learning outcomes and ensures alignment with recognised competence standards.

Teaching methods introduced in WP4 are applied and tested in WP5, including experiential learning, collaborative tasks, case-based activities, and the use of digital tools tailored to the agri-food context. These methodologies promote active participation and strengthen learners' ability to apply green competences in real-world scenarios. The training sessions piloted across partner institutions also support the refinement of module content, informing future curriculum development and allowing for the adjustment of materials to national, regional, and sector-specific realities.

The task also incorporates mechanisms for the **monitoring** and **assessment** of learner performance, ensuring that the impact of the training can be measured consistently across delivery formats and partner countries. Combined, these elements ensure that Task 5.2 not only deploys

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the WP4 modules effectively but also contributes to the broader project goal of fostering a skilled workforce capable of supporting sustainable innovation within the agri-food system.

3.2 The GEEK4Food approach to modules' and pilots' syllabus' design

The identification of the three GEEK4Food training modules to be delivered under Task 5.2 builds on the work conducted in WP2, WP3, and WP4. WP2 provided an analysis of green-skills needs in the agri-food labour market, while WP3 identified existing competence gaps among learners and professionals in the sector. WP4 translated these needs into a structured training model and a set of modular, competence-driven learning units. Task 5.2 applies this model in practice by delivering the selected modules to higher-education learners and agri-food professionals across partner institutions.

The selection of the three modules delivered in T5.2 was based on their relevance to emerging areas of green innovation and their potential to equip learners with competences needed for a sustainable agri-food system. In addition, expert knowledge from HEI partners was combined to ensure scientific depth, practical relevance, and alignment with the GEEK4Food competence framework.

The three GEEK4Food training modules delivered are:

1. Eco-design of food packaging (Aarhus University)
2. Optimised/Precision fermentation (USAMV Cluj-Napoca)
3. Food waste valorisation in food product design (UNITE)

These training modules correspond to the harmonised WP5 training structure described in the project materials and reflect the competency priorities identified in earlier work packages.

The design and delivery approach for these modules is based on two foundational principles, modularity and homogeneity to ensure pedagogical coherence, flexibility, and high-quality learning experiences across all partner institutions. While delivery formats varied (online or on-site), each module followed the same instructional logic and learning architecture defined in WP4, ensuring consistency in both learner experience and intended learning outcomes.

1. Homogeneity

A homogeneous training model ensures that content, structure, and learning progression remain consistent across all learning units and across partner institutions. This means that each module delivered under T5.2 followed a similar format in terms of:

- definition of learning outcomes based on the GEEK4Food competence model;
- organisation of units and sequence of topics;
- use of interactive and problem-based teaching methods;
- integration of sustainability-focused case studies;
- alignment with assessment strategies developed in WP4.

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This homogeneity supports transparency, comparability, and coherence across the training programme while allowing for minor contextual adaptations.

2. Modularity

The modular approach ensures that each training module is a self-contained learning unit addressing a specific topic, skill, or competence relevant to green transformation in the agri-food system. Modularity allows the modules to be:

- delivered independently or combined depending on institutional needs;
- scheduled flexibly (e.g., one-day intensive sessions, half-day workshops);
- adapted to diverse learner backgrounds;
- integrated into existing HE curricula or professional development programmes.

Each module contains multiple “chunks” of content, such as theoretical lectures, real-life examples, demonstrations, exercises, and reflections, that work together toward achieving the module’s learning objectives.

The modular–homogeneous approach used in T5.2 ensures that the training delivered under WP5 is scalable, transferable, and aligned with the project’s overarching goal of supporting the development of green skills for a sustainable agri-food sector.

3.3 Module structure

To develop the GEEK4Food modules’ structure, the HEI partners considered several fundamental aspects to ensure that all training delivered under WP5 remains coherent, pedagogically sound, and aligned with the project’s green-skills framework.

Balance between theory and practice: The modules are designed to blend essential theoretical knowledge with practical application. This balance helps learners understand complex concepts while also learning how to apply them in real-world contexts.

Interactive elements: Group work, discussions, and activity-based exercises are included throughout the module to maintain engagement and promote peer learning. The interactive format supports deeper understanding and encourages learners to reflect on the implications of sustainability-driven innovation in the agri-food sector.

Assessment and reflection: each module ends with an assessment activity, such as a quiz or group presentation, ensuring that learners have demonstrated both their understanding of the material and their ability to apply key concepts.

Time management: the structure of each module is carefully organised to ensure that learners can remain focused and attentive without becoming overwhelmed. The progression from challenge to content, then to case studies and solution refinement, helps pace the learning experience effectively.

In summary, GEEK4Food partners have created a structured and uniform training model where each module follows the same core sequence. This ensures comparability across partner institutions and helps maintain consistent quality across all WP5-delivered modules.

- The challenge-based lecture, which introduces the content through a real-world problem.

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The challenge-based lecture is a teaching method that integrates real sustainability challenges or problem-solving activities into the learning process. Instead of beginning with a traditional lecture, learners are immediately exposed to an applied scenario that frames the relevance of the module. This approach encourages critical thinking and supports the application of knowledge from the outset.

- Three content sessions, which break the material into thematic learning units.

These sessions typically align with the module's key knowledge areas. Dividing the content into three manageable parts helps learners progress through the training without cognitive overload. Each content block presents a cluster of essential concepts that build the foundation for later applied activities.

- The two case-study activities, which enable learners to apply the concepts in practice.

These activities are central components of the module, providing authentic, hands-on learning experiences. Learners analyse real or simulated industry scenarios, evaluate constraints, explore innovation strategies, and work collaboratively to propose solutions. The case studies ensure a balanced mix of theory and practice, and they promote decision-making, contextualised problem-solving, and reflective learning.

- A refining-solution session, which supports critical review and improvement.

This session allows learners to revisit the outcomes of their case-study work, refine their proposals, and integrate feedback. It encourages iteration, deeper analysis, and the enhancement of strategies developed during the group tasks.

- A final assessment, which evaluates learning outcomes.

The assessment component verifies whether learners have achieved the module's intended competences. This may include multiple-choice quizzes, group presentations, reflective tasks, or short written exercises. The assessment serves as a checkpoint to measure progress and consolidate learning.

In Table 1 below, the modules' structure is presented:

Title of the module
1 challenge-based lecture
Content part 1
Content part 2
Activity based content – case study 1
Content part 3

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Activity based content – case study 2
Refining solution/ concluding session
Assessment

Table 1: GEEK4Food modules' structure

Table 1 summarises the common GEEK4Food module structure used across WP5. This design ensures consistency, clarity, and depth, while allowing flexibility in delivery depending on institutional context. It is a learner-centred model that encourages active participation, problem-solving, and continuous feedback. Each module is independent, but all contribute to achieving the same overall educational goals using a coherent and standardised approach.

3.3.1 Module duration

Each GEEK4Food training module delivered under WP5 was structured as a one-day training programme, divided into 30-minute core sections. This duration was selected to ensure an effective balance between attention, cognitive load, and meaningful learning. Thirty-minute segments are long enough to explore key concepts in depth, while also short enough to maintain learner engagement throughout the module.

The one-day format is particularly suitable for higher education learners and agri-food professionals who may not be able to commit to longer, multi-day training activities but still wish to gain relevant green skills efficiently. The structure ensures that each module remains concise, focused, and aligned with practical application. Every 30-minute segment includes opportunities for interaction, short discussions, and clarification of concepts.

The structure also allows instructors to begin each section with a short introduction to contextualise the topic and to conclude with space for questions and feedback. A short Q&A session is typically placed at the end of the day to consolidate learning, ensure comprehension, and encourage reflection before learners proceed to the refining and assessment components.

Title of the module	Content's core duration
1 challenge-based lecture	30'
Content part 1	30'
Content part 2	30'
Activity based content – case study 1	30'

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Content part 3	30’
Activity based content – case study 2	30’
Refining solution	30’
Assessment	30’

Table 2: GEEK4Food modules’ structure and sessions’ core duration

4. Target group

The delivery of the GEEK4Food training modules under Task 5.2 required a clear identification of the target group who would participate in the learning activities. Understanding the target group is essential not only for determining who the learners are, but also for ensuring that the training delivered is relevant, engaging, and aligned with the real needs of higher education learners and agri-food sector professionals.

Identifying the appropriate target group for the WP5 training is not limited to knowing the demographics of the participants; it also includes recognising their prior knowledge, motivations, professional contexts, and learning preferences. This understanding allows the training delivery to be tailored in ways that support effective participation and maximise the impact of the WP4-developed modules.

Several key reasons demonstrate why selecting the right audience is critical for WP5 training delivery, and these include:

<u>Relevance of content</u>. Different target groups have varying levels of academic background, technical experience, and interest in sustainability and food systems. By clearly identifying the audience, WP5 ensured that the modules delivered were relevant, context-appropriate, and aligned with the learners’ expectations. This relevance allows the training to focus on addressing real-world agri-food challenges and green skills needs identified in WP2 and WP3.

<u>Optimised learning outcomes</u>. Effective training delivery depends on matching the instructional methods to learners’ needs. When the content, format, and activities align with what the target group finds meaningful, learners are more motivated to participate actively, engage with the material, and transfer the newly acquired knowledge into their practice or studies. This alignment is particularly important in WP5, where the training modules combine theoretical knowledge with applied, hands-on exercises.

<u>Improved behavioural impact</u>. One of the objectives of the GEEK4Food training approach is to encourage learners to adopt sustainable practices, innovative thinking, and problem-solving behaviours within the agri-food sector. By understanding the target group, instructors can design and deliver activities that resonate with participants, increase their confidence in applying green

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competences, and inspire them to take up new sustainability-oriented strategies in their academic or professional environments.

In summary, identifying the correct target group ensures that the WP5 training delivery is not only informative but also practical, accessible, and impactful. It increases learner engagement, supports stronger learning outcomes, and enhances the likelihood of behavioural change in favour of sustainability-driven food system innovation.

For WP5 Task 5.2, the GEEK4Food consortium targeted higher education learners and early-career and mid-career professionals within the agri-food sector. These include postgraduate students, junior researchers, and practitioners from food technology, agriculture, biotechnology, environmental sciences, and related domains. By addressing the needs of these groups, at different stages of their academic or professional development, the GEEK4Food project supports the strengthening of innovation capacity, the transfer of green knowledge, and the long-term resilience of the agri-food system. This approach contributes to building a skilled, sustainability-oriented workforce that is prepared to meet emerging challenges in food production, processing, and environmental management.

5. Content mapping files

For the delivery of the GEEK4Food training modules under Task 5.2, the HEI partners organised and implemented the training sessions using the content mapping files developed in WP4. These files provided a structured and standardised blueprint that guided the instructors in planning the sessions, sequencing the materials, and ensuring alignment between the delivered content and the intended learning outcomes.

During WP5, the content mapping files served as an internal organisational tool for the HEI partners. They ensured that the training delivered to participants—higher education learners and agri-food professionals—**was coherent, consistent, and fully aligned with the green-skills framework of the project. By mapping each block of content to a specific learning outcome, instructors could ensure that each activity contributed meaningfully to the competencies targeted in WP2 and WP3.

The HEI partners used the mapping files to structure the modules so that the participants experienced a clearly organised progression: from conceptual introduction to applied analysis, followed by case-based learning and assessment. This consistency was important because the training was delivered in different institutions and formats (online, on-site, hybrid), yet had to maintain the same pedagogical quality.

To define and align **learning outcomes** across partners, the GEEK4Food consortium applied Bloom's Taxonomy, which distinguishes six levels of cognitive learning:

- Remembering
- Understanding
- Applying

- Analysing
- Evaluating
- Creating

These levels supported the organisation of content and assessments used by HEI trainers, helping them ensure that participants engaged not only in knowledge acquisition but also in higher-order thinking such as analysis, problem-solving, and innovation, key elements of the green skills required in the agri-food sector.
Overall, by using the content mapping files, the HEI partners were able to organise and deliver WP5 training in a focused, pedagogically consistent, and outcome-oriented manner, while ensuring that participants received high-quality learning experiences aligned with the project's sustainability objectives.

The three GEEK4Food modules' content mapping files are provided in the **Annexes I, II, and III.**

6. Module syllabi

The GEEK4Food modules' syllabi used during the WP5 training delivery are designed to support an effective and meaningful learning experience. They ensure that both instructors and participants have a clear understanding of the modules' aims, structure, content, and expected learning outcomes. The syllabi specify the module objectives, thematic areas, learning activities, and assessment components, allowing learners to understand what competencies they will develop and what is expected of them throughout the training.

Within Task 5.2, the syllabi guided the delivery of the one-day training modules, ensuring consistency across partner institutions and alignment with the project's green skills framework. They provided a reference for instructors when organising the sessions and ensured that the training remained structured, coherent, and linked to the content mapping files used across WP5. The modules' syllabi used during the WP5 delivery phase are included in Annexes I, II, and III.

7. Training modules

The Green Skills Training Modules provided a unique opportunity to deepen participants' expertise in sustainable practices within the agri-food sector. Choosing from three impactful modules – Optimised Fermentation, Eco-design of Food Packaging, and Waste Valorisation in Food Product Design – the participants developed the necessary green skills to drive meaningful innovation. All the participants received a certificate of completion for each module they participate in, recognising their engagement with sustainable practices and innovation within the agri-food sector.

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By participating at the training, participants were also invite to further collaborate and participate and take part in the Foodathon (Sept-October 2025), where the trainees could apply the new skills to real-world challenges.

7.1 Module training on Eco-design of food packaging (organized by Aarhus University)

Date and time: 28/04/2025 13:00 am to 17:00 pm CET
Location: Online
Module Delivery Overview
The module was delivered as a highly interactive, activity-driven online training session, designed to engage participants in both theoretical and practical aspects of sustainable food packaging. It combined concise, focused lectures with facilitated group discussions, fostering critical thinking and collaborative learning. Two carefully structured case-study exercises enabled participants to apply eco-design principles and evaluate sustainable material options in realistic scenarios, bridging the gap between theory and practice. Reflection and feedback opportunities were integrated throughout, allowing participants to consolidate learning, clarify key concepts, and explore innovative approaches to sustainable packaging solutions.
The module began with a **challenge-based lecture**, introducing the concept of eco-design in food packaging, focusing on materials that come into contact with food and their impact on preservation, safety, and sustainability. It highlighted the need to move from single-use plastics to reusable or recyclable solutions, in line with EU strategies, and explained how circular economy principles can help minimise waste and environmental impact. The session encouraged innovative thinking to balance regulatory requirements, material optimisation, and lifecycle sustainability in food packaging. This introductory challenge-based lecture was presented by Professor Milena Corredig.
The second part (**Eco-design principles and Safe and Sustainable by Design (SSbD**) introduced the principles of eco-design and the Safe and Sustainable by Design (SSbD) framework, focusing on food packaging. It explained how eco-design and SSbD aim to create products that are safe for people and the environment, while also being sustainable throughout their lifecycle. The session highlighted the basic SSbD principles, key benefits, implementation steps, and challenges, whilst encouraging discussion on how businesses can adopt these approaches. This technical session was presented by the Affiliated Associate Professor Emmanouil Tsochatzis.
The third session (**Safety and risk assessment of eco-designed food packaging**) introduced the safety and risk assessment of eco-designed food packaging. It covered key concepts such as migration of chemicals from packaging to food, types of packaging materials, different types of contamination and their potential sources, as well as the Regulatory framework in the EU. Participants get an overview on how to assess risks, what are the current EU compliance requirements, and apply safety standards to ensure consumer protection in the context of

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environmentally friendly packaging. This session was presented by the Affiliated Associate Professor Emmanouil Tsochatzis.
The fourth session (**Existing eco-designed food packaging materials. Pros and cons**) provided an overview of the current landscape of eco-designed food packaging. It introduced the importance of packaging in food preservation, transport, and protection, highlighting the environmental challenges posed by conventional plastic packaging and the need for sustainable alternatives. The session covered various categories of eco-friendly packaging materials, including biodegradable, recyclable, compostable/edible, and reusable designs, explaining their characteristics and the regulatory context driving innovation in this field. Participants gained knowledge about the types of materials used in eco-design, their environmental attributes, functionality, and compliance requirements. The session offered a balanced view by discussing the pros and cons of each material type, such as environmental benefits, cost implications, infrastructure needs, and performance limitations. It concluded by emphasising the importance of plastic alternatives in a circular economy, the need for scaling up new technologies, and the role of education and policy in advancing sustainable packaging solutions. This session was presented by the Tenure Track Assistant Professor Ilke Uysal Ünalan.

After completing the theoretical part of the module, participants moved into a hands-on group exercise. Working in small teams, they explored two practical case studies designed to connect eco-design principles with real packaging challenges:

1. **Identifying a fossil-fuel-based plastic that could be replaced with a more sustainable, eco-designed alternative** (e.g., substituting PET with PLA based on food safety, barrier performance and functional properties), and
2. **Proposing an innovative packaging solution from a holistic perspective**, considering application needs, environmental impact, raw material sourcing, cost implications and end-of-life scenarios.

Teams worked independently in small groups to apply the concepts from the module. For the first case study, they compared material properties, assessed trade-offs, and drafted potential replacement strategies for conventional plastics with eco-designed alternatives. In the second case study, teams developed innovative solutions from a holistic perspective, considering factors such as performance requirements, sustainability impact, raw material choices, cost, and potential barriers to adoption.
At the end of the activity, each group presented their findings during the online session, explaining the reasoning behind their material choices, the environmental advantages of their proposed solutions, and the practical challenges that manufacturers or end users might face. This activity reinforced participants' analytical and problem-solving skills and demonstrated how eco-design principles can be applied to real-world packaging scenarios, even in a fully online setting.

Case study activities

Case study 1: Identify an existing fossil fuel plastic that can be replaced by an eco-designed plastic, e.g. PET with PLA, based on food and functional properties

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Working group activity

The group collaborated to assess whether polylactic acid (PLA) could replace polyethylene terephthalate (PET) in food packaging for products like carbonated drinks, sugar, and pasta. Teams examined the functional and safety aspects of both materials, considered environmental impacts, and proposed eco-designed solutions, including multilayer packaging options, tailored to the client's needs.

Key discussion points

- **PET's strengths**: PET is widely used in food packaging for its excellent barrier properties, durability, and clarity.
- **Environmental concerns**: PET's reliance on fossil fuels and recycling challenges raise sustainability issues.
- **PLA as an alternative**: PLA, made from renewable resources, offers a more sustainable option but faces challenges with functional properties and cost.
- **Compatibility and safety**: The suitability of PLA for packaging carbonated drinks, sugar, and pasta was debated, with attention to food safety and performance.
- **Lifecycle impact**: The group discussed the environmental impact of both materials, including carbon footprint, biodegradability, and recyclability.
- **Eco-design solutions**: Multilayer packaging options were considered to balance sustainability, functionality, and cost for the client's needs.

Methods:

Challenge-based learning

Pedagogical tools:

- Peer reflection
- Short pilot exercise
- Model design activity

Assessment Approach

- Small pilot (prototype or concept validation)
- Feedback discussions

Case study 2: Propose/describe an innovative solution from holistic perspective (applications, environmental impact, raw materials, cost etc.)

Working group activity

Teams were tasked with developing an innovative solution for EcoPack Solutions to reduce food waste in fresh vegetables without increasing plastic use. Focusing on the high loss of fresh produce due to spoilage, participants proposed a sustainable, eco-designed edible coating made from food-grade polysaccharides and essential oils. The coating aimed to extend shelf life by acting as a barrier to moisture and oxygen, while remaining safe for consumption or easy to wash off. Teams evaluated their solutions holistically, considering applications, environmental impact, materials, regulations, cost, and consumer acceptance

Key discussion points

During the group discussions, several critical aspects were evaluated:

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- **Applications**: The coating's suitability for fruits, vegetables, and bakery products was considered, with particular attention to high-waste categories such as avocados, bananas, and berries.
- **Environmental Impact**: The solution's potential to eliminate single-use plastics and reliance on renewable, biodegradable resources was highlighted.
- **Raw Materials**: The group discussed sourcing materials from food industry by-products (e.g., citrus peels for pectin) and non-food industry by-products, ensuring sustainability.
- **Regulatory Requirements**: Compliance with upcoming regulations, such as the Packaging and Packaging Waste Regulation (PPWR), was identified as essential.
- **Cost Considerations**: The team compared the indicative production costs of the edible coating with traditional plastic coatings and assessed scalability for both small and large producers.
- **Consumer Perspective**: Acceptance of additional costs, safety of raw materials, and scalability were debated, with a focus on consumer trends and expectations.
- **Stakeholder Perspectives**: The solution was evaluated from manufacturing, environmental, regulatory, and consumer viewpoints. Guiding questions included practicality and scalability, potential regulatory or logistical barriers, and alignment with consumer expectations. The group also listed potential benefits (such as reduced waste and environmental impact) and challenges (including regulatory hurdles and consumer acceptance).

Methods:
Challenge-based learning
Pedagogical tools:
- Peer reflection
- Short pilot exercise
- Model design activity

Assessment Approach
- Small pilot (prototype or concept validation)
- Feedback discussions

After the completion of the assessment, **42** trainees were assessed to have successfully acquired the knowledge presented during the training. This outcome demonstrates the effectiveness of the module in equipping participants with the intended green skills and competencies in sustainable food packaging.

1. **Annexe 4: Participant feedback – Eco-design of food packaging**
2. **Annexe 5: Event brochure and poster**
3. **Training lectures and presentations: PPT presentations in the "GEEK4Food training modules" Dropbox folder, WP4**

https://www.dropbox.com/home/Geek4Food/WPs/WP4%20%20Innovative%20HE%20tools%20and%20methodologies/GEEK4Food%20training%20modules/Content_Ecodesign%20of%20food%20packaging

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7.2 Module training on Optimised fermentation

This training was replicated by two different partners with different approaches, i.e. USAVM-Cluj Napoca and Technological University of Dublin

7.2.1 Module training on Optimised fermentation – organized by USAMV Cluj-Napoca

Date and time: 05/05/2025 09:00 am to 13:00 pm EEST
Location: USAVM-Cluj-Napoca (RO) Library building, Room 47, Calea Manastur 3-5, Cluj-Napoca
The *Optimised Fermentation* module was delivered as a one-day intensive training, combining conceptual input, practical demonstrations and collaborative problem-solving activities. The session followed the GEEK4Food training structure and aimed to familiarise learners with the scientific, technological and sustainability aspects of fermentation-based food innovation, according to the agenda. A total of 43 participants enrolled in the Optimised Fermentation training module, representing a diverse and motivated group of learners. The participant cohort included postgraduate students, early-career researchers, and junior and senior professionals from the agri-food sector. Their varied backgrounds contributed to a rich learning environment, fostering interdisciplinary perspectives during discussions, practical activities, and case study exercises.
The high level of engagement throughout the session demonstrated strong interest in sustainable fermentation technologies and their applications in food innovation.

The module began with a **challenge-based lecture**, introducing the role of fermentation in modern food systems and inviting participants to reflect on real-world problems associated with developing safe, sustainable, and scalable fermentation processes. This introductory challenge-based lecture was presented by Professor Dan Vodnar. This introductory part relied on the materials covering the *fundamental principles of traditional and optimised fermentation*, where learners explored the distinctions between spontaneous, traditional fermentations and controlled fermentations conducted in bioreactors. Concepts such as microbial metabolism, culture types, environmental control, and downstream processing were presented and contextualised using industrial examples. This section on fundamental principles was presented by Lecturer Lavinia Mureșan.

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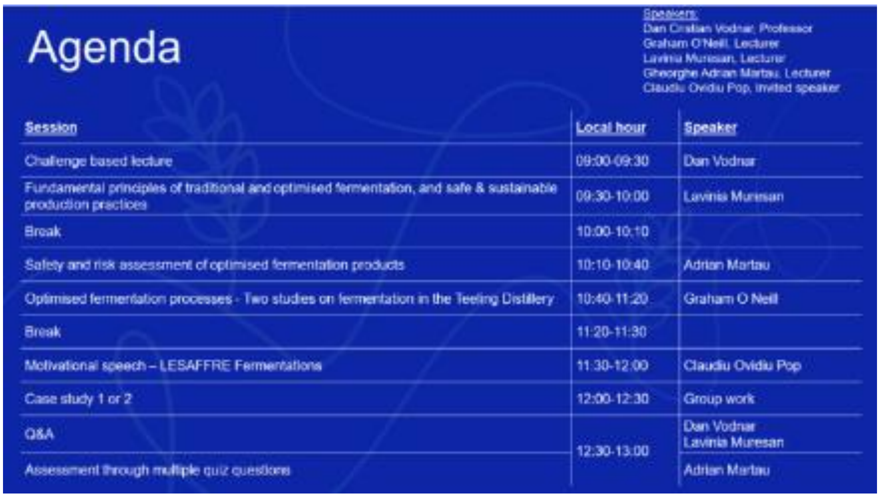
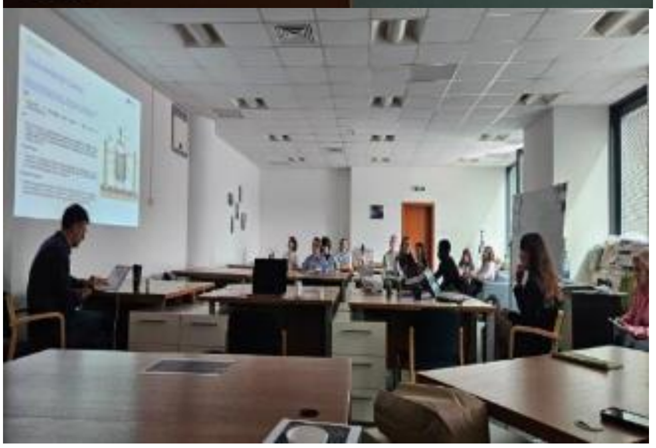


Agenda

Speakers:
Dan Cristian Vodnar, Professor
Graham O'Neill, Lecturer
Lavinia Muresan, Lecturer
Gheorghe Adrian Martau, Lecturer
Claudiu Ovidiu Pop, invited speaker

Session	Local hour	Speaker
Challenge based lecture	09:00-09:30	Dan Vodnar
Fundamental principles of traditional and optimised fermentation, and safe & sustainable production practices	09:30-10:00	Lavinia Muresan
Break	10:00-10:10	
Safety and risk assessment of optimised fermentation products	10:10-10:40	Adrian Martau
Optimised fermentation processes - Two studies on fermentation in the Teeling Distillery	10:40-11:20	Graham O Neill
Break	11:20-11:30	
Motivational speech – LESAFFRE Fermentations	11:30-12:00	Claudiu Ovidiu Pop
Case study 1 or 2	12:00-12:30	Group work
Q&A	12:30-13:00	Dan Vodnar Lavinia Muresan
Assessment through multiple quiz questions		Adrian Martau

Agenda of optimized fermentation module held in USAMV



The second part focused on **safety and risk assessment**, drawing from the session content that detailed contamination risks, HACCP implementation, raw material variability, regulatory

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frameworks (including EU legislation), and process-efficiency considerations such as energy use, water management and resource optimisation. Participants discussed how safety protocols, monitoring technologies and regulatory compliance shape the development of fermented products. This specialised technical session was presented by Lecturer Adrian Martau.
A dedicated section then introduced optimised fermentation processes, illustrating how fermentation is applied in real industrial environments. Participants were presented with two studies on fermentation activities in the Teeling Distillery, providing practical insight into process optimisation, quality control and product consistency. This session on industrial fermentation processes was presented by Lecturer Graham O'Neill.

To ensure a strong link with industry practice, the module also featured a **company-led presentation** from Lesaffre Romania, introducing learners to real fermentation workflows, the industrial production of baker's yeast (*Saccharomyces cerevisiae*), and the role of starter cultures in bread-making and traditional sourdough processes. This session provided valuable insights into industrial challenges, strain performance, quality control and product innovation in fermentation-driven sectors. This industry-focused presentation was delivered by invited expert Claudiu Ovidiu Pop.

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Following the theoretical sessions, participants were organized into **small collaborative teams**. Each team selected a case topic, such as alternative protein sources or sustainable fermentation workflows, and translated the lecture content into a practical concept. Using whiteboards and worksheets, they mapped ideas, drafted process steps and refined proposed solutions (as shown in the photos). Teams then presented their outputs, discussing technical feasibility, sustainability considerations and potential barriers. This activity strengthened problem-solving skills and demonstrated the applicability of fermentation knowledge to real agri-food challenges. This teamwork session was facilitated by the USAMV teaching team, with guidance from Dan Vodnar, Lavinia Mureșan and Adrian Martau.
Finally, the module concluded with a short reflective discussion and photo documentation. To support project visibility, all dissemination materials, including the event poster and photo highlights, were shared via **LinkedIn and other social media channels**, where the training attracted engagement from academic staff, students, and industry professionals. The closing session and assessment were conducted by Dan Vodnar and Lavinia Mureșan.

Case study activities

Case study 1: Alternative protein sources

Working group activity

Participants worked collaboratively to analyze the theme “**Alternative protein sources**”, focusing on the development of sustainable, innovative food solutions derived from non-traditional protein inputs.

Key discussion points

- Identification of innovative protein alternatives (e.g., fungal fermentation, microbial biomass)

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- Understanding the fermentation process as a method for transforming raw substrates into valuable products
- Integration of alternative protein ingredients into functional food design
- Exploration of consumer acceptance, regulatory aspects, and food safety considerations
- Reflection on how alternative protein systems support sustainable food transitions

Learning outcomes formulated by the group

Participants agreed learners should be able to:

- Competently describe emerging bioactive compounds derived from alternative protein sources
- Identify and articulate relevant technologies used for protein valorisation
- Apply and explain circular economy principles in designing food products based on alternative proteins
- Develop entrepreneurial and critical-thinking skills for sustainable food innovation
- Understand the complexity of alternative protein production chains

Teaching methodology proposed

- Format: in-person
- Duration: 2 weeks

Methods:

Flipped classroom
Hands-on workshops
Storytelling
Challenge-based learning

Pedagogical tools:

- Peer reflection
- Short pilot exercise
- Model design activity

Assessment Approach

- Small pilot (prototype or concept validation)
- Model design
- Evaluation report
- Feedback discussions
- Involvement of invited experts

Working group evidence:

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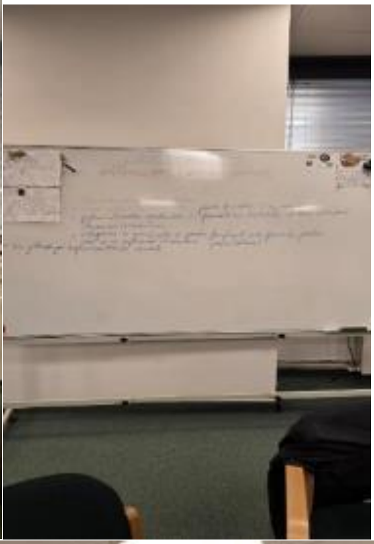

- **Case Study 2: Circular Citric Acid Fermentation**

Working group activity

This group explored **"Citric Acid Circular Fermentation"**, focusing on valorising food side-streams through biotechnological processes and designing a training module around sustainable fermentation systems.

Key Discussion Points

- Identification of major problems linked to current citric acid production (waste, cost, inefficiencies)
- Identification of opportunities created by circular fermentation models

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- Analysis of environmental and economic benefits of circular systems
- Exploration of potential applications of citric acid derived from circular processes (food preservation, beverages, bioproducts)
- Mapping the skills required for students in such a module (technical, analytical, entrepreneurial)

Learning outcomes defined by the group

Learners completing the module should be able to:

- Understand the biotechnological principles of citric acid fermentation
- Evaluate the sustainability impacts of circular fermentation systems
- Analyse and apply risk assessment and safety strategies for fermentation
- Propose innovative uses for citric-acid-based ingredients
- Develop problem-solving competencies related to circular bioeconomy models

Teaching Methodology Proposed

- Format: hybrid or in-person
- Duration: 1–2 weeks

Methods:

- Hands-on workshops
- Team-based project work
- Use of real-world case studies
- Challenge-based learning
- Short expert interventions or guest lectures

Assessment Approach

- Group project
- Pitching session
- Participation in discussions
- Portfolio submission
- Creativity and applicability of solutions

Working Group Evidence

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1. <u>Annexe 6:</u> Group Picture
2. <u>Annexe 7:</u> Event brochure and poster
3. **Training lectures and presentations: PPT presentations in the "GEEK4Food training modules" Dropbox folder, WP4**

https://www.dropbox.com/home/Geek4Food/WPs/WP4%20%20Innovative%20HE%20tools%20and%20methodologies/GEEK4Food%20training%20modules/Content_Optimised%20fermentation

7.2.2 Module training on Optimised fermentation – organized by TU Dublin, Ireland

Date and time: 22 May 2025, 14:00 – 17:00 Irish time, English, organized by TU Dublin, Ireland
Location: On-site & online

The *Optimised Fermentation* module delivered at TU Dublin was delivered as hybrid afternoon training. The session followed the GEEK4Food training structure and aimed to familiarize learners with the scientific, technological and safety of fermentation-based food.
A total of 24 participants enrolled in the training module, 17 online and 7 in person. The participant cohort included a balance from university, industry and research institutes associated to the agri-food sector.

Agenda
The agenda of the training course followed a format of a challenge lecture with an introduction to the technological area followed by a series of case studies.

2 - 2:20	**Dr Graham O'Neill**	**Challenge Based Lecture**
2:20 - 2:40	**Dr Graham O'Neill**	**Fundamental Principals of fermentation**
2:45 - 3:15	**Dr Elena Alexa**	**Case study**
3:30 - 4	**Dr Adrian Martau**	**Safety and risk assessment of optimised fermentation process**
4 - 4:30	**Gemma Lyons**	**Case study**
4:30 - 5	**Dr Jesus Frias**	**Existing optimized fermentation products: Pros and Cons**

Graham O'Neill started with an introduction to what is Fermentation? Presenting examples in Foods Then discussing Why Fermentation Matters in Health, Sustainability, Innovation. This was followed by Modern Uses in Food Industry of fermentation. Graham then focused on the technology of fermented foods, focusing on the key differences between traditional fermentation—driven by natural, uncontrolled microbial activity—and optimised fermentation, which uses bioreactors to precisely regulate conditions for consistency and efficiency. This was followed by a review on how microbial cultures have evolved from wild, naturally occurring strains to carefully selected pure cultures tailored for flavour, speed, and functionality. Finally, Elena covered applied biotechnology, safety requirements, and sustainability practices that support modern, safe, and environmentally responsible fermentation systems.
Adrian Mortau presented an overview of **safety and risk assessment in optimized fermentation**, explaining the key concepts that underpin safe, efficient, and sustainable microbial processes. She outlined the importance of **strain selection, substrate quality, contamination control, and supply-chain traceability** as critical components of fermentation safety. Her presentation also covered how **process efficiency** can be improved through resource optimization, microbial strain enhancement, time and energy management, and waste minimization. She highlighted the **regulatory frameworks** governing fermentation, including EU rules for food safety, novel foods, labeling, and microbial strain approval to ensure consumer protection and compliance. Finally, she emphasized sustainability through **advanced technologies**, circular-economy approaches, environmental impact assessment, and continuous process improvement to support safe and scalable fermentation systems.

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Gemma Lyons presented the first case study on the challenge of replacing conventional animal proteins with **single-cell proteins (SCPs)** such as mycoproteins and yeast-derived biomass, focusing on sustainability and reduced environmental impact. It highlighted how SCPs offer strong nutritional profiles, rapid production cycles, and lower resource requirements compared to livestock proteins. The scenario tasked students with evaluating nutritional, environmental, economic, and consumer-acceptance factors before proposing a viable microbial protein alternative for a food company. It also emphasised practical production considerations—such as fermentation design, concentration and drying steps, and scalability—to ensure SCPs can be successfully integrated into high-protein food products.

The unit from Jesus Frias explored how **optimized fermentation** is used in the food industry to create products such as probiotics, mycoproteins, enzymes, alternative oils, and algae-based ingredients, highlighting real-world examples like Quorn, Nature's Fynd, Algama, DIC Corporation, and C16 Biosciences. It outlined the **advantages** of optimized fermentation, including improved efficiency, consistency, cost-effectiveness, and environmental benefits. The session also examined **limitations**, such as high initial investment, system complexity, contamination risks, and regulatory challenges. Finally, it presented emerging **future trends** like precision fermentation, alternative substrates, microbial engineering, clean-label production, and circular-economy integration.

Elena Alexa presented the second case study in which a food manufacturer aims to switch from purchasing conventional citric acid to producing it **in-house using food waste** such as citrus peels and starchy residues, creating a circular and sustainable fermentation process. The case challenges students to evaluate the **technical suitability, environmental impact, and economic feasibility** of converting waste into citric acid through controlled fermentation. It also requires proposing an **innovative, scalable fermentation system**, addressing issues like feedstock variability, quality control, automation, and regulatory compliance. Finally, students were challenged to develop a **transition plan** that integrates sustainability goals, cost savings, and consumer acceptance to support the company's move toward a circular production model.

1. **Annexe 8: Participant feedback**
2. **Annexe 9: Group Picture**
3. **Annexe 10: Event brochure and poster**
4. **Training lectures and presentations: PPT presentations in the "GEEK4Food training modules" Dropbox folder, WP4**

7.3 Module training on Food waste valorisation in food product design (UNITE)

Date and time: 06/06/2025, 10:00 am to 15:30 pm CEST, English | Organised by Teramo University, Italy, in collaboration with TU Dublin, Ireland

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Location: Online
Agenda:
The agenda of the training course followed a format of a challenge lecture with an introduction to the technological area followed by a series of case studies.

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Training workshop

Glocal Ecosystems and Expanded Knowledge for skills and capabilities in the food sector - GEEK4Food

Training on "Food waste valorisation in food product design"
6th June 2025 - 10:00 am –
Online: https://us02web.zoom.us/j/88479098486

AGENDA

Time (CEST)	***Activity***	*Teachers/tutors*
9:45 am	**Opening of the virtual room**	
10:00 am-10:15 am	**Welcome and introduction**	Paola Pittia, *University of Teramo- IT*
10:15 am-10:45 am	**Food waste: from what, what, what for and how: current and future sustainable strategies for valorization**	Paola Pittia, *University of Teramo - IT*
10:45 am-11:15 am	**Biorefinery approaches and innovative technologies for food ingredients**	Jesus Frias *TU Dublin - IE*
11:15 am-11:45 am	**Technological functionalities of food waste for green ingredients design**	Marco Faieta - *University of Teramo- IT*
11:45 am-12:00 pm	***Break***	
12:00 pm-12:30 pm	**Circular economy, industrial sustainability and social impact**	Jesus Frias *TU Dublin - IE*
12:30 pm-1:15 pm	***Activity/Case-study 1***– From waste to value: the case of chocolate	*UNITE tutor*
	Activity/Case-study 2– *Mushroom production and the circular economy*	*TU Dublin tutor*
1:15 pm-1:45 pm	**Joint discussion on case study 1 and 2**	TU Dublin/UNITE, all
1:45 pm – 2:00 pm	***Wrap up and conclusions***	
2:00 pm – 12:00 am	***Assessment***	

The module attracted a rather high number of participants after the dissemination via social and email with 119 pre-registered but only 69 confirmed 69 and 40 were the effective participants.
The course started with a brief introduction by **Paola Pittia** on the project GEEK4Food, aims and activities with the scope of creating the frame where the short course was developed. Thereafter, prof Pittia continued with the "scenario" or challenge presentation related to the topic "Food waste: from what, what, what for and how: current and future sustainable strategies for valorization that focused on definitions, causes of the food waste and potentialities of the valorisation of both lost and wasted foods in to new biomolecules or ingredients. The challenges related to the food waste recovery, management and valorisation were illustrated considering the safety, costs and technological constraints, along with the lack of skills of the workforce in the agrifood sector.
The first content lecture was delivered by prof **Jesus Frias** (TUD) dealing on "Biorefinery approaches and innovative technologies for food ingredients": biorefinery is one of the more applied technological approaches in recovery of valuable biomolecules from food waste. The lecture described the most applied technologies, including some examples and potential evolution.
The second content lecture was delivered by dr **Marco Faieta** (UNITE), after a general overview of the technological functionalities of foods and food ingredients and how the valorisation of the food waste and/or the derived biomolecules depend on their ability to be used in food formulations based on their capacity to have a role on the final quality, stability, nutritional value of the final product.
After the break, a lecture title "Circular economy, industrial sustainability and social impact was delivered **by Jesus Frias** focused on the aspects that should be considered when food waste/loss is re-introduced as "second – raw material" into the food production system, its role on the sustainability and in our society".
Therafter, participants were divided in two groups and each of them dealt with one of the two cases studies related to the food waste recovery, namely

- Activity/Case-study 1– From waste to value: the case of chocolate (rapporteur: UNITE)
- Activity/Case-study 2– Mushroom production and the circular economy (rapporteur: TUD)

Participants were led in the activity by brief presentation illustrating the case study; the discussion was supported by interactive online tools (e.g. Wooclap) from were some feedbacks were collected for the final discussion.
After the presentation of the results of the case studies a final joint discussion on the topic was carried out.
An **assessment session** with 9 questions (multiple choice, open) was then open to the participants and 30 (75% of participants) responded to all the questions, providing very positive feedbacks in terms of knowledge and skills acquired; suggestions, challenges and problems to be sorted out were also included in some of the open answers especially from the participants from Africa.

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1. **<u>Annexe 11:</u> Event brochure and poster**
2. **Training lectures and presentations: PPT presentations in the "GEEK4Food training modules" Dropbox folder, WP4**

https://www.dropbox.com/home/Geek4Food/WPs/WP4%20%20Innovative%20HE%20tools%20and%20methodologies/GEEK4Food%20training%20modules/Content_Waste%20valorisation%20in%20food%20product%20design

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8. GEEK4Food Foodathon

The **Foodathon** is an intensive competition based on a **challenge-based and learning-by-doing approach**, implemented within WP5 of the GEEK4Food project as the **final stage** of the training pathway. Particularly, WP5 encompasses three major training streams:

1. *Training for Trainers focused on upskilling academic staff in emergent green skills and transversal competences*
2. *Training for Learners in higher education and agri-food sectors, based on the skill needs identified in WP2 and WP3 and the training modules developed in WP4*
3. *The Foodathon, a challenge-based experiential activity*

The Foodathon was organised as a **fully online 3-day event (10–12 October 2025)**, following a clearly defined structure, which alternated between:

- learning moments
- autonomous teamwork
- iterative feedback

The competition was structured around three main thematic areas (derived from the training modules):

1. **Eco-design of food packaging**
2. **Waste valorisation in food product design**
3. **Optimised fermentation (including novel ingredients and waste-based processes)**

As regards participation, the Foodathon targeted **students and young professionals in the agri-food sector**. Participants (**34**) developed 6 project ideas and worked in **interdisciplinary teams**. While a strong emphasis was placed on peer-to-peer learning and continuous interaction, support was ensured by **mentorship** (1/2 mentors per partner institution), focussing on **scientific validity**, **technical feasibility** and **project development**.

The evaluation system consisted of the following aspects:

- A set of criteria, each assigned a relative weighting:
    1. **Quality and credibility of the innovation idea (25%)**
    2. **Business model and systems thinking (20%)**
    3. **Impact potential (25%)**
    4. **Team strength and appropriateness (10%)**
    5. **Pitch quality and scientific-entrepreneurial communication (20%)**
- A **score ranging from 1 to 5** for each criterion (potentially expressed as a decimal for greater accuracy) – these scores were then combined taking into account the different weighting of the criterion

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- The involvement of **multiple evaluators**, in order to guarantee transparency and minimise evaluator bias

Below are the teams participating in the Foodathon, along with the corresponding projects:

- **Yeasteam** – Project's title: ***Giving New Life to Wine Lees*** **(Applicability of dehydrated wine lees in food and feed industries)**
- **RedShift** – Project's title: ***Natural β-Carotene from Tomato Waste*** **(From Waste to Worth – Clean-Label Colorants for a Healthy Fitures)**
- **Loopack** – Project's title: ***Sprayable PHA film for climacteric fruits preservation***
- **LegumeCycle** – Project's title: ***Upcycled Synbiotic Flour from Legume By-products***
- **GrainOva** – Project's title:
- **Beanbeyond** – Project's title: ***Turning legume by-products into sustainable nutrition***

The Foodathon served as a simulated environment for assessing the acquisition of green skills throughout the training pathway. Therefore, a full account and report of its development is provided in **Deliverable D5.3**.

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ANNEX 1: Content mapping file, syllabus and content of the module "Eco-design of food packaging"

1. Content mapping file

Type of content	Session's Title	Partner responsible for content creation	Content's core duration	Indicative resources
Challenge based lecture / discussion	How can we design safe food packaging that minimizes environmental impact across its entire lifecycle—from material sourcing to disposal—while still ensuring food safety, durability, and consumer convenience?	AU Food	Expert's lecture lasts 30 min	
Content part 1	Eco-design principles and Safe and Sustainable by Design (SSbD)	AU Food	30 min	1. European commission, Research and Innovation/Safe and sustainable by design/Link 1 2. European commission, Joint Research Centre/ Safe and sustainable by design chemicals and materials-Framework for the definition of criteria and evaluation procedure for chemicals and materials/Link 2 3. European commission, Joint Research Centre/Ecodesign for Sustainable Products Regulation-preliminary study on new products/Link 3
Content part 2	Safety and risk assessment of eco-designed food packaging.	AU Food	30 min	1. European Food Safety Authority (EFSA)/ Principles that could be applicable to the safety assessment of the use of mixtures of natural origin to manufacture food contact materials/Link 4 2. Intentionally (IAS) and non-intentionally added substances (NIAS)/European Commission (EU) Regulation 10/2011/Link 5

				3. Food contact chemicals in lfe-cycle assessment/ Challenges of including human exposure to chemicals in food packaging as a new exposure pathway in life cycle impact assessment/Link 6
Activity based content – aiming systems approach, identify the problem	Activity/Case-study 1	AU Food	Activity's core duration: 30 min	Identify an existing fossil fuel plastic that can be replaced by an eco-designed plastic, e.g. PET with PLA, based on food and functional properties.
Content part 3	Existing eco-designed food packaging materials. Pros and cons	AU Food	30 min	Several sources*/ Food waste and date labelling/Link 7
Activity based content – aim to bring solutions	Activity/Case-study 2	AU Food	Activity's core duration: 30 min	Propose/describe an innovative solution from holistic perspective (applications, environmental impact, raw materials, cost etc.)
Refining solution/Concluding session	Overview of the 2 case studies/discussion (e.g. Eco-design: Balancing functionality, sustainability and cost)	AU Food	30 min	
Learning outcomes	1. Understand the fundamentals of eco-design and its importance in the context of food contact materials. 2. Identify sustainable materials suitable for food packaging applications. 3. Understand the environmental impact of different food packaging. 4. Develop innovative and sustainable design solutions for food packaging.			
Assessment method	1. Group exercises (Case studies 1 and 2). 2. Multiple choice quiz/questions			

2. Module's syllabus

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Module's syllabus
Title: Eco-Design of Food packaging

General information	
Course	Eco-design of food packaging
Scope	Sustainability, design thinking, food safety
Language	English
Evaluation	Case studies/ multiple choice questions
Holders	Milena Corredig
Length	One day course
Didactic method	Lectures with activity-based content
Location	Online or in class or hybrid

Learning objectives

1. Understand the fundamentals of eco-design and its importance in the context of food contact materials.
2. Identify sustainable materials suitable for food packaging applications.
3. Understand the environmental impact of different food packaging.
4. Develop innovative and sustainable design solutions for food packaging.

Required skills

Learners need a multidisciplinary skill set, including a foundational understanding of environmental sustainability (eco-design principles, life cycle assessment, and the UN's SDGs), food packaging basics (material properties, functions, and sustainability challenges), and safety and risk assessment (food safety regulations, toxicology, and migration studies). Knowledge of materials science, particularly biodegradable and compostable materials, is essential, alongside the ability to balance functionality, sustainability, and cost in design thinking. Learners should be proficient in analysing case studies, understanding eco-design standards, and interpreting sustainability data. Additionally, skills in communication, interdisciplinary collaboration, and awareness of emerging trends like circular economy, sustainable-by-design and eco-design for innovative materials are important, as well as a basic understanding of statistical methods for risk assessments and lifecycle analyses.

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Subjects

Challenge based lecture/discussion: How can we design safe food packaging that minimizes environmental impact across its entire lifecycle—from material sourcing to disposal—while still ensuring food safety, durability, and consumer convenience?
Teaching session 1: Eco-design principles and Safe and Sustainable by Design (SSbD)
Teaching session 2: Safety and risk assessment of eco-designed food packaging
Case study 1: Identify an existing fossil fuel plastic that can be replaced by an eco-designed plastic, e.g. PET with PLA, based on food and functional properties
Teaching session 3: Existing eco-designed food packaging materials. Pros and cons
Case study 2: Propose/describe an innovative solution from holistic perspective (applications, environmental impact, raw materials, cost etc.)

Teaching methods

Lectures, case studies

Verification of learning

The achievement of the training objectives for the six teaching sessions would be assessed through the presentation of the required topics, evaluating the learner's ability to analyze, synthesize, and articulate their thoughts, as well as their judgment and calculation skills. Specifically, multiple-choice questions and case studies are used to assess decision-making in scenarios that reflect real-world conditions related to eco-design of food packaging. These methods help gauge how well learners apply their knowledge in practical, operational contexts.

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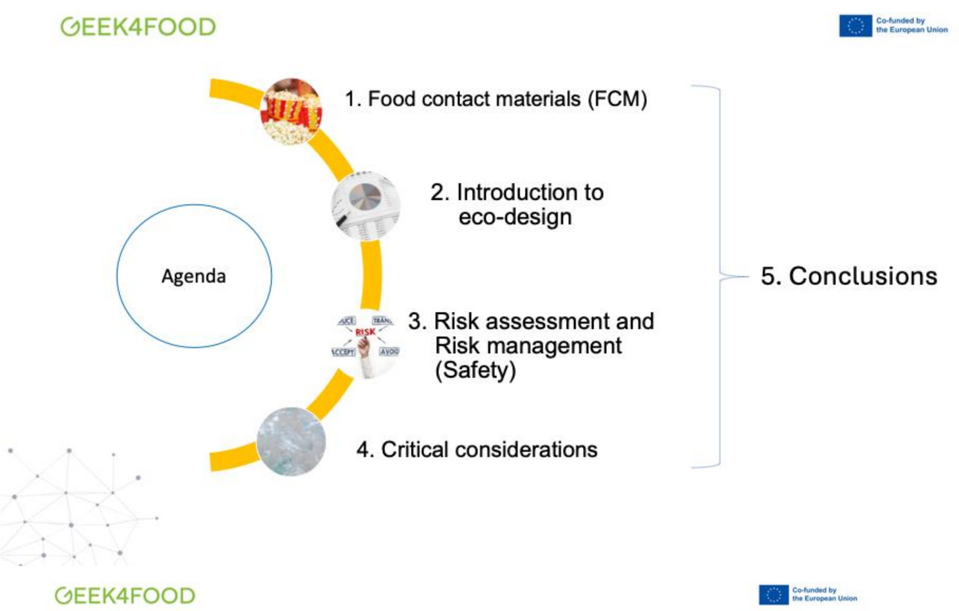
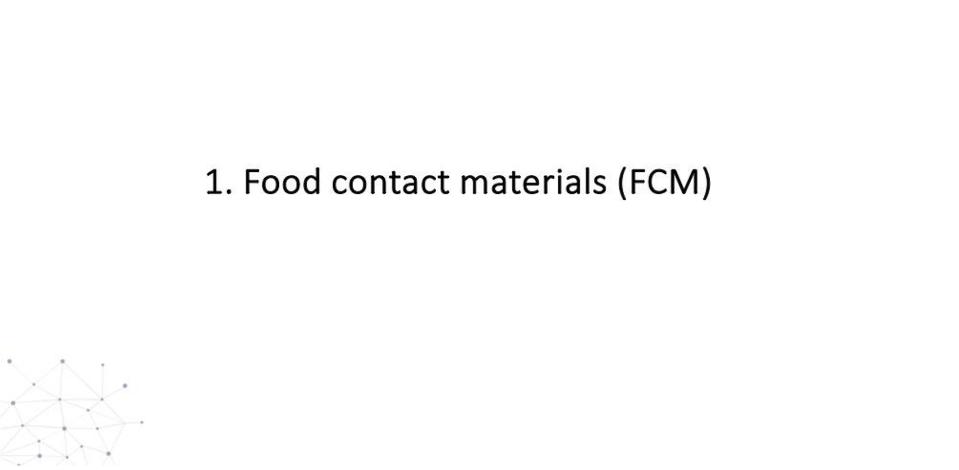
Indicative resources

- European commission, Research and Innovation/Safe and sustainable by design/Link 1
- European commission, Joint Research Centre/ Safe and sustainable by design chemicals and materials-Framework for the definition of criteria and evaluation procedure for chemicals and materials/Link 2
- European commission, Joint Research Centre/Eco-design for Sustainable Products Regulation-preliminary study on new products/Link 3
- European Food Safety Authority (EFSA)/ Principles that could be applicable to the safety assessment of the use of mixtures of natural origin to manufacture food contact materials/Link 4
- Intentionally (IAS) and non-intentionally added substances (NIAS)/European Commission (EU) Regulation 10/2011/Link 5
- Food contact chemicals in life-cycle assessment/ Challenges of including human exposure to chemicals in food packaging as a new exposure pathway in life cycle impact assessment/Link 6
- Food waste and date labelling/Link 7

3. Module's content





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A. What is a FCM?

Food contact materials (FCM) are all materials and articles intended to come in contact with food:

- Packaging and containers, kitchen equipment, cutlery and dishes (e.g., plastics, rubber, paper and metal);
- Materials of processing equipment;
- Production machinery;
- Containers for transport.

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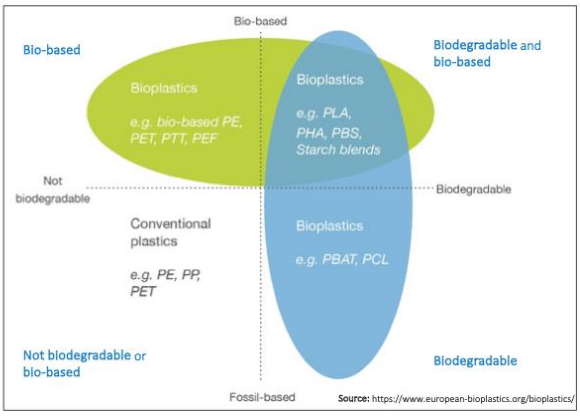
B. Types of FCM



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C. Why we need food packaging

- Preservation of food and its quality characteristics.
- Extending shelf life (bacterial growth).
- Facilitate transport.
- Protection of the food (e.g., contamination).
- Avoiding food spoilage (bacterial growth, oxidation).

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D. EU strategy/policy for FCM

EU plastics strategy ALL PLASTIC PACKAGING placed on the EU market to be REUSABLE or EASILY RECYCLED by 2030 (only PET at the moment).

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E. Current Regulated polymers for FCM at EU level

1. Plastics
2. Silicones
3. Rubbers and elastomers
4. Wood
5. Cork
6. Regenerated cellulose
7. Paper and board
8. Metals and alloys
9. Glass
10. Ceramics and enamel
11. Wax
12. Varnishes and coatings
13. Ion exchange (and adsorbent) resins
14. Printing inks
15. Adhesives


JRC SCIENCE FOR POLICY REPORT

Non-harmonised food contact materials in the EU: regulatory and market situation

BASELINE STUDY
Final report

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F. EU FCM Regulatory Framework

- **Framework Regulation (EC) 1935/2004** on materials and articles intended to come into contact with food
- **Commission Regulation (EC) 2022/1616** on recycled plastic materials and articles intended to come into contact with foods
- **Commission Regulation (EU) No. 10/2011** on plastic materials and articles intended to come into contact with food
- **Commission Regulation (EC) No 2023/2006** on good manufacturing practice for materials and articles intended to come into contact with food
- **Commission Regulation (EC) 450/2009** on active and intelligent materials and articles intended to come into contact with food.
- **Commission regulation (EU) 2018/213** on the use of bisphenol A in varnishes and coatings intended to come into contact with food
- **Directive 2007/42/EC** on materials and articles made of regenerated cellulose film that come into contact with food
- **Council Directive 84/500/EEC and 2005/31/EC** on the approximation of the laws of the Member States relating to ceramic articles intended to come into contact with foodstuffs
- **Council Directive 84/500/EEC of 15 October 1984** on the approximation of the laws of the Member States relating to ceramic articles intended to come into contact with foodstuffs
- **Council directive (EU) 2019/904** on the reduction of the impact of certain plastic products on the environment (single use plastics)

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2. Introduction to eco-design

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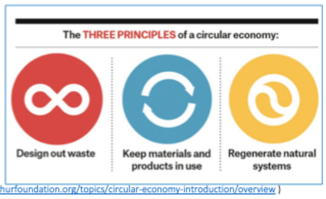
A. Circular economy

- **Definition**: A circular economy is an economic system aimed at eliminating waste and the continual use of resources through principles like reuse, recycling, and regeneration.
- **Contrast with Linear Economy**: Unlike the "take, make, dispose" model, a circular economy focuses on closing the loop by keeping materials in use for as long as possible.
- **Relevance to Plastics**: Moving away from single-use plastics towards materials that can be recycled, reused, or safely biodegraded or (bio)recycled.

Source: European Parliament Research Service

The 3Rs

- The circular economy **prevents waste** and **regenerates nature**.
- It keeps materials in use through **recycling**, **reuse**, and other methods (**3Rs**).
- Addresses **climate change**, **biodiversity loss**, **waste**, and **pollution**.
- Separates **economic growth** from the **use of finite resources**.



Source: Ellen Macarthur Foundation, 2024 (https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview)

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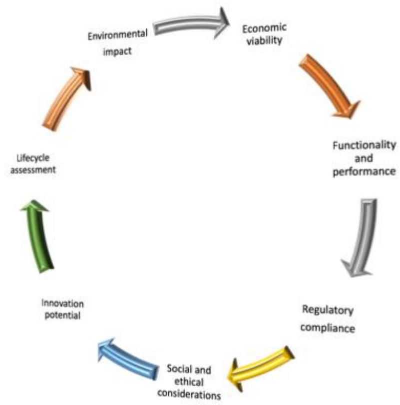
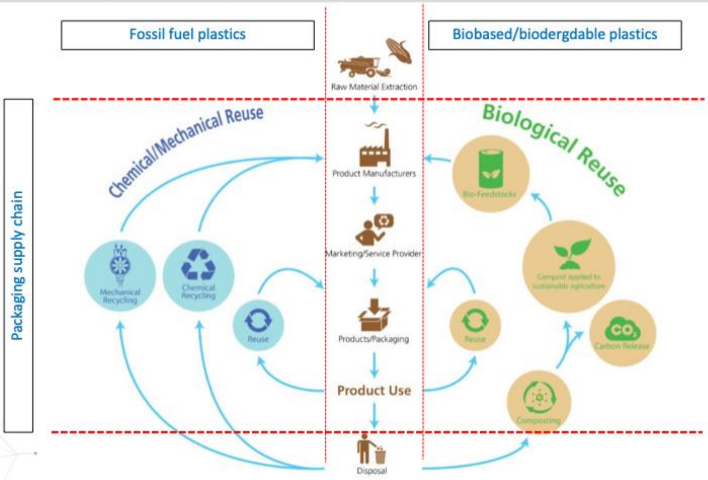
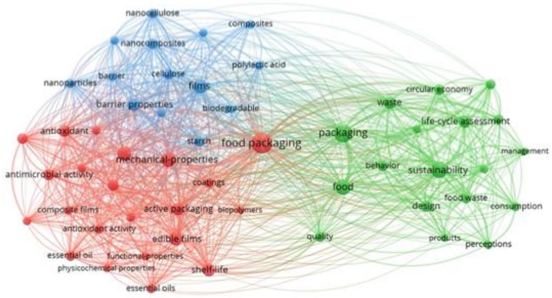


B. Circular and eco-designed packaging



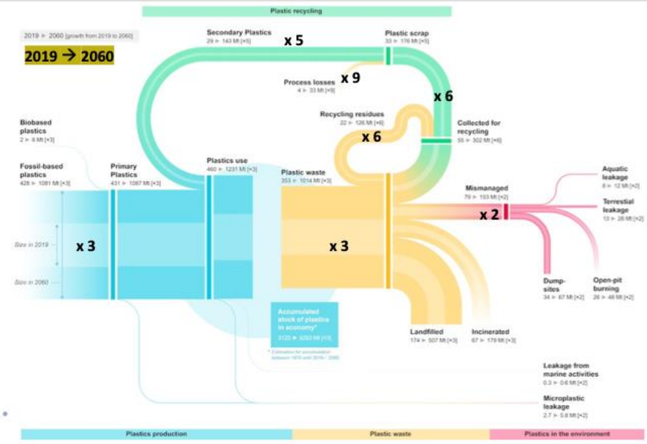
C. Eco-design and sustainable packaging

- <u>Definition:</u> *Sustainable food packaging is an optimized, measured (quantified) and validated solution, which takes into consideration the balance of social, economic, ecological and safe implementations of the circular value chain, based on the entire history (life cycle) of the food product-package unit.*

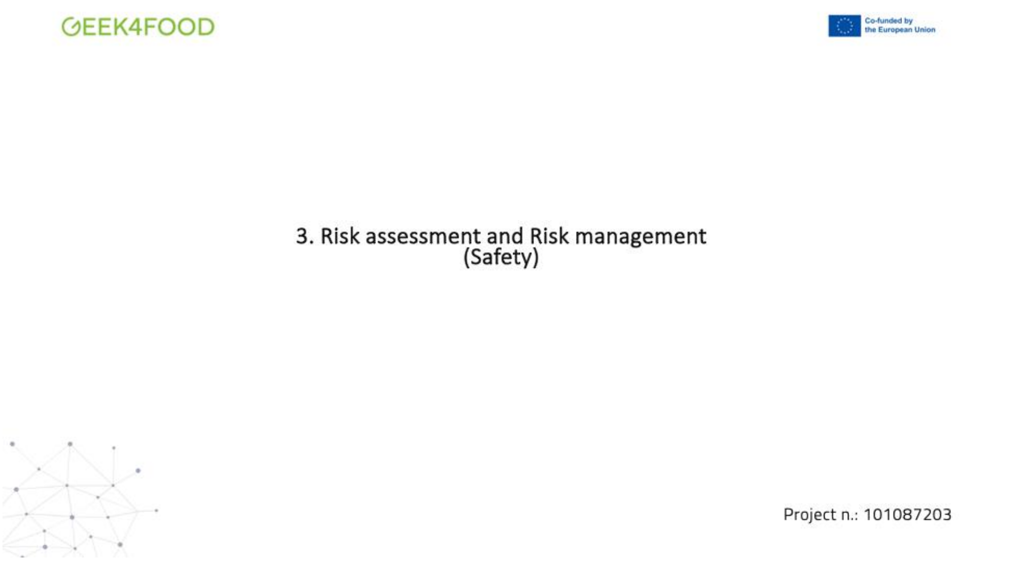


Source: Dornyei et al 2023, Front. Sustain. Food Syst. 7:1119052. https://10.3389/fsufs.2023.1119052

D. Challenge for Sustainable Packaging in a Circular Economy



Sources: [1] OECD/Global Plastics Outlook – Policy Scenarios to 2060
[2] OECD (2022), *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options*, OECD Publishing, Paris, https://doi.org/10.1787/de747aef-en.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3. Risk assessment and Risk management
(Safety)
Project n.: 101087203


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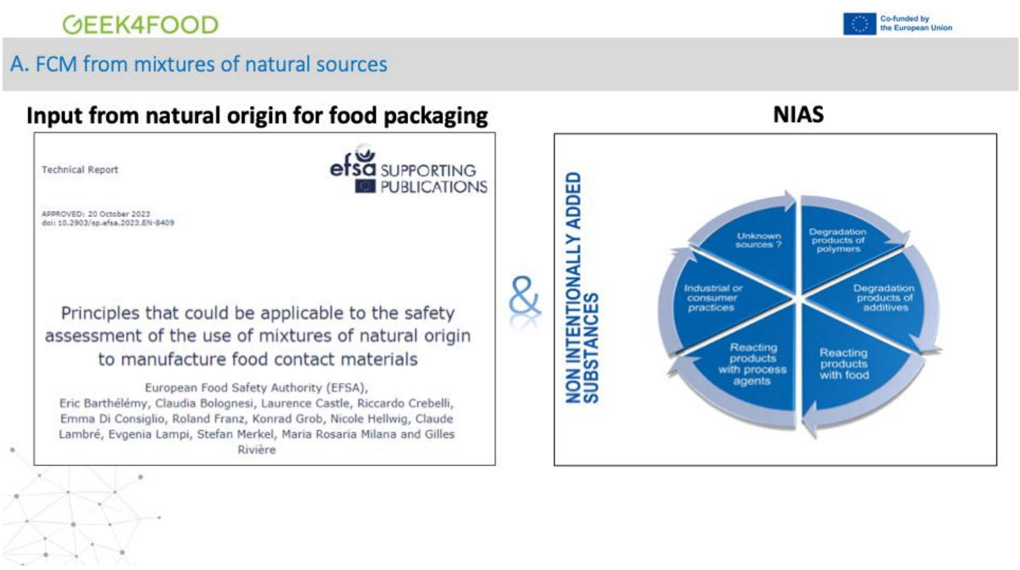
Risk management
European Commission
Directorate-General for Health and Food Safety (DG SANTE)
Risk Assessment
efsa
European Food Safety Authority
COMMISSION
proposes legislation
COUNCIL
PARLIAMENT
codecision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A. FCM from mixtures of natural sources
Input from natural origin for food packaging
Technical Report
efsa SUPPORTING PUBLICATIONS
APPROVED: 20 October 2023
doi: 10.2903/sp.efsa.2023.EN-8409
Principles that could be applicable to the safety assessment of the use of mixtures of natural origin to manufacture food contact materials
European Food Safety Authority (EFSA),
Eric Barthélémy, Claudia Bolognesi, Laurence Castle, Riccardo Crebelli, Emma Di Consiglio, Roland Franz, Konrad Grob, Nicole Hellwig, Claude Lambré, Evgenia Lampi, Stefan Merkel, Maria Rosaria Milana and Gilles Rivière
&
NIAS
NON INTENTIONALLY ADDED SUBSTANCES
Unknown sources ?
Degradation products of polymers
Degradation products of additives
Reacting products with food
Reacting products with process agents
Industrial or consumer practices

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B. IAS and NIAS

- **IAS - "Intentionally Added Substances"**
- *Regulated chemical substances (monomers, additives, stablizei agents, platicisers, etc) that are [risk assessed](#)!*

- **NIAS – "Non-intentionally added substances**
- *Substances that may be originated through several paths and they are not regulated (sometimes not even risk assessed!)* → not regulated

→ the majority remains **unknown** and NOT risk assessed.

Source: Geueke et al. et al. *Crit. Rev. Food Sci.* 2022 (https://doi.org/10.1080/10408398.2022.2067828)

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4. Critical considerations

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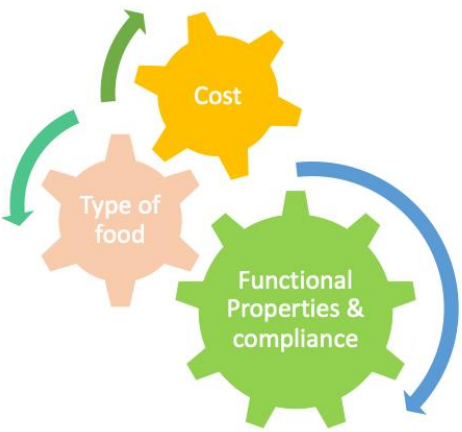

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5. CONCLUSIONS

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1. Plastic alternatives in a circular economy are of great importance.
2. Sustainability will increase together with Plastic waste → recycling NOT enough.
3. Extensive research exists to develop plastic alternatives. But:
   - Scaling up is needed (cost reduction)
   - Low CO2 fingerprint processes are still at a premature phase
   - High costs (compared to fossil-fuel).
   - End-users training and education (e.g. professionals, consumers).
4. Recycling technologies not covering all materials (only PET).
5. Policies (Risk managers) are making progress….(slow).
6. A single solution approach is not enough.

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CHALLENGE???

- To minimize the waste of plastic!
- How??
- Requirements?
- Legilsation

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Eco-Design of Food packaging

Session 2:

Eco-design principles and Safe and Sustainable by Design (SSbD)

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Agenda

1. Introduction to eco-design principles and sustainable by design (SSbD)
2. Benefits of eco-design and SSbD
3. Implementation of SSbD: State-of-the art and challenges
4. Discussion/Q&A

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1. Introduction to eco-design principles and sustainable by design (SSbD)

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A. Eco-design key principles:

1. **Material Optimization:** Use fewer resources and prioritize renewables.
2. **Energy Efficiency:** Minimize energy use in production and operation.
3. **Longevity:** Design for durability, reuse, or repair.
4. **Recyclability:** Simplify recovery of materials at end-of-life.
5. **Reduce Toxicity:** Eliminate hazardous substances from the design.
6. **Circularity:** Enable closed-loop systems through design.

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B. SSbD

1. What is it ?

"A framework ensuring that products are safe for human health and the environment while being sustainable."

2. Pillars of SSbD:

1. **Safety:** No harmful chemicals or materials.
2. **Sustainability:** Minimal ecological footprint throughout the lifecycle.
3. **Functionality:** Meets user and performance needs.

3. Steps in SSbD

1. **Hazard Identification:** Assess materials for toxicity and environmental risks.
2. **Impact Assessment:** Evaluate lifecycle impacts (carbon footprint, waste).
3. **Design Integration:** Incorporate safer, sustainable alternatives.
4. **Testing and Validation:** Verify safety and functionality standards

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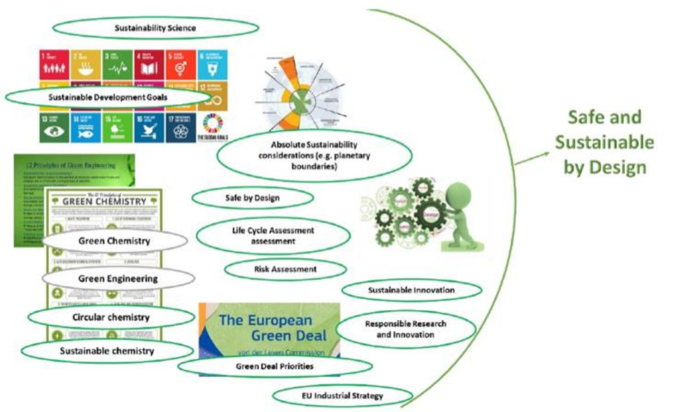

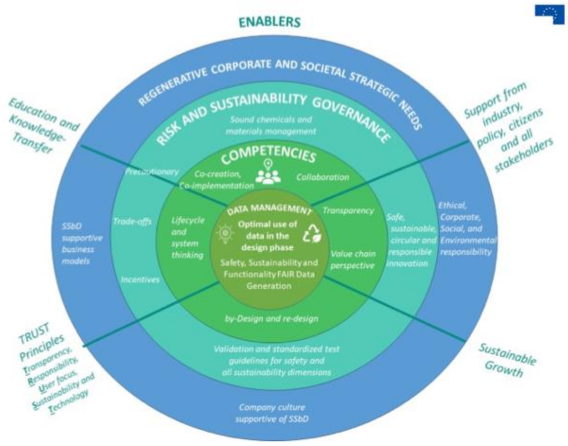

Source: Lya G. Soeteman-Hernández et al. 2024, Envir. Sustain. https://doi.org/10.1007/s42398-024-00324-w

2. Benefits of eco-design and SSbD

A. Eco-design

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B. SSbD

1. **Environmental:**
    - Reduced waste and emissions.
    - Improved recyclability and resource efficiency.

2. **Economic:**
    - Cost savings through material efficiency.
    - Competitive advantage in eco-conscious markets.

3. **Social:**
    - Healthier products for consumers.
    - Positive brand reputation.

4. **Safety**
    - Safe products for consumers.
    - Reduced exposure to chemicals

5. **Functionality**

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3. Implementation of SSbD: State-of-the art and challenges

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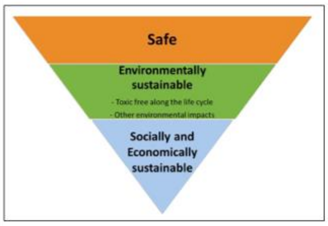

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Table 1. Non-exhaustive list of potential benefits and challenges of the adoption of the SSbD approach from a technological and a legal perspective.

	Potential Benefits	Potential Challenges
T	*Ex ante* safety and sustainability	Lack of knowledge about technological risk
E	Active risk awareness	Complexity of implementation
C	Fostering innovation	Conflicts between safety and sustainability
H	Flexible principles-based regulation	Legal uncertainty
L	Simpler rules and standards	Compliance and enforcement
E	Transparency of legal objectives	Legitimacy and accountability
G	Wider scope of application	Regulatory capture
A	Management of regulatory challenges	Liability*
L	Compliance with existing rules	Potential clashes with WTO rules*

*Liability and potential clashes with WTO rules are outside of the scope of this paper because that domain is so complex that it would require a separate investigation.

Source: Reins and Wijns, 2024, Euroep[an Journal of Risk Regulation; 1-18; doi: 10.1017/err.2024.29

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4. Discussion/Q&A

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"How can businesses overcome barriers to adopting SSbD?"

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Eco-Design of Food packaging

Session 3:

Safety and risk assessment of eco-designed food packaging

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Agenda

1. Basic terms
2. Introduction to safety
3. Regulatory framework
4. Risk assessment framework

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1. Basic terms

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Basic concepts

1. Migration
2. Polymeric materials
3. Types of polymeric materials
4. Supply chain
5. Contamination sources

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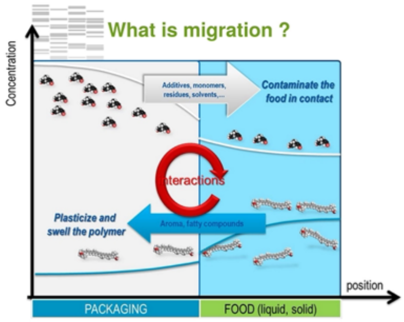
1. Migration

- Complex physicochemical phenomenon
- Diffusion
- Based on Fick's 2nd law

Migration (Migration)
The phenomenon that describes the transfer of substances (chemicals) from packaging to food or vice versa (food to packaging).

Migrating chemical compounds (migrants)
Compounds that are transferred from the packaging to the food as a result of contact or interaction between the food and the packaging material.

Migration limits
Defined by European Regulations or national legislation.



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2. Types of migration

A. Overall migration(OM- limit 60 mg/kg of food or 60 mg/dm^2 plastic)

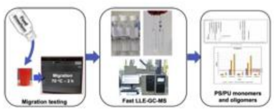
OM is the maximum permitted total amount of non-volatile substances that can migrate from a food packaging material or food container into the food.

Gravimetric method

B. Specific migration (SM- specific migration limit- mg/kg of food - Annex I, Reg. 10/2011)

The specific migration limit (SML) is the maximum permitted amount of a particular substance that can migrate from a food packaging material or food container into food. It is a safety limit derived from toxicological studies.

Instrumental analytical techniques



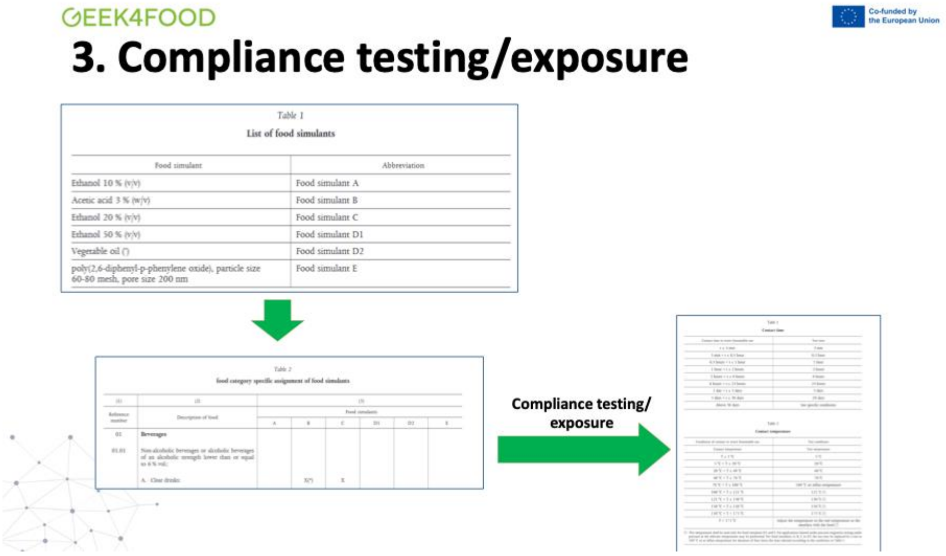
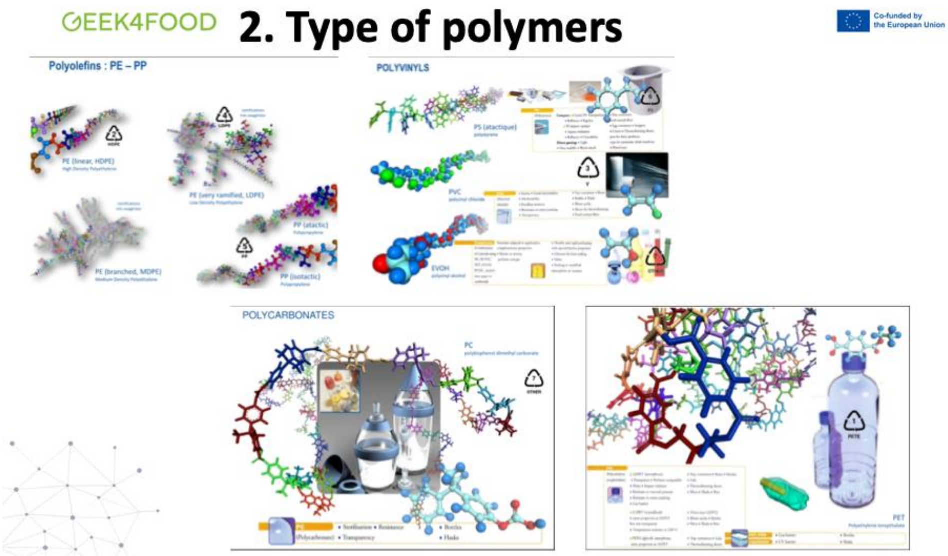
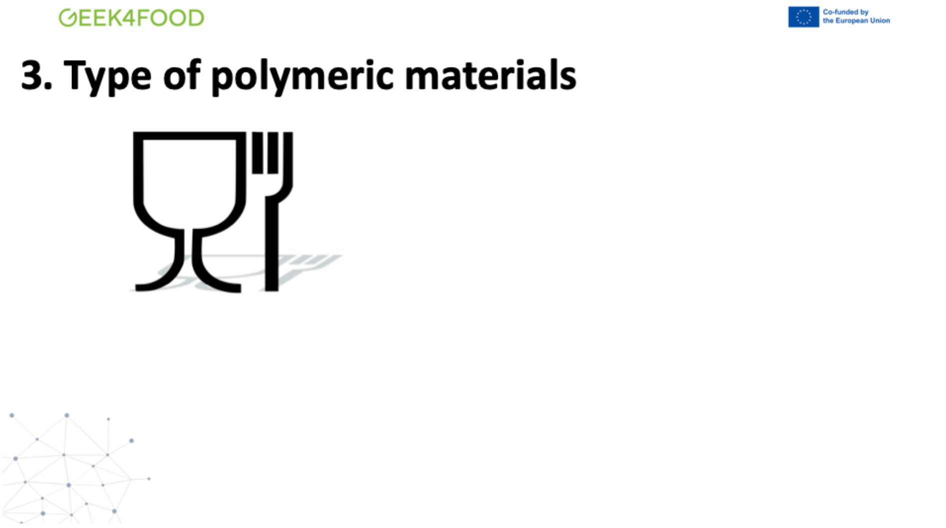


Table 1

List of food simulants

Food simulant	Abbreviation
Ethanol 10 % (v/v)	Food simulant A
Acetic acid 3 % (w/v)	Food simulant B
Ethanol 20 % (v/v)	Food simulant C
Ethanol 50 % (v/v)	Food simulant D1
Vegetable oil (*)	Food simulant D2
poly(2,6-diphenyl-p-phenylene oxide), particle size 60-80 mesh, pore size 200 nm	Food simulant E





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4. Supply chain

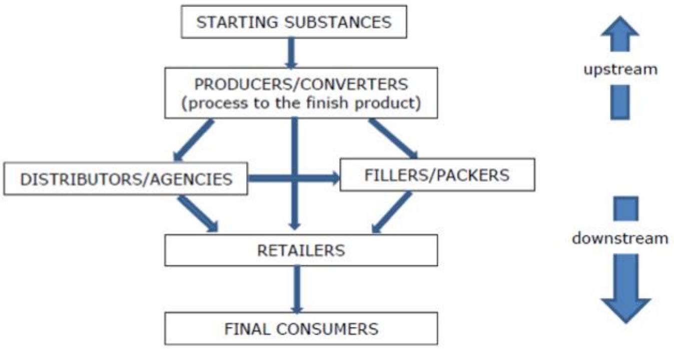

Figure 1: Simplified structure of the organisation of the FCM supply chain

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5. Contamination sources

Polyurethane based
Sylil terminated polyether based
Butyl rubber based
Natural rubber water-based adhesives
Carboxylated-SBR water-based adhesives
Epoxies
Modified acrylics
Cyanoacrylates

Component	Formulation level	Exposed contact surface	Interaction with food	Contamination risk
Plastic layer in contact withfood	+++	+++++	+ to +++	+++++
Layer non-intented to be in contact with food	+++	+++++	-	+++
Cap, lid	+++	++	- to +	++
Gasket	+++++	+	- to +	+ to ++
Varnish	+++ to +++++	+++++	-	+++
Ink	+++++	+ to +++	-	+ to +++

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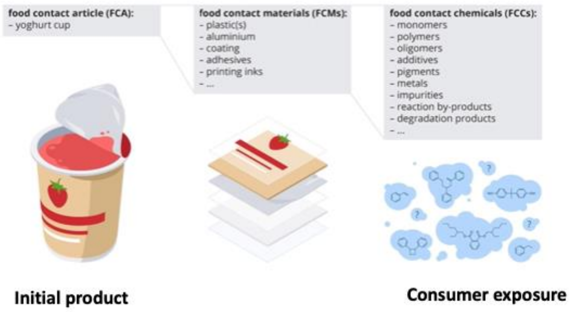
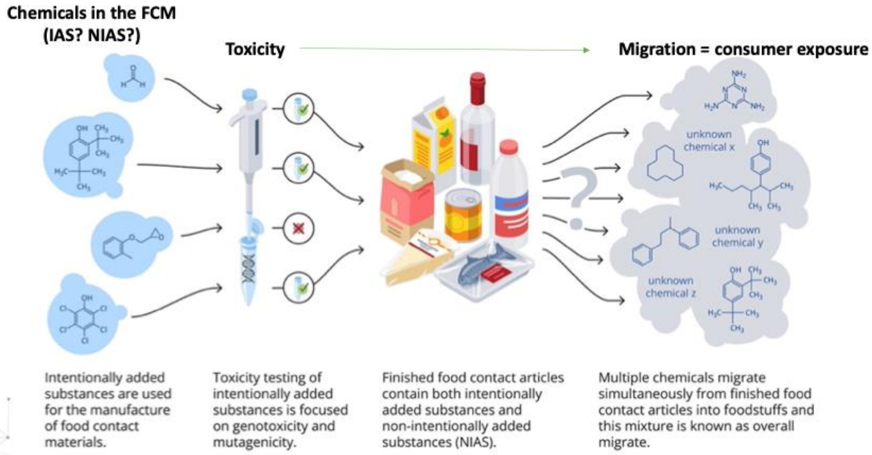
2. Introduction to safety





Source: Muncke et al. 2023. Envrionmental International; https://doi.org/10.1016/j.envint.2023.108161

2. Regulatory framework

EU FCM Regulatory Framework

- **Framework Regulation (EC) 1935/2004** on materials and articles intended to come into contact with food
- **Commission Regulation (EC) 2022/1616** on recycled plastic materials and articles intended to come into contact with foods
- **Commission Regulation (EU) No. 10/2011** on plastic materials and articles intended to come into contact with food
- **Commission Regulation (EC) No 2023/2006** on good manufacturing practice for materials and articles intended to come into contact with food
- **Commission Regulation (EC) 450/2009** on active and intelligent materials and articles intended to come into contact with food.
- **Commission regulation (EU) 2018/213** on the use of bisphenol A in varnishes and coatings intended to come into contact with food
- **Directive 2007/42/EC** on materials and articles made of regenerated cellulose film that come into contact with food
- **Council Directive 84/500/EEC and 2005/31/EC** on the approximation of the laws of the Member States relating to ceramic articles intended to come into contact with foodstuffs
- **Council Directive 84/500/EEC of 15 October 1984** on the approximation of the laws of the Member States relating to ceramic articles intended to come into contact with foodstuffs
- **Council directive (EU) 2019/904** on the reduction of the impact of certain plastic products on the environment (single use plastics)

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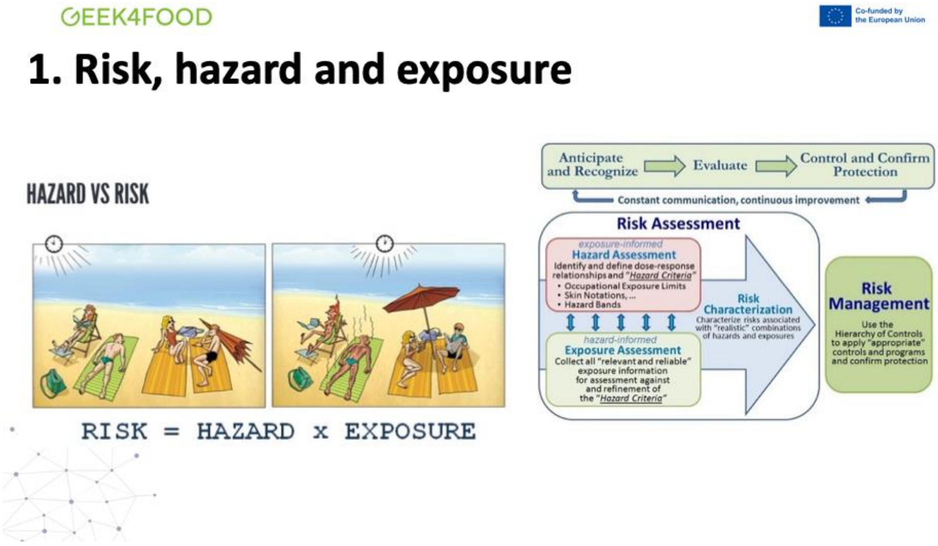
3. Risk assessment framework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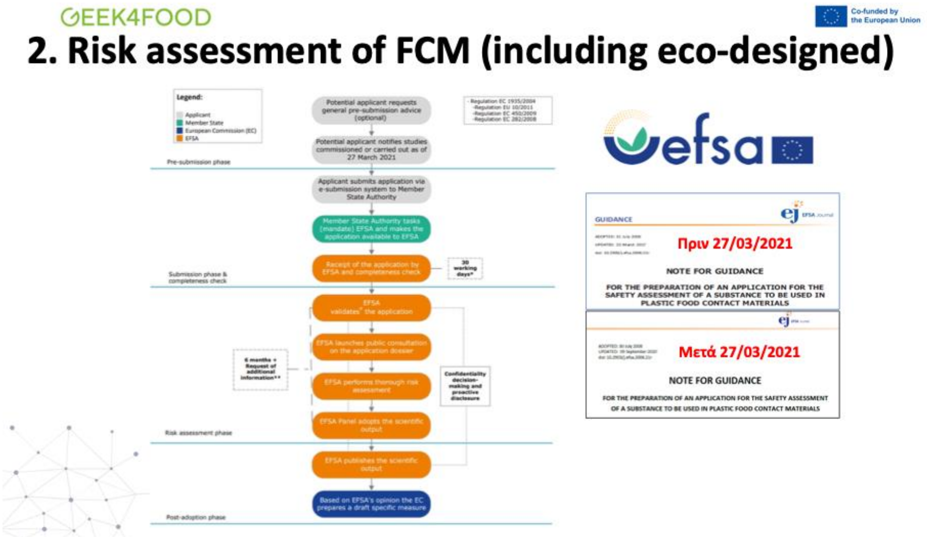
1. Risk, hazard and exposure
HAZARD VS RISK
RISK = HAZARD x EXPOSURE
Anticipate and Recognize
Evaluate
Control and Confirm Protection
Constant communication, continuous improvement
Risk Assessment
exposure-informed
Hazard Assessment
Identify and define dose-response relationships and "Hazard Criteria"
• Occupational Exposure Limits
• Skin Notations, ...
• Hazard Bands
Risk Characterization
Characterize risks associated with "realistic" combinations of hazards and exposures
hazard-informed
Exposure Assessment
Collect all "relevant and reliable" exposure information for assessment against and refinement of the "Hazard Criteria"
Risk Management
Use the Hierarchy of Controls to apply "appropriate" controls and programs and confirm protection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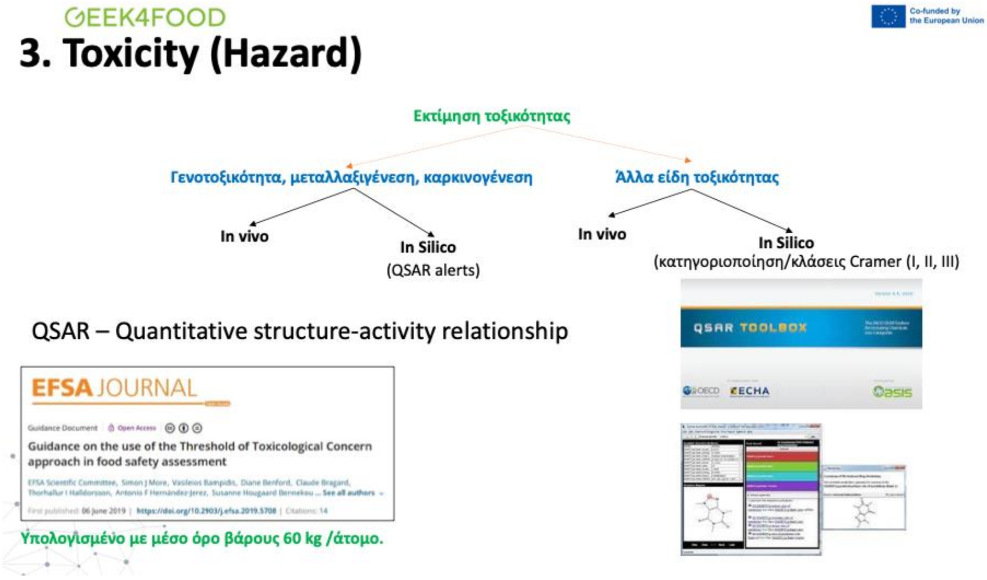
2. Risk assessment of FCM (including eco-designed)
efsa
GUIDANCE
Πριν 27/03/2021
NOTE FOR GUIDANCE
FOR THE PREPARATION OF AN APPLICATION FOR THE SAFETY ASSESSMENT OF A SUBSTANCE TO BE USED IN PLASTIC FOOD CONTACT MATERIALS
Μετά 27/03/2021
NOTE FOR GUIDANCE
FOR THE PREPARATION OF AN APPLICATION FOR THE SAFETY ASSESSMENT OF A SUBSTANCE TO BE USED IN PLASTIC FOOD CONTACT MATERIALS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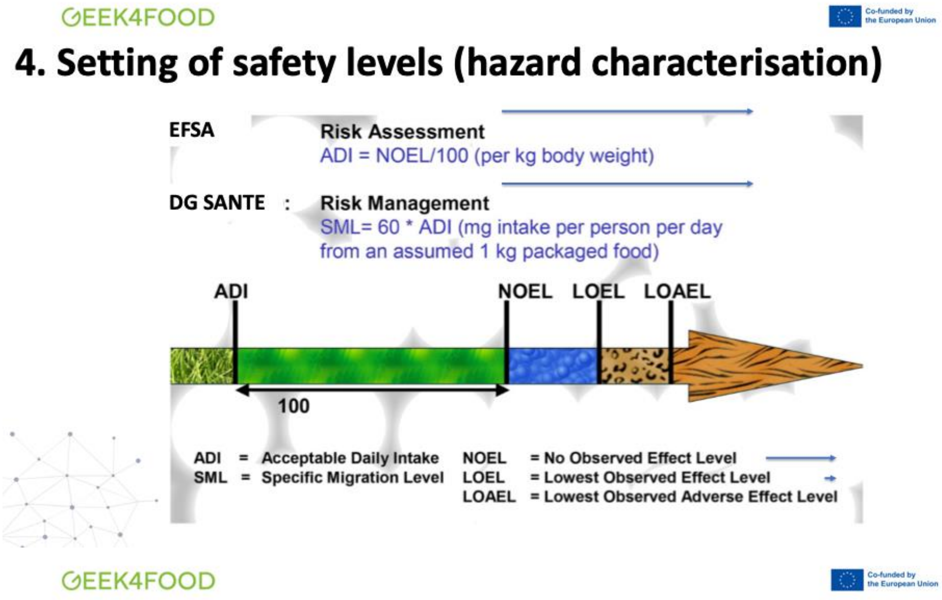
3. Toxicity (Hazard)
Εκτίμηση τοξικότητας
Γενοτοξικότητα, μεταλλαξιγένεση, καρκινογένεση
Άλλα είδη τοξικότητας
In vivo
In Silico
(QSAR alerts)
In vivo
In Silico
(κατηγοριοποίηση/κλάσεις Cramer (I, II, III)
QSAR – Quantitative structure-activity relationship
QSAR TOOLBOX
OECD
ECHA
Oasis
EFSA JOURNAL
Guidance Document
Open Access
Guidance on the use of the Threshold of Toxicological Concern approach in food safety assessment
First published: 06 June 2019
https://doi.org/10.2903/j.efsa.2019.5708
Υπολογισμένο με μέσο όρο βάρους 60 kg /άτομο.


GEEK4FOOD
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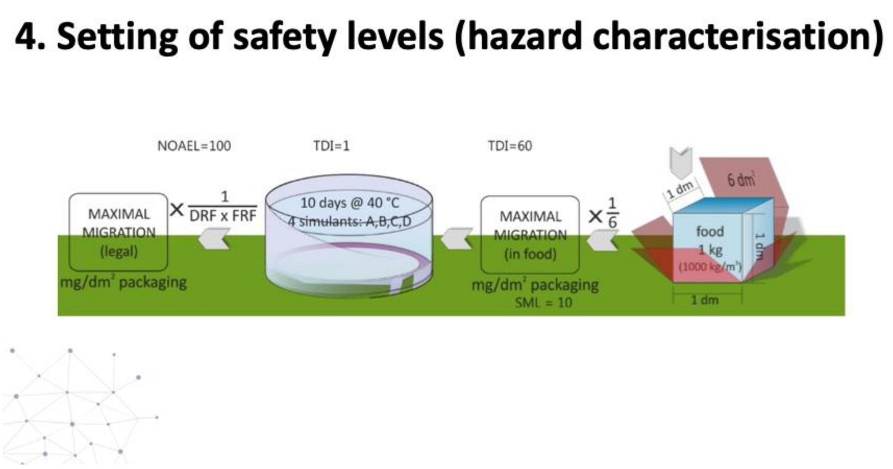
4. Setting of safety levels (hazard characterisation)
EFSA
Risk Assessment
ADI = NOEL/100 (per kg body weight)
DG SANTE :
Risk Management
SML= 60 * ADI (mg intake per person per day from an assumed 1 kg packaged food)
ADI
NOEL
LOEL
LOAEL
100
ADI = Acceptable Daily Intake
SML = Specific Migration Level
NOEL = No Observed Effect Level
LOEL = Lowest Observed Effect Level
LOAEL = Lowest Observed Adverse Effect Level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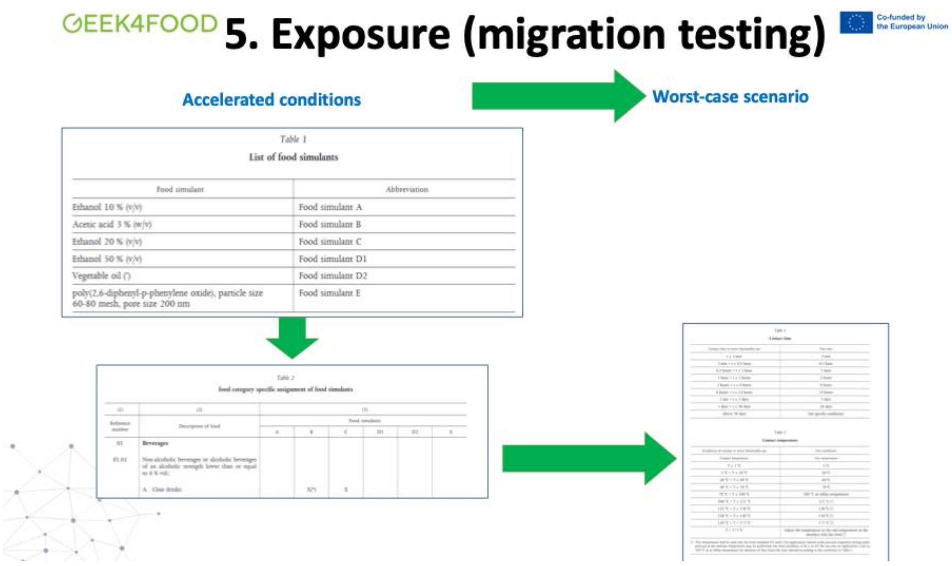
4. Setting of safety levels (hazard characterisation)
NOAEL=100
TDI=1
TDI=60
MAXIMAL MIGRATION (legal)
mg/dm² packaging
1 / DRF x FRF
10 days @ 40 °C
4 simulants: A,B,C,D
MAXIMAL MIGRATION (in food)
mg/dm² packaging
SML = 10
1/6
1 dm
6 dm²
food
1 kg
(1000 kg/m³)
1 dm
1 dm


GEEK4FOOD
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5. Exposure (migration testing)
Accelerated conditions
Worst-case scenario
Table 1
List of food simulants
Food simulant | Abbreviation
Ethanol 10 % (v/v) | Food simulant A
Acetic acid 3 % (w/v) | Food simulant B
Ethanol 20 % (v/v) | Food simulant C
Ethanol 50 % (v/v) | Food simulant D1
Vegetable oil (*) | Food simulant D2
poly(2,6-diphenyl-p-phenylene oxide), particle size 60-80 mesh, pore size 200 nm | Food simulant E
Table 2
Food category specific assignment of food simulants

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Activity/Case-study 1

Identify an existing fossil fuel plastic that can be replaced by an eco-designed plastic, e.g. PET with PLA, based on food and functional properties

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Scenario

- Polyethylene terephthalate (PET) is a widely used plastic in the food packaging industry due to its excellent barrier properties, durability, and clarity. However, its reliance on fossil fuels and the challenges of recycling have raised environmental concerns. Polylactic acid (PLA), a bioplastic derived from renewable resources like cornstarch, offers a sustainable alternative but comes with challenges related to functional properties and cost.
- Your company, **EcoPack Solutions**, has tasked you with developing a sustainable alternative to PET packaging for a client, a mid-sized beverage company looking to adopt eco-friendly practices. The company currently uses PET bottles for their products, which include carbonated soft drinks, fruit juices, and water.

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Task Overview

Working in different teams:

1. **Analyze the suitability of PET and PLA for food packaging,** considering functional properties (e.g., barrier to oxygen and moisture, durability, clarity), food safety, and compatibility with beverages.
2. **Evaluate the environmental impact** of both materials across their lifecycle (e.g., carbon footprint, biodegradability, recyclability).
3. **Propose an eco-designed solution** tailored to the client's needs, identifying challenges and trade-offs.
4. **Develop a transition plan** for the client, considering economic feasibility, regulatory compliance, and consumer acceptance.

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Resources to be provided to the students

- Technical datasheets for PET and PLA.
- Summary of LCA data for PET and PLA.
- Case examples of companies that transitioned to bioplastics.
- Access to online tools for calculating material carbon footprints.

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For the tutor

Discussion Points Post-Case Study

- What are the limitations of PLA as a replacement for PET in food packaging?
- How can advancements in bioplastic technology improve the adoption of eco-design practices?
- What role do consumer perceptions play in the success of sustainable packaging transitions?
- This case study is designed to equip industry professionals with the skills to evaluate and implement eco-design solutions in the food packaging sector, fostering innovation and sustainability.

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Eco-Design of Food packaging

Session 4:

Existing eco-designed food packaging materials. Pros and cons

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Agenda

1. Introduction
2. Existing eco-designed food packaging materials
3. Pros and cons
4. Conclusions

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1. Introduction

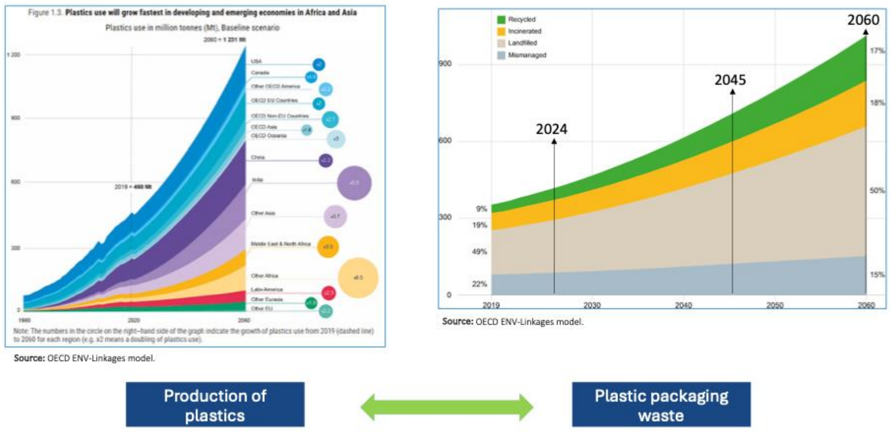
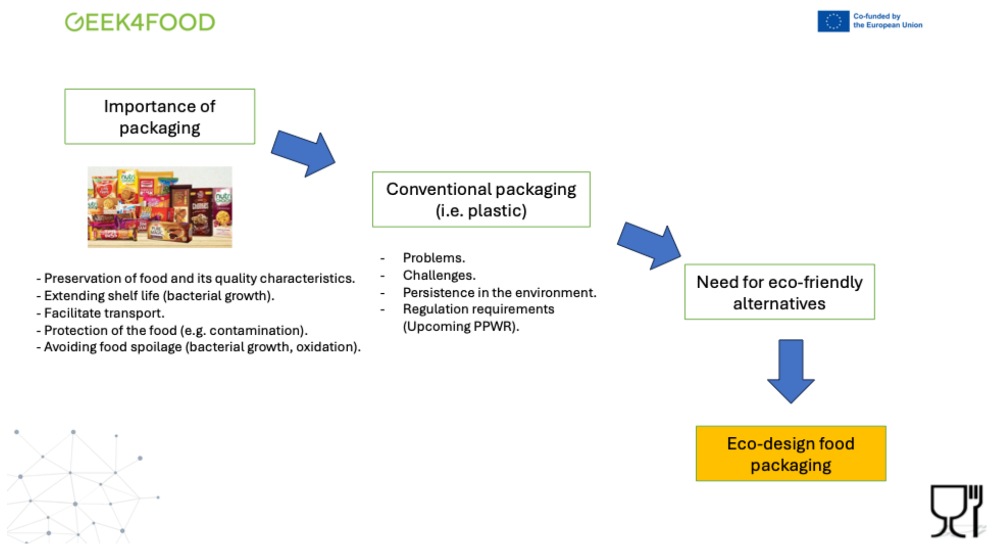


Figure 1.3. Plastics use will grow fastest in developing and emerging economies in Africa and Asia
Plastics use in million tonnes (Mt), Baseline scenario
Source: OECD ENV-Linkages model.
Recycled
Incinerated
Landfilled
Mismanaged
2024
2045
2060
Source: OECD ENV-Linkages model.
Production of plastics
Plastic packaging waste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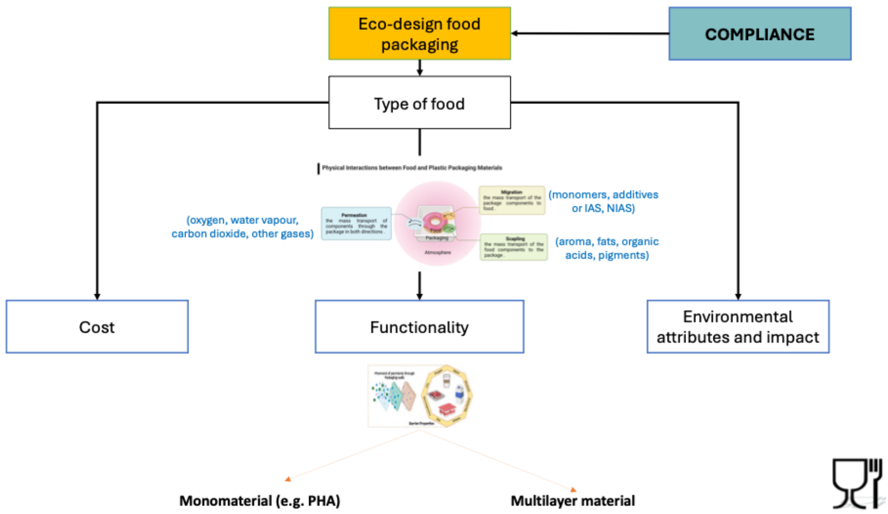
Importance of packaging
- Preservation of food and its quality characteristics.
- Extending shelf life (bacterial growth).
- Facilitate transport.
- Protection of the food (e.g. contamination).
- Avoiding food spoilage (bacterial growth, oxidation).
Conventional packaging (i.e. plastic)
- Problems.
- Challenges.
- Persistence in the environment.
- Regulation requirements (Upcoming PPWR).
Need for eco-friendly alternatives
Eco-design food packaging


Eco-design food packaging
COMPLIANCE
Type of food
Physical Interactions between Food and Plastic Packaging Materials
(oxygen, water vapour, carbon dioxide, other gases)
(monomers, additives or IAS, NIAS)
(aroma, fats, organic acids, pigments)
Cost
Functionality
Environmental attributes and impact
Monomaterial (e.g. PHA)
Multilayer material

2. Existing eco-designed food packaging materials

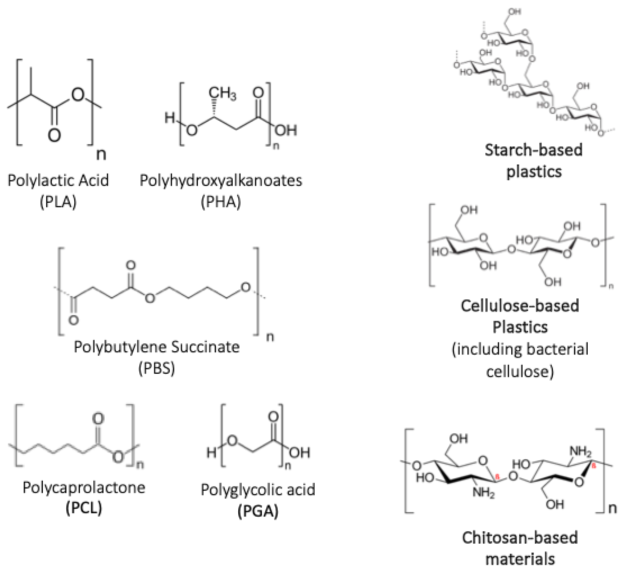
Categories of eco-designed packaging materials

1. Biodegradable materials
2. Recyclable materials
3. Compostable/edible packaging materials
4. Reusable designs

1. Biodegradable materials

- Polylactic Acid (PLA)
- Polyhroxyalkanoates (PHA)
- Polybutylene succinate (PBS)
- Starch-based plastics
- Chitosan-based materials
- Polycaprolactone (PCL)
- Polyglygolic acid (PGA)

Blends and composites….



2. Recyclable materials

- Plastic packaging (PET, PE, PP, etc)
- Paper-based (kraft paper, wax-coared paper, cardboard, laminated paper)
- Bio-PE → from sugarcane ethanol (*not biodegradable*)
- Bio-PET → part ially from sugarcane (*not biodegradable*)

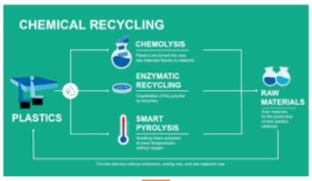
Advanced recycling technologies

Advacnced recycling technologies for FCM uses

Mechanical Recycling (only PET)

- High energy consumption
- Recycled material MORE EXPENSIVE than virgin.
- It cannot cover all materials (e.g. HDPE excluded).
- Production of high number of micro-/nanoplastics.

Chemical Recycling



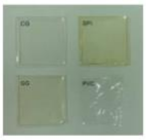
- High energy consumption
- Use of solvents.
- For EU is not Recycling but regeneration of monomers → ***PURITY*** shall be declared and risk assessed (NIAS).

3. Compostable/edible materials

1. **Starch-Based Films** (from starch)
2. **Protein-Based Films** (from proteins like gelatin, casein from milk, whey, soy, or wheat gluten).
3. **Seaweed-Based Films:** Extracted from seaweed or algae.
4. **Polysaccharide-Based Films** (cellulose, chitosan, pectin, or pullulan → edible coatings for fruits, vegetables).
5. **Lipid-Based Films** (e.g. beeswax or carnauba wax).

(1)

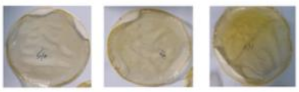
(2)



(3)

(4)

(5)



4. Reusable designs

- Glass Containers
- Stainless Steel Containers
- Silicons??? (Toxic silica oligomers)
- Plastic???
- A-B-A monomaterial polymers (Virgin-recycled/ decontaminated - virgin)

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3. Pros and cons

1. Biodegradable materials

A. Pros

- **Environmental Benefits:** Breaks down into natural elements under industrial composting conditions.
- **Renewable Resources:** Made from plant-based feedstocks like corn, sugarcane, or potatoes.
- **Versatility:** Suitable for a wide range of applications, including containers, films, and utensils.

B. Cons

- **Limited Infrastructure:** Requires specific composting facilities; may not degrade in natural environments.
- **High Cost:** Generally more expensive than conventional plastics.
- **Raw material/Resources:** May divert agricultural resources from food production.

Blends and composites….

2. Recyclable materials (bio-Pe, bio-PET; non-biodegradable)

A. Pros

- **Recyclability:** Easily recycled in most systems.
- **Compatibility:** Works with existing recycling systems.
- **Lower Carbon Footprint:** Production reduces reliance on fossil fuels.
- **Performance:** Comparable to traditional plastics in strength and flexibility.

B. Cons

- **Non-Biodegradable:** May still contribute to long-term waste if not recycled.
- **Resource Competition:** Relies on agricultural inputs like sugarcane or corn.
- **Cost:** Generally more expensive than fossil-based plastics.

2. Recyclable materials (paper)

A. Pros

- **Recyclability:** Easily recycled in most systems.
- **Renewable:** Sourced from trees and agricultural byproducts.
- **Customizable:** Can be shaped, printed, or coated for various uses

B. Cons

- **Water Resistance:** Susceptible to moisture without additional coatings, which can hinder recyclability.
- **Energy-Intensive Production:** Pulp and paper manufacturing requires significant energy and water.
- **Durability Issues:** Less durable compared to plastic alternatives.

3. Compostable/edible materials (waxed, cellulose-based)

A. Pros

- **Zero Waste:** Can be consumed with the food product.
- **Innovative Appeal:** Offers novelty and aligns with zero-waste principles.
- **Renewable Ingredients:** Uses food-grade and natural components.
- **Compostability/degradability:** Biodegradable in home and industrial composting systems.
- **Resource Efficiency:** Utilizes agricultural byproducts that would otherwise be waste.
- **Wide Applications:** Plates, bowls, and trays for food service industries.

B. Cons

- **Limited Durability:** Not suitable for high-moisture or high-pressure conditions.
- **Cost and Scalability:** More expensive and less available for large-scale applications.
- **Specialized Facilities Needed:** Composting requires controlled conditions.
- **Consumer Acceptance:** May face cultural or regulatory barriers.
- **Moisture Resistance:** Requires coatings to handle wet or oily foods, which may hinder compostability.
- **Cost:** Production can be more expensive compared to plastic alternatives.
- **Durability:** Less sturdy than plastic or metal counterparts.

4. Reusable designs

A. Pros

- **Durability:** Can be used multiple times, reducing overall waste (e/g/ a bottle of beer can be reused more than 60x times!)
- **Recyclability:** Materials like glass and metal are fully recyclable.
- **Consumer Preference:** Increasingly popular for environmentally conscious buyers.

B. Cons

- **Energy-Intensive Production:** Initial manufacturing has a high environmental impact.
- **Weight:** Heavier than single-use options, increasing transportation emissions.
- **Cost:** Higher upfront costs for consumers and businesses.

4. Conclusions

1. Plastic alternatives in a circular economy are of great importance.
2. Sustainability will increase together with Plastic waste → recycling NOT enough.
3. Recycling technologies not covering all materials (only PET) → new technologies needed
4. Scaling up is needed (cost reduction) → raw materials??? Not sufficient at the moment
5. Low CO2 fingerprint processes are still at a premature phase.
6. High costs (compared to fossil-fuel).
7. End-users training and education (e.g. professionals, consumers).
8. Policies (Risk managers) are making progress....(slow).
9. A single solution approach is not enough.

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Activity/Case-study 2

Propose/describe an innovative solution from holistic perspective (applications, environmental impact, raw materials, cost etc.)

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Scenario

"Developing Eco-Friendly Edible Coatings to Extend Food Shelf Life: A Holistic Perspective"

- Fictional Scenario: ***"You are a team of innovators tasked by a multinational food company (EcoPack solutions) to develop a sustainable and eco-designed coating to reduce food waste in freshly produced vegetables without increasing plastic usage."***

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Information provided to the students

Working in different teams:

1. **Problemproblem:** Fresh fruits and vegetables often spoil before reaching consumers, contributing to 30% of food waste globally. Existing plastic-based packaging solutions exacerbate environmental pollution.
2. **Proposed eco-designed solution** e.g. development of a biodegradable, edible coating made from food-grade polysaccharides (e.g., pectin) and essential oils.
3. **Identify key functionalities:** barrier properties to moisture and oxygen. Enhances shelf life while maintaining food safety. Can be safely consumed by end-users or washed off.
4. **Assessment from holistic perspective** (see next slide)

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Holistic perspective

A. Applications:
1. Coating fruits, vegetables, and bakery products.
2. Market suitability for high-waste categories like avocados, bananas, and berries.

B. Environmental perspective:
1. Eliminates single-use plastics.
2. Made from renewable, biodegradable resources.

C. Raw Materials:
1. Derived from food industry by-products (e.g., citrus peels for pectin).
2. Derived from non food industry by-products (from fresh fruits).

D. Regulatory requirements
1. Compliance
2. PPWR (Upcoming Regulation on wastes)

E. Cost Considerations:
1. Compared production cost vs. traditional plastic coatings (indicative).
2. Assess scalable manufacturing potential for small and large producers.

F. Consumer perspective
1. Acceptance to pay additional cost.
2. Safety of raw materials (waste, new materials)
3. Scalability (raw materials, sustainability).

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Interactive discussion/Stakeholder perspectives

- Groups represent stakeholders (1) Food manufacturers, (2) Environmentalists, (3) Regulators, and (4) Consumers.
- Evaluate the proposed solution from your stakeholder's perspective (1-4; see above). What are the benefits and potential challenges?"
- **Guiding Questions:**
  1. Is the innovation practical and scalable?
  2. What regulatory or logistical barriers might arise?
  3. How does this align with consumer trends and expectations?

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For the tutor

Discussion Points Post-Case Study

- Encourage critical thinking and inter-group dialogue to explore conflicting priorities (e.g., cost vs. sustainability)

Recap:

- Restate the importance of taking a holistic perspective when proposing innovations.
- Summarize the key points discussed (applications, environmental impact, raw materials, cost).

Take-Home Message:

- "Sustainable solutions in the food industry require balancing technical feasibility, economic viability, and environmental responsibility."

Closing Engagement:

- Ask participants: *"What other sustainable innovations could address similar challenges in the food industry?"*

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Thank you

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Project n.: 101087203

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Contents

1. Introduction

Question 1: What is the goal of the EU plastics strategy regarding plastic packaging?
- **A)** To increase the use of single-use plastics
- **B)** To make all plastic packaging placed on the EU market reusable or easily recyclable by 2030
- **C)** To reduce the use of biodegradable plastics
- **D)** To promote the use of fossil fuels

Correct answer: B) To make all plastic packaging placed on the EU market reusable or easily recyclable by 2030.

Question 2: What is the definition of a circular economy?
- **A)** An economic system aimed at increasing waste and the use of finite resources
- **B)** An economic system aimed at eliminating waste and the continual use of resources through principles like reuse, recycling, and regeneration
- **C)** An economic system focused on reducing the use of plastics
- **D)** An economic system focused on increasing the use of fossil fuels

Correct answer: B) An economic system aimed at eliminating waste and the continual use of resources through principles like reuse, recycling, and regeneration.

Question 3: What is the main difference between IAS (Intentionally Added Substances) and NIAS (Non-Intentionally Added Substances) in the context of food contact materials?
- **A)** IAS are regulated, while NIAS are not
- **B)** IAS are not regulated, while NIAS are
- **C)** IAS are biodegradable, while NIAS are not
- **D)** IAS are used in food packaging, while NIAS are not

Correct answer: A) IAS are regulated, while NIAS are not

2. CONTENT PART 1

Question 1. What is meant "Sustainable-by-design"

A) A system that is sustainable only after its useful life is over.
B) A framework ensuring safe products for human and the envirnoment .
C) A system that is made from recycled materials.
D) A system that is energy-efficient only.
Correct answer: B)

Question 2: According to eco-design key principles, which of the following is an example of the principle of "Longevity"?

A) Using recycled materials in product manufacturing.

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B) Designing a product with durability, reusability and potential to be repaired.
C) Minimizing energy consumption during the product's operation.
D) Eliminating hazardous substances from the product's design.
Correct answer: B) Designing a product with interchangeable parts to facilitate repair and reuse.

3. CONTENT PART 2

Question 1: What is migration in the context of food packaging, according to the document?
A) The transfer of food from packaging to the environment.
B) The transfer of substances (chemicals) from packaging to food or vice versa.
C) The breakdown of packaging materials over time.
D) The recycling of packaging materials.
Correct answer: B) The transfer of substances (chemicals) from packaging to food or vice versa.

Question 2: What is the purpose of setting specific migration limits (SMLs) in food packaging regulations?
A) To establish a minimum amount of chemicals that must be present in food packaging.
B) To set a maximum permitted amount of a particular substance that can migrate from food packaging to food.
C) To determine the type of materials that can be used in food packaging.
D) To establish a standard for packaging design.
Correct answer: B) To set a maximum permitted amount of a particular substance that can migrate from food packaging to food.

Question 3: What is the purpose of the EU's Framework Regulation (EC) 1935/2004 on materials and articles intended to come into contact with food?
A) To regulate the use of recycled plastic materials in food packaging.
B) To establish guidelines for good manufacturing practice in the food industry.
C) To provide a framework for the safety assessment of food packaging materials. **D)** To prohibit the use of certain chemicals in food packaging.
Correct answer: C) To provide a framework for the safety assessment of food packaging materials.

4. CONTENT PART 3

Question 1 What are the four categories of eco-designed food packaging materials mentioned in the document? (ref: 1)
A) Biodegradable, recyclable, compostable, and reusable
B) Biodegradable, recyclable, compostable, and edible
C) Biodegradable, recyclable, compostable, and bioplastic
D) Biodegradable, recyclable, compostable, and non-biodegradable
Correct answer: A) Biodegradable, recyclable, compostable, and reusable

Question 2 What is one of the cons of biodegradable materials mentioned in the document? (ref: 1)
A) High cost
B) Limited infrastructure
C) Non-renewable resources
D) All of the above
Correct answer: D) All of the above (High cost, Limited infrastructure, and Raw material/Resources: May divert agricultural resources from food production)

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Question 3: What is one of the pros of recyclable materials (paper) mentioned in the document? (ref: 1)
A) Water resistance
B) Energy-intensive production
C) Customizable
D) Durability issues
Correct answer: C) Customizable

ANNEX 2: Content mapping file, syllabus and content of the module “Optimised fermentation”

1. Content mapping file

Type of content	Session’s Title	Partner responsible for content creation	Content's core duration	Indicative resources
Challenge based lecture / discussion	How can we explore optimised fermentation processes to produce sustainable, nutritious, and affordable food ingredients while addressing potential challenges in resource efficiency, consumer acceptance, regulatory compliance, and environmental impact?"	TUD	Expert’s lecture lasts 30 min	
Content part 1	Fundamental principles of traditional and optimised fermentation, and safe & sustainable production practices	TUD, MINHO	30 min	1. FOOD FERMENTATION EUROPE; EFSA; GOOD FOOD INSTITUTE: Understanding optimised fermentation/ Link 1 2. European Commission, Eur-Lex, European Union Law: Key Principles of Safe & Sustainable by Design (SSbD) in Optimised Fermentation/Link 2 3. European Comission; EU’s Novel Foods Regulation (EU Regulation 2015/2283): Frameworks and standards for responsible production/Link 3
Content part 2	Safety and risk assessment of optimised fermentation products	USAMVCN	30 min	1. European Food Safety Authority (EFSA): Understanding safety protocols in optimised fermentation process/Link 4 2. EFSA's risk assessment procedures/ EFSA’s scientific publications: Risk Assessment Methodologies/ Link 5 3. Novel foods regulation: Consumer safety and public perception/ Link 6

Activity based content – aiming systems approach, identify the problem	Activity/Case-study 1	USAMVCN, TU Dublin	activity's core duration: 30 min	Identify alternative microbial-derived protein sources (biomass fermentation) to conventional ones. e.g. mycoproteins/single-cell proteins to vegetal/animal origin proteins. Discuss the challenges of cultivated meat production.
Content part 3	Existing eco-designed food packaging materials. Pros and cons	USAMVCN	30 min	1. Several resources 2. Quorn mycoprotein: Microbial derived protein/Link 7 3. Good Food Institute 4. Isomerase: Microbial natural products/ Link 8
Activity based content – aim to bring solutions	Activity/Case-study 2	MINHO	activity's core duration: 30 min	Propose/describe an innovative solution for controlled fermentation-derived products from holistic perspective (applications, environmental impact, raw materials, cost etc.)
Refining solution/Concluding session	Overview of the 2 case studies/Discussions (e.g. Optimised fermentation: Balancing functionality, sustainability and cost)	USAMVCN	30 min	
Learning outcomes	1. Understand the fundamental principles of optimised fermentation, including the selection of microorganisms in producing specific food ingredients and bioreactor parameters 2. Differentiate between optimised fermentation and traditional fermentation methods/products, highlighting the technological optimization involved. 3. Knowledge of the regulatory landscape surrounding optimised fermentation products 4. Develop innovative and sustainable optimised fermentation processes. 4. Develop innovative and sustainable optimised fermentation processes.			
Assessment method	1. Group exercises (Case studies 1 and 2). 2. Multiple choice quiz/questions			

2. Module's syllabus

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Module's syllabus
Title: Optimized fermentation

General information	
Course	Optimized fermentation
Scope	Sustainability, design thinking, food biotechnology
Language	English
Evaluation	Case studies/ multiple choice questions
Holders	Dan Cristian Vodnar
Length	One day course
Didactic method	Lectures with activity-based content
Location	Online or in class or hybrid

Learning objectives

1. Understand the fundamental principles of optimised fermentation, including the selection of microorganisms in producing specific food ingredients and bioreactor parameters
2. Differentiate between optimised fermentation and traditional fermentation methods/products, highlighting the technological optimization involved.
3. Knowledge on the regulatory landscape surrounding optimised fermentation products.
4. Develop innovative and sustainable optimised fermentation processes.

Required skills

Learners need a multidisciplinary skill set, including a foundational understanding of fermentation processes (types of fermentation, microbial growth, and bioreactor operations), sustainability principles (circular economy, resource optimization, and waste-to-value systems), and the ability to assess environmental impacts (life cycle analysis, carbon footprint, and resource efficiency). Proficiency in microbiology and biotechnology is essential, particularly microbial strain selection for optimized production.
Additionally, learners should develop process design and innovation skills, including computer bioreactor monitoring, scalability considerations, and real-time data analysis. The ability to integrate functionality, sustainability, and cost in decision-making is critical, as is the capacity to analyze case studies, interpret process efficiency data, and ensure compliance with food safety and environmental regulations.

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Strong communication and interdisciplinary collaboration skills and awareness of emerging trends in green technologies, sustainable bioprocessing, and microbiology are essential. Basic knowledge of statistical methods for analyzing process efficiency and environmental impacts is also beneficial.

Subjects

Challenge-based lecture/discussion: How can we explore optimized fermentation processes to produce sustainable, nutritious, and affordable food ingredients while addressing potential challenges in resource efficiency, consumer acceptance, regulatory compliance, and environmental impact?
Teaching session 1: Fundamental principles of traditional and optimized fermentation and safe & sustainable production practices
Teaching session 2: Safety and risk assessment of optimized fermentation products
Case study 1: Identify alternative microbial-derived protein sources (biomass fermentation) to conventional ones. e.g., mycoproteins/single cell proteins to vegetal/animal origin proteins.
Teaching session 3: Existing optimized fermentation products: Pros and Cons
Case study 2: Proposing an innovative solution for controlled fermentation-derived products - a holistic perspective on applications, environmental impact, raw materials, and cost

Teaching methods

Lectures, case studies

Verification of learning

The achievement of the training objectives for Optimized Fermentation will be assessed through interactive methods, including multiple-choice questions and case study analyses. These assessments will evaluate the learners' ability to understand and apply fermentation concepts, analyze and synthesize information, and make informed decisions in scenarios that mirror real-world conditions in fermentation-based processes.
Specifically, multiple-choice questions will test foundational knowledge, while case studies will challenge learners to solve problems related to process optimization, scalability, and environmental impact. Practical exercises, such as fermentation process simulations or data interpretation, will measure their ability to effectively apply theoretical knowledge to operational contexts. These methods ensure a comprehensive evaluation of both conceptual understanding and practical skills.

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Indicative resources
- FOOD FERMENTATION EUROPE; EFSA; GOOD FOOD INSTITUTE / Understanding optimized fermentation / Link 1 - European Commission, Eur-Lex, European Union Law / Key Principles of Safe & Sustainable by Design (SSbD) in Optimised Fermentation / Link 2 - European Commission; EU's Novel Foods Regulation (EU Regulation 2015/2283) / Frameworks and standards for responsible production / Link 3 - European Food Safety Authority (EFSA) / Understanding safety protocols in optimized fermentation process / Link 4 - EFSA's risk assessment procedures/EFSA's scientific publications / Risk Assessment Methodologies / Link 5 - Novel foods regulation / Consumer safety and public perception / Link 6 - Quorn mycoprotein / Microbial derived protein / Link 7 - Isomerase / Microbial natural products/ Link 8

3. Module's content

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"Optimised fermentation process" onsite training

GEEK4Food project overview

Dan Cristian Vodnar, Adrian Martau,
Lavinia Muresan, Graham O'Neill, Claudiu Ovidiu Pop
USAMV, TUD, MINHO, LESSAFRE

info@geek4food.eu
www.geek4food.com

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Project description

- **Develop an AI-based Skills Intelligence tool** to forecast current and future green skills needs (GEEK4Food Platform).
- **Design and deliver future-focused training** for higher education and cross-sector learning to strengthen green skills.
- **Promote innovative teaching methods** and entrepreneurial education focused on green skills.
- **Support evidence-based policy actions** to drive skill development for the green transition in the food sector.

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GEEK4Food skills platform at a glance

- AI-powered platform for **tracking and developing skills** in the agri-food sector, developed by **SkyHive by Cornestone**.
- Offers **personalised learning paths** and **career opportunities**.
- Supports the shift to a **skills-based labour market**.
- Helps **employers** identify needed skills for emerging roles.
- Guides **educators** in updating training programmes.
- Provides **policymakers** with real-time labour market insights.
- **Now live across Europe**, supporting upskilling, reskilling, and career growth.

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Join the Foodathon

- 🏆 **Complete the training** and earn the chance to join the Foodathon.
- ⚡ **Challenge-based event** to put your skills into action.
- **Collaborate** with learners, trainers, mentors, and agri-food stakeholders.
- **Apply your knowledge** to real-world challenges.
- 🌍 **Create impactful solutions** for the future of the agri-food sector.

Agenda

Speakers:
Dan Cristian Vodnar, Professor
Graham O'Neill, Lecturer
Lavinia Muresan, Lecturer
Gheorghe Adrian Martau, Lecturer
Claudiu Ovidiu Pop, Invited speaker

Session	Local hour	Speaker
Challenge based lecture	09:00-09:30	Dan Vodnar
Fundamental principles of traditional and optimised fermentation, and safe & sustainable production practices	09:30-10:00	Lavinia Muresan
Break	10:00-10:10	
Safety and risk assessment of optimised fermentation products	10:10-10:40	Adrian Martau
Optimised fermentation processes - Two studies on fermentation in the Teeling Distillery	10:40-11:20	Graham O Neill
Break	11:20-11:30	
Motivational speech – LESAFFRE Fermentations	11:30-12:00	Claudiu Ovidiu Pop
Case study 1 or 2	12:00-12:30	Group work
Q&A	12:30-13:00	Dan Vodnar Lavinia Muresan
Assessment through multiple quiz questions		Adrian Martau

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Our partners

Associated partners


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Challenge based lecture
Session 1:
SkyHive
DUBLIN
ICC


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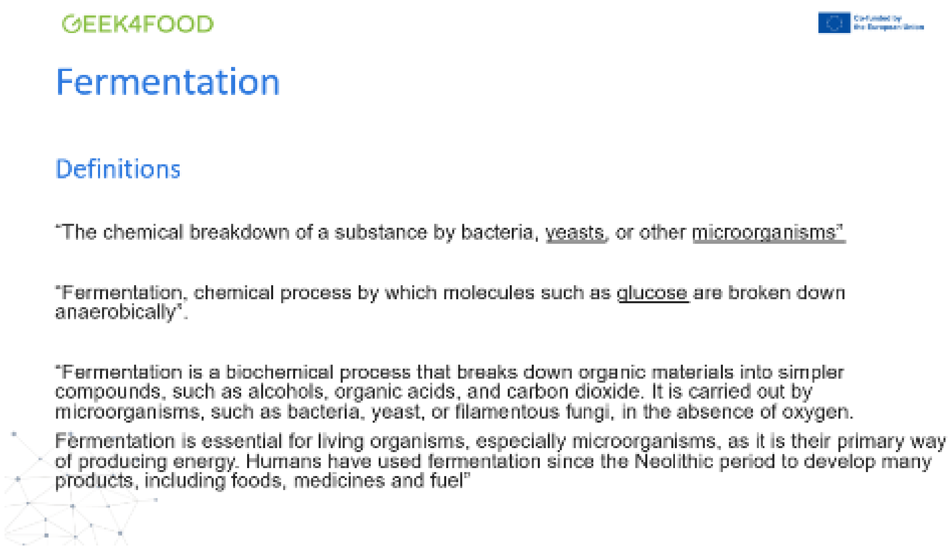
Question
Briefly explain fermentation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Fermentation
Definitions
"The chemical breakdown of a substance by bacteria, yeasts, or other microorganisms"
"Fermentation, chemical process by which molecules such as glucose are broken down anaerobically".
"Fermentation is a biochemical process that breaks down organic materials into simpler compounds, such as alcohols, organic acids, and carbon dioxide. It is carried out by microorganisms, such as bacteria, yeast, or filamentous fungi, in the absence of oxygen.
Fermentation is essential for living organisms, especially microorganisms, as it is their primary way of producing energy. Humans have used fermentation since the Neolithic period to develop many products, including foods, medicines and fuel"

Question

Name / discuss examples of fermentation in foods

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Fermentation – Cheese

Role – acid production and flavour production

Steps

1. **Inoculate**: Lactic acid bacteria and rennet are added to milk in a vat.
2. **Curdle**: The lactic acid and rennet cause the milk to curdle, separating the curds and whey.
3. **Drain**: Excess liquid is drained away.
4. **Salt, press, and ripen**: The cheese is salted, pressed, and ripened

Did you know – during ripening, bacteria, yeast and fungi can play a critical role in flavour development in cheese. Furthermore, the microorganisms are often location specific, giving rise to unique flavour profiles. Check out the paper for more information.

https://www.sciencedirect.com/science/article/pii/S0958694615001892

Fermentation in action

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Fermentation – Bread

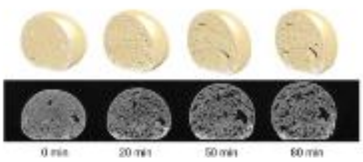
Role – Carbon Dioxide production

Fermentation is a biological process that occurs in bread dough when yeast and other microorganisms consume sugars and produce carbon dioxide and other compounds.

This process causes the dough to rise, contributing to the texture of the bread. Furthermore, it contributes characteristic flavor.

https://www.sciencedirect.com/science/article/pii/S266592712300047#sec3

Fermentation in action



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Question

How can fermentation help in producing more sustainable and nutritious ingredients?

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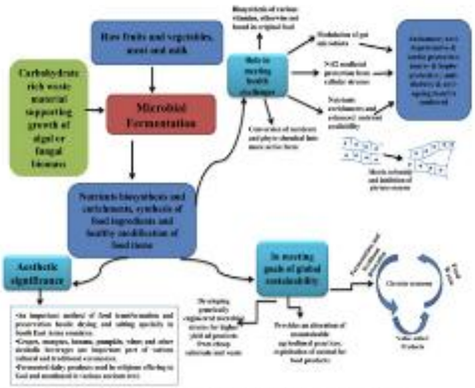
Discuss this diagram and consider the potential of fermentation.

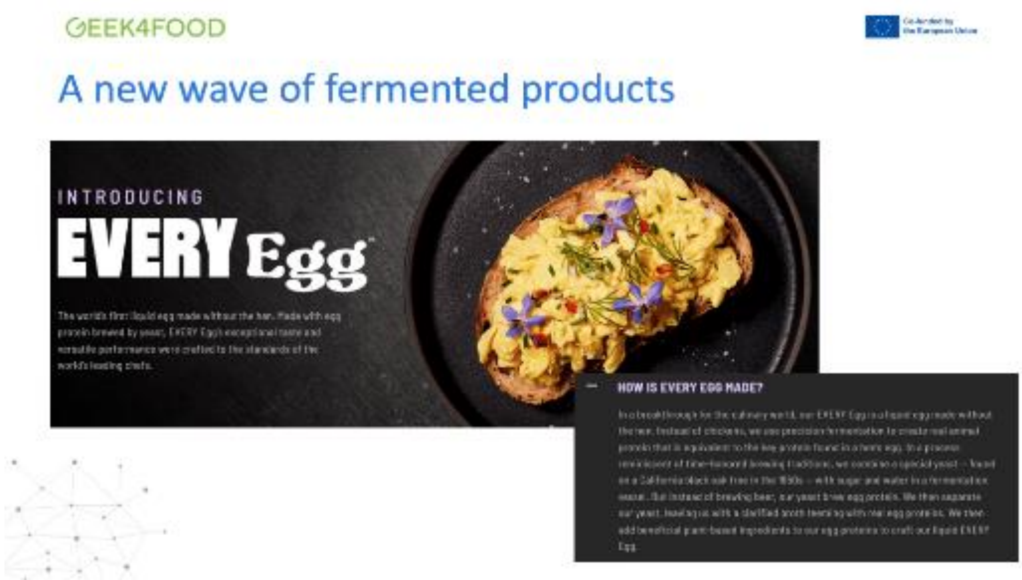
Consider
- Fermented foods and health
- Fermented foods and the microbiome.
- Fermentation as a tool in valorization.



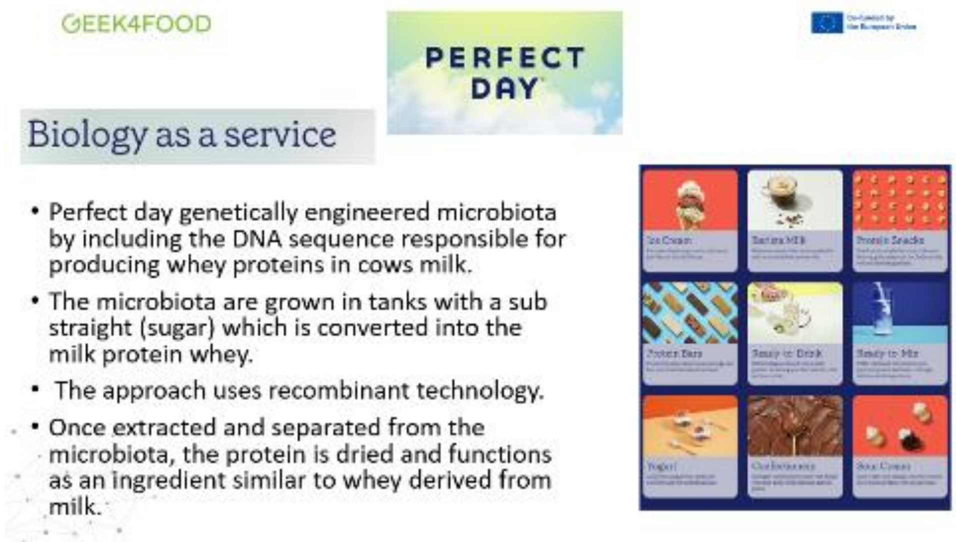
https://www.sciencedirect.com/science/article/pii/S0168160522001374#f0005

Question

Are you familiar with companies using fermentation to develop a new range of food products.


GEEK4FOOD
A new wave of fermented products
INTRODUCING
EVERY Egg
HOW IS EVERY EGG MADE?


GEEK4FOOD
REAL ANIMAL PROTEIN WITHOUT THE ANIMAL
The world's first animal-free egg white protein that is nature-equivalent to chicken egg white protein - enabling a transition to sustainable, animal-free products without compromise in taste or functionality.
FUNCTIONS LIKE AN EGG
Just like a chicken egg white, EVERY EggWhite™ has similar protein content and all nine essential amino acids. It delivers on foaming, whipping, gelling, and binding capabilities and can easily be used as a 1:1 replacement across many of the same applications one would use eggs in: cakes, cookies, bread, protein bars, plant-based meats, pasta, and more.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PERFECT DAY
Biology as a service
• Perfect day genetically engineered microbiota by including the DNA sequence responsible for producing whey proteins in cows milk.
• The microbiota are grown in tanks with a sub straight (sugar) which is converted into the milk protein whey.
• The approach uses recombinant technology.
• Once extracted and separated from the microbiota, the protein is dried and functions as an ingredient similar to whey derived from milk.


GEEK4FOOD
Optimised fermentation process
Session 2:
Fundamental principles of traditional and optimised fermentation, and safe & sustainable production practices
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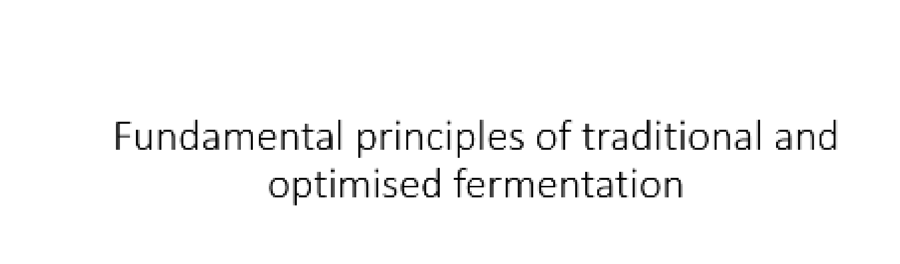
Fundamental principles of traditional and optimised fermentation


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Fermentation
Traditional Fermentation
Shaped by natural processes with minimal input or control from the operator. Examples would include traditional farmhouse cheeses or homemade sauerkraut.
Optimised fermentation
Often conducted in a bioreactor to give a higher level of control and precision over the environment (temperature, pH, light, atmosphere), leading to a more consistent product. The use of filters prevents contamination and precise control allows scale up of production.

Use of cultures – from wild to pure (1/2)

- Microorganisms are the powerhouse of fermentation.
- Traditionally wild cultures would have played a significant role in the fermentation of different foods.
- Less prevalent today, however, some products such as sauerkraut rely on cultures present on the cabbage while certain types of cheeses, such as those matured in caves rely on wild cultures for flavour development. Lambic beer is naturally fermented using wild yeasts
- In recent decades there has been a move towards more specific strains for fermentation, the reasons very but include flavour profile, speed and product attributes. saccharomyces cerevisiae is commonly used in beer production while Lactobacillus bulgaricus and Streptococcus thermophilus are commonly used in yoghurt.

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Use of cultures – from wild to pure (2/2)

Cell activities are critical to the successful completion of fermentation, these include;

Anaerobic metabolism;

- Occurs in the absence of oxygen, microorganisms such as yeasts and bacteria breaking down organic compounds such as carbohydrates.

Glycolysis

- The production of pyruvate following the breakdown of glucose

Pyruvate Conversion

- The conversion of pyruvate into different end products including; ethanol, lactic acid or organic acids (propionic acid, butyric acid)

NAD+ Regeneration

- When NAD+ is converted to NADH as part of fermentation (glycolysis), it needs to be converted back to NAD+ to continue fermentation.

Yield (Energy).

- Fermentation is less efficient than aerobic respiration.

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Environmental Control

Cultures have optimum ranges for a series of environmental conditions, providing these conditions increases fermentation rate and output.

Light

- Important to microalgae who require a light source to photosynthesis.

pH

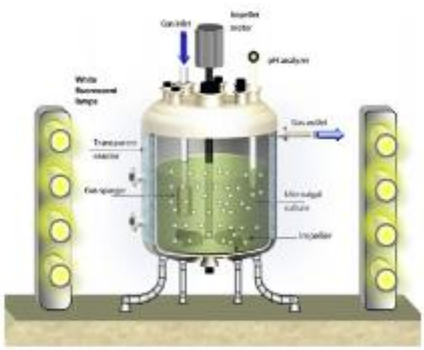
- Cultures have an optimized pH range for metabolism. Outside of this range is potentially detrimental to the culture and can therefore significantly slow or halt fermentation. Bioreactors often have pH probes built in.

Temperature

- Cultures can become heat stressed, leading to possible by products, reduced fermentation rate or cell death. Reactors are often jacketed to control temperature to one degree °C

Dissolved oxygen

- Many bioreactors monitor for dissolved oxygen and carbon dioxide to ensuresufficent levels for respiration and to avoid toxicity. This can be controlled by bubbling in the required gas via a sparge ring.



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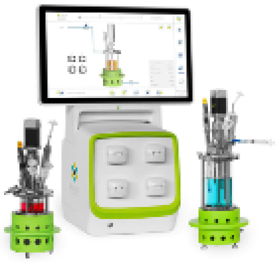
Enhanced process efficiency

The use of fermenters equipped with sensors, probes, cell counting functionality and aseptic addition of growth media helps to provide the perfect environment.

This leads to;

- Increased yield
- Decreased fermentation time
- Optimised substrate use.
- Minimise contamination



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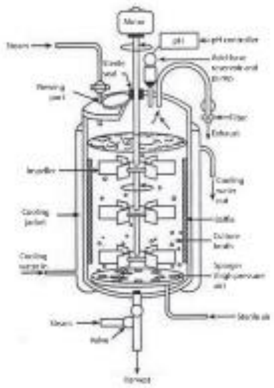
Bioreactors



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Downstream processing

Downstream can improve functionality and add value

Filtration

- Microfiltration, nanofiltration and ultrafiltration can all be achieved using membrane technology. This allows different fractions to be separated based on molecular weight.
- Reverse osmosis can be used to remove or alter the mineral profile of liquid formulations.

Centrifugation

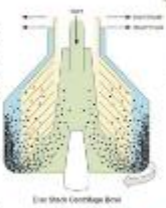
- Can separate different products from fermentation based on their densities. It can remove solid particles for clarification, isolation of lipid fractions.

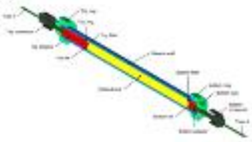
Extraction

- This can include physical disruption of cells to release valuable components. It often includes other technologies such as adsorption methods, evaporation and filtration.

Purification

- Used to optimize functionality and therefore increase value, purification can be achieved in a series of ways including chromatographic approaches, precipitation, freeze drying and crystallization.





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Scale up

- Process design – allow for differences in scaling; mixing, aeration, heat transfer as they do not scale in a linear manner. Larger fermenters can have mixing dead zones while cooling systems become more important at scale.
- Mass and Heat transfer – consider oxygen transfer and CO2 removal rates.
- Bioreactor design – select appropriate type (stirred, air lift) and its ability to scale, can help with flow dynamics.
- Microbial considerations – nutrient distribution, strain performance at increasing volume and strict SOP for

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Applied Biotechnology

- Genetic engineering, metabolic engineering, and synthetic biology are used to design better microbes for specific products.
- Enzyme optimization and metabolic pathway modifications improve yields
- Improved Strain Development – genetic engineering, Metabolic Engineering
- Industrial Enzyme Production – amylases, proteases.
- Microbial fermentation produces biodegradable plastics like polyhydroxyalkanoates (PHA) and polylactic acid (PLA).
- Flavor and Additives: Production of food-grade flavor compounds and additives through microbial fermentation. Example: Biotechnological production of citric acid using Aspergillus niger

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Safety in fermentation

1. Personal Safety
   1. Use of containment measures (Biosafety cabinet)
   2. Sterilization procedures – effective CIP
   3. Active monitoring – build up of hazardous gases.
   4. Appropriate PPE.
   5. Sufficient training
2. Environmental Safety
   1. Containment of GMO's if in use.
   2. Waste management
   3. Emissions control.
3. Product Safety
   1. Quality control – testing for possible contaminants.
   2. Assurance of sterile conditions.
   3. Regulatory compliance – GMP.

Sustainability in fermentation

- Sustainable Feedstocks
- Energy Efficiency
- Water Management
- Waste Reduction and Management
- Carbon Footprint Reduction
- Use of Biodegradable Products
- Process Optimization and Green Technology
- Regulatory and Social Responsibility

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Optimised fermentation process

Session 3:

Safety and risk assessment of optimised fermentation process

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Agenda

1. Key concepts in fermentation
2. Introduction to process efficiency
3. Regulatory considerations in fermentation
4. Framework for process optimization and sustainability

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1. Key concepts in fermentation

Definition: Controlled use of microorganisms to produce sustainable and nutritious food or food ingredients.

Goal: Address sustainability, affordability, and safety while minimizing environmental impact.

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Key concepts in fermentation

1. Selection strains
2. Fermentation substrates
3. Types of fermentation processes
4. Supply chain in fermentation
5. Contamination risks

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1. Strains selection

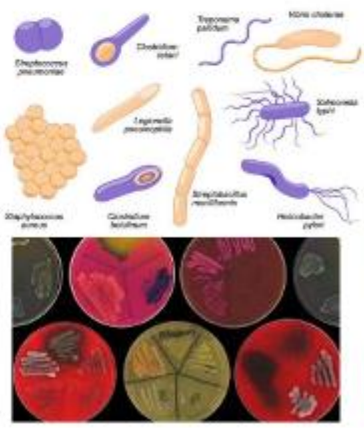
Microbial Strains
Microbial strains are specific types of microorganisms used in fermentation, influencing the quality and characteristics of the final product.

Types of Microbial Strains
Fermentation employs bacteria, yeast, or fungi, such as *Lactobacillus* for lactic acid fermentation and *Saccharomyces cerevisiae* for ethanol production.

Selection Criteria for Microbial Strains
Strains are chosen for their efficiency, tolerance to environmental factors, and high production yields.

Role in Fermentation
Microbial strains transform substrates like sugars into valuable products such as ethanol, organic acids, or bioactive compounds.

Regulatory Limits
The use of microbial strains is governed by EFSA or FDA guidelines to ensure safety and compliance.



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2. Fermentation substrates

Importance

The substrate (e.g., sugar, fruit pulp, or agricultural by-products) feeds the microorganisms.

Safety risks

Potential contaminants, such as pesticides, heavy metals, or mycotoxins.
Allergenic raw materials that could transfer risks to the final product.

Control measures

Pre-screening and pre-treatments of the substrates for purity and safety.
Using sustainable and traceable supply chains for raw materials.

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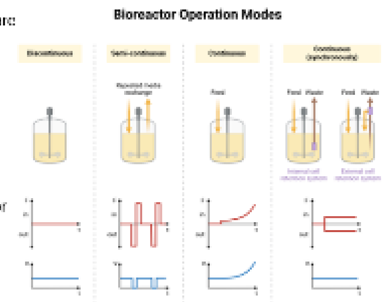
3. Types of fermentation processes

Batch fermentation: safer and easier to control contamination risks (a discontinue process)
Feed-batch fermentation: a semi continuous process where nutrients are added during fermentation, optimizing growth and yield
Continuous fermentation. higher efficiency but greater contamination risk.

Submerse fermentation: (probiotic, etc, in liquid media)
Solid-state fermentation: minimal water use but requires strict contamination control.

Risk Factors
Suboptimal conditions (e.g., pH, temperature) that allow contamination or toxin formation
Open-system processes prone to external contamination.

Control Measures
Real-time monitoring of key parameters (pH, temperature, oxygen).
Use of automated and closed systems to limit external risks.



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4. Supply chain in fermentation

Risk factors
- Improper storage leading to microbial or chemical degradation
-gaps in documentation affecting traceability during recalls

Control measures
traceability systems for all materials
supplier audits and compliance with international safety standards

Ensuring traceability of raw materials, microbial strains, and process conditions.
Managing storage and transportation to prevent contamination.

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5. Contamination risks

Sources

Raw materials, environmental exposure, equipment, or operator errors.
Formation of harmful by-products (e.g., biogenic amines, off-flavors).

Impact

Health risks, regulatory non-compliance, or product recalls.

Mitigation

Implementation of Hazard Analysis and Critical Control Points (HACCP).
Cleaning and sterilization protocols for equipment.

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2. Introduction to process efficiency

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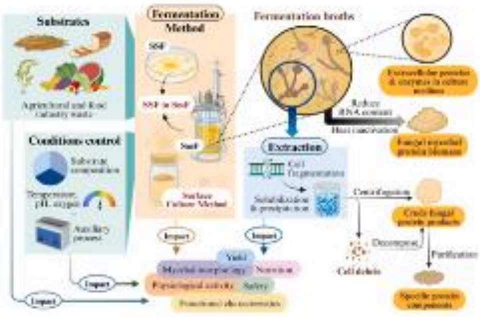
Process efficiency refers to the ability to maximize the desired output while minimizing the use of resources (e.g., energy, raw materials, water) and reducing waste during the fermentation process.

It involves optimizing conditions to achieve high yields, minimize time, and ensure sustainable practices in the production of fermented food ingredients.



Source: https://doi.org/10.1016/j.tifs.2023.104178

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Key aspects of process efficiency – Resource optimization

Raw material utilization

Efficient use of fermentation substrates (e.g., sugars, starches, or agricultural by-products) to ensure minimal waste and maximum conversion into the desired product.

Water and energy management

Reducing energy consumption and water usage during fermentation by using technologies like energy recovery systems, temperature control, and water recycling.

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Key aspects of process efficiency – Time efficiency

Fermentation rate

Optimizing fermentation time by controlling variables such as temperature, pH, and microbial strain activity to ensure faster processing times without compromising product quality.

Continuous vs. batch fermentation

Selecting the appropriate fermentation system (batch or continuous) based on desired production rates, product consistency, and operational costs.

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Key aspects of process efficiency – Microbial strain optimization

The selection of efficient and robust microbial strains that can tolerate stress (e.g., high ethanol, acidity) while maintaining high productivity levels. Strain optimization helps reduce process time and increase yield.

Genetic Engineering

In some cases, using genetically modified organisms to enhance microbial productivity and strain efficiency, though this requires careful regulatory compliance.

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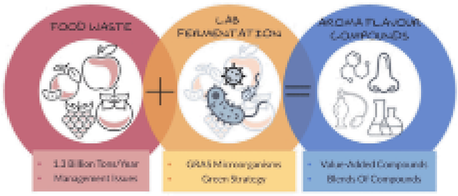
Key aspects of process efficiency – Waste minimization

By-product management

Efficient management and utilization of by-products (e.g., fermentation residuals, spent grains, or biomass) to minimize waste and possibly recycle them into other valuable products (e.g., animal feed, biofuels, or fertilizers).

Circular economy

A circular approach within fermentation processes aims to close the loop by reusing and recycling materials and energy.



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Importance of process efficiency

Cost reduction

By minimizing raw material usage, reducing fermentation time, and optimizing energy consumption, companies can significantly reduce production costs, making fermented products more affordable.

Sustainability

Efficient fermentation processes are key to reducing the environmental impact of food production. This includes minimizing the carbon footprint, reducing waste, and using renewable resources.

Scalability

Optimized processes enable scaling up production without a corresponding increase in resource usage, allowing for large-scale production that remains cost-effective and sustainable.

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Challenges in achieving process efficiency

Variable raw material quality

The quality of raw materials can fluctuate, affecting the consistency and yield of the fermentation process.

Microbial contamination

Uncontrolled microbial growth can lead to suboptimal fermentation conditions and loss of product quality, making strict hygiene and sterilization protocols essential.

Technological constraints

Not all fermentation systems are designed for large-scale applications, which may limit process efficiency when transitioning from laboratory to industrial-scale production.

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3. Regulatory considerations in fermentation

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EU Regulatory Framework

Regulations for food safety – *General Food Law Regulation* (Regulation EC No 178/2002), which ensures traceability, risk management, and consumer safety throughout the supply chain.

Authorization of novel foods – *Novel Food Regulation* (EU 2015/2283) – pre-market authorization to ensure safety for human consumption and adherence to ethical standards.

Microbial strains approval – regulated under the *EFSA Guidelines*. Only strains classified as Qualified Presumption of Safety (QPS) by the European Food Safety Authority (EFSA) can be utilized without further assessment.

Labeling requirements – *Food Information to Consumers Regulation* (EU No 1169/2011) – proper labeling of ingredients, nutritional value, allergens, and health claims, ensuring transparency for consumers.

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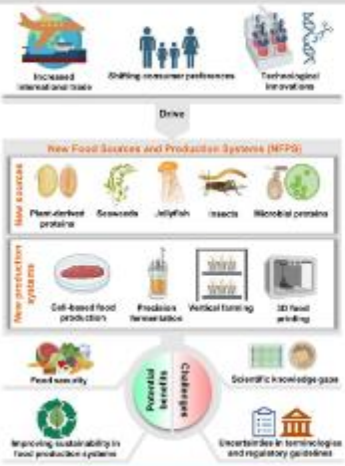
EU Regulatory Framework

Hygiene and Good Manufacturing Practices (GMPs) – The *Hygiene of Foodstuffs Regulation* (EC No 852/2004) mandates that fermentation facilities follow GMPs and Hazard Analysis and Critical Control Points (HACCP) principles to minimize contamination risks.

Use of Additives in Fermentation – *Regulation* (EC No 1333/2008) on food additives.

Environmental Impact Regulations – *Regulation* (EU) No 995/2010.



Source: https://doi.org/10.1111/1541-4337.13341

4. Framework for process optimization and sustainability

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Adoption of sustainable practices

- reducing waste, utilizing renewable resources, and improving energy efficiency

Integration of Advanced Technologies

- automation, artificial intelligence (AI), and Internet of Things (IoT) devices can monitor and control critical parameters like temperature, pH, and oxygen levels in real time

Use of Life Cycle Assessment (LCA)

- allows manufacturers to evaluate the environmental footprint of their processes

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Improvement of microbial strain performance

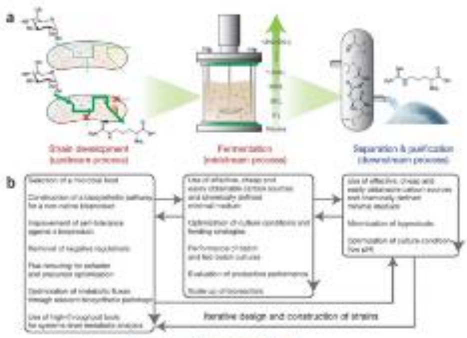
- strain optimization through genetic engineering or adaptive evolution can further enhance productivity and sustainability

Energy optimization

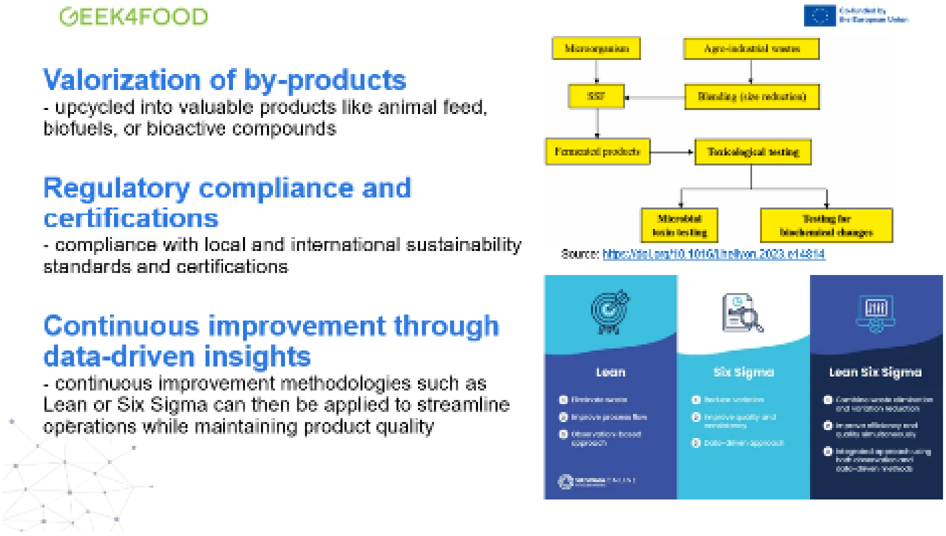
- employing energy-efficient equipment and renewable energy sources can significantly reduce carbon emissions and operational costs

Water recycling and management

- implementing water recycling systems ensures minimal freshwater use, reducing the environmental burden and operating expenses



Source: https://doi.org/10.1038/nbt.3365



Optimised Fermentation

Two studies on fermentation in the Teeling Distillery


Introduction
DUBLIN
Dr Graham O'Neill
Food Scientist
Head of Food, Environmental Health & Safety


Distilleries in Ireland – The future is bright
DUBLIN
TEELING WHISKEY
JAMESON DISTILLERY MIDLETON
WEST CORK DISTILLERS
BUSHMILLS
GLENDALOUGH DISTILLERY
BOANN DISTILLERY
CHURCH OF OAK
CONNACHT
MIDLETON
DINGLE DISTILLERY

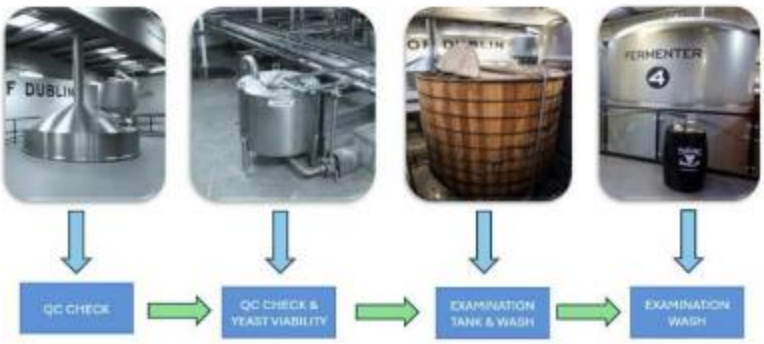

Whiskey production
DUBLIN
WHISKEY PRODUCTION PROCESS
Whiskey Making Essentials
Whisky
PRODUCTION PROCESS

Wooden wash back tank analysis – the role of bacteria

Teamwork

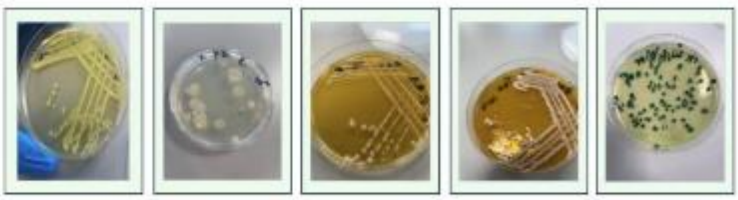
Teeling

Process



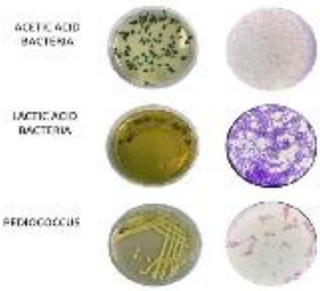
Agars used for initial studies

AGAR PORTFOLIO SPECIALLY SELCTED FOR OUR STUDY



Nutrient Agar — Potato Dextrose Agar — M.R.S. Agar — Raka- Ray Agar — W.L. Differential Agar

Initial identification



Common bacteria

- Acetic acid bacteria
- Lactic acid bacteria
- Pediococcus

Genomic analysis 1/2

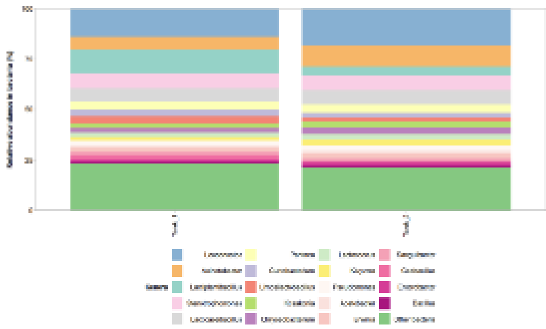


Fig 7: Top bacteria present in the washback tank organised by genera

Genomic analysis 2/2

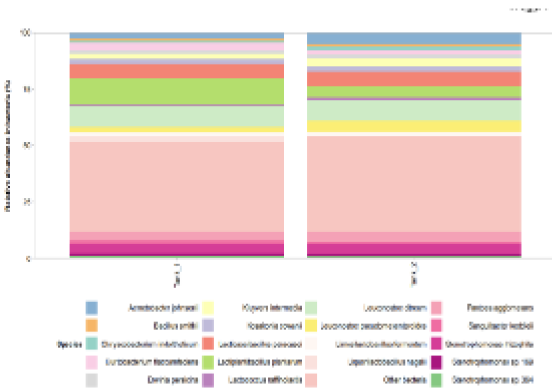


Fig 8: Top bacteria present in the washback tank organised by species

Wood v Steel tanks

Table 1: Physicochemical characterisation of fermentation samples from 0, 24, 48, 72 and 96 hours in wooden and stainless steel tanks.

	Steel				Wooden			
	T0	**T24**	**T48**	**T72**	**T0**	**T24**	**T48**	**T72**
pH	6.1	4.6	4.6	3.8	6.1	4.5	4.8	4.4
ABV % V/V	0.0	3.3	6.5	6.1	0.0	3.5	5.8	6.3
Conductivity (uS)	4.0	293.9	402.6	1269.9	3.8	163.8	1003.5	1239.0
Colour (L)	15.1	36.2	45.5	55.9	11.6	35.5	49.6	51.4
Colour (a)	0.1	0.1	0.8	2.1	0.3	0.3	2.7	1.1
Colour (b)	4.9	11.5	12.6	15.9	5.3	11.9	15.7	14.1

Changes in % ABV

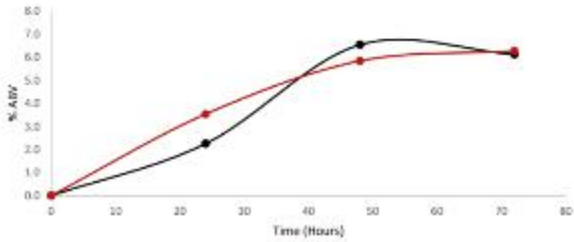
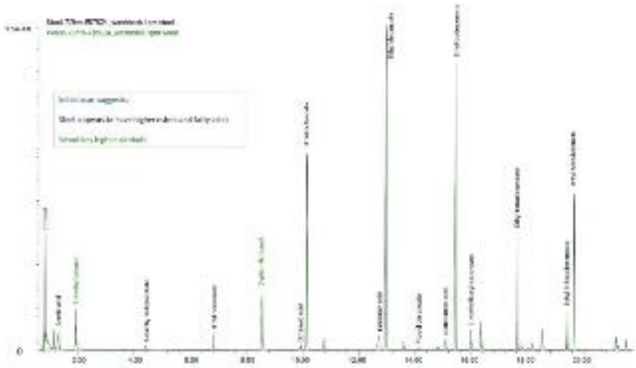


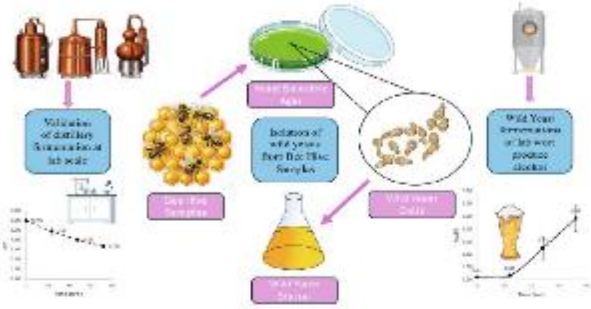
Fig 11: Change in ABV % over a 72 hour fermentation in wooden (red) and stainless steel (black) fermenters)

Changes in volatile profile



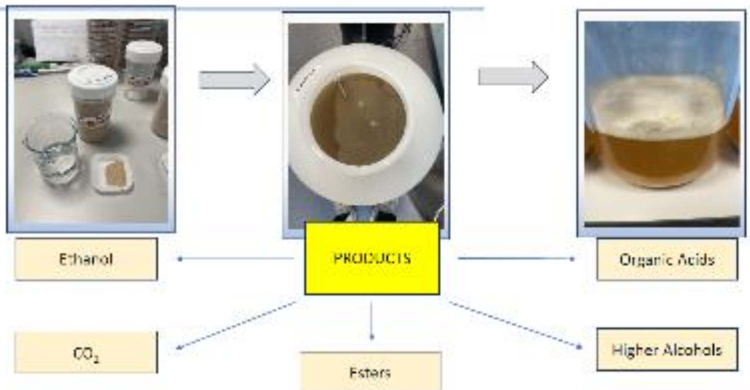
Role of wild yeast in fermentation

Introduction



Lab Scale v Production environment fermentation

The Role of Yeast in Brewing



Production process

Lab Scale v Production fermentates

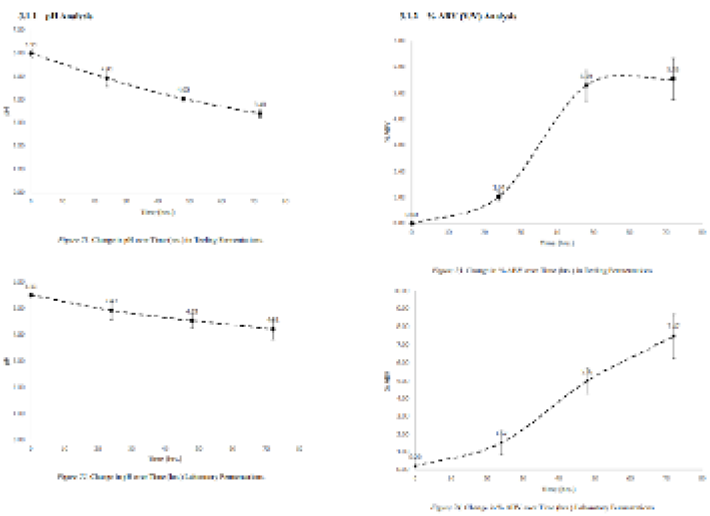


Table 7.

CIELab L, a*, b* colour analysis of wort pre fermentation*

Wort	L*	a*	b*
Teeling	13.53	-0.40	5.66
Laboratory	14.37	-0.16	9.71

Table 8.

CIELab L, a*, b* colour analysis of wort post 72 hrs. fermentation*

Wort	L*	a*	b*
Teeling	54.20	1.14	13.46
Laboratory	35.85	0.93	12.47

First Innoculation

First fermentation – no isolation

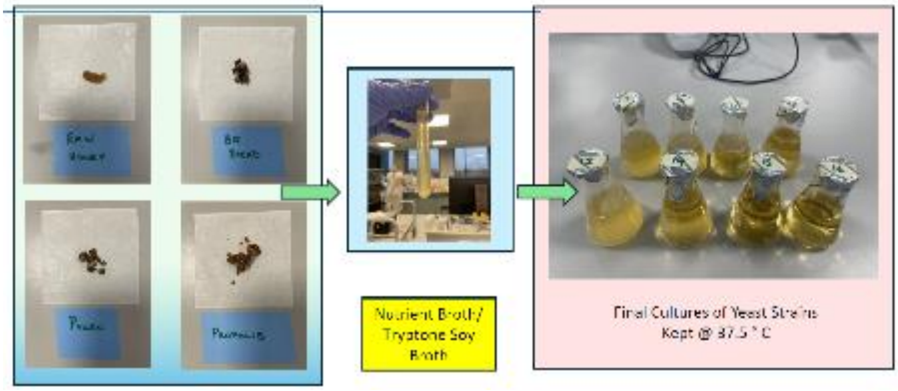
- Initial inoculation of full sample
- 4.27 % ABV In 96 hrs.
- Sensory Observations:

Aniseed
Smokey/Woody
Mixed Spice
Citrus
Honey/Caramel

Bee Hive Inoculations

TEELING WHISKEY — GEEK4FOOD — TU DUBLIN

Yeast Extraction from Honey



Bee hive sample inoculations

Individual Fermentations

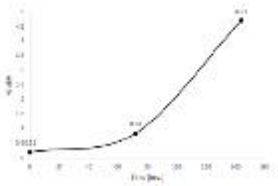
- Individual inoculations of sample:

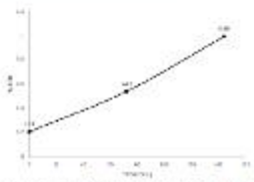
1) Raw Honey
2) Bee Bread
3) Pollen
4) Propolis

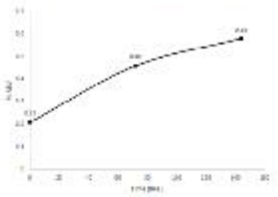
- 4.71 % ABV in 144 hrs. Raw Honey Sample
- 0.55 % ABV in 144 hrs. Bee Bread

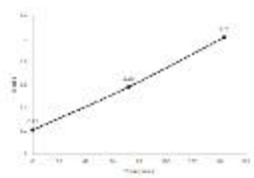
[illegible]	[illegible]	[illegible]	[illegible]
RAW HONEY	[illegible]	[illegible]	[illegible]
BEE BREAD	0.21	[illegible]	[illegible]
POLLEN	0.21	[illegible]	[illegible]
PROPOLIS	0.21	[illegible]	[illegible]

Bee hive sample inoculations







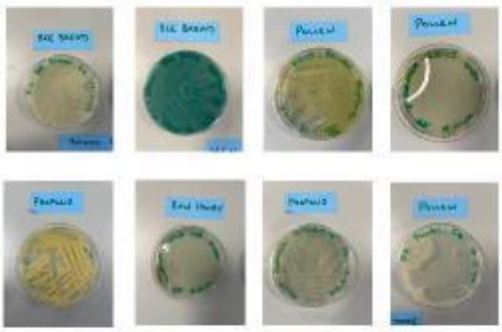


Plating for wild yeast isolation

Wild Yeast Isolation

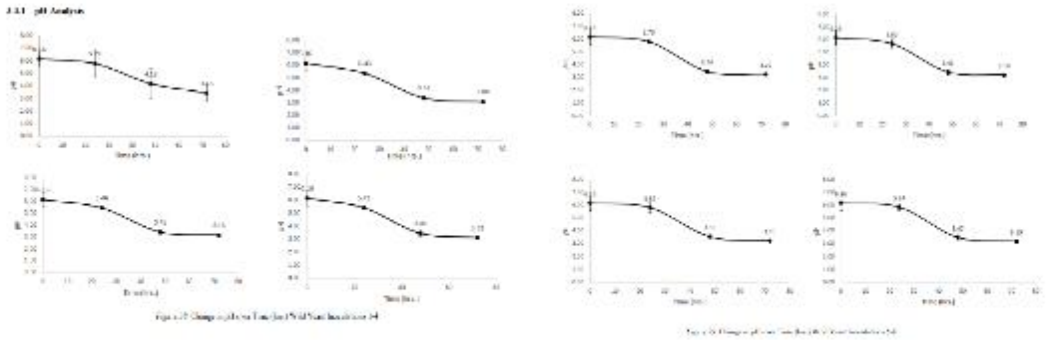
Wild Yeast No.	Biological Source	Colour	Morphology
1	Raw Honey	Teal Blue/Green	Wrinkled, Raised
2	Raw Honey	Cream, Opaque	Smooth, Oval
3	Pollen	Cream	Small, Raised Oval
4	Propolis	Dark Green	Streaky, Flat
5	Bee Bread	Translucent	Shiny, Clustered
6	Bee Bread	White	Chalky, Wrinkled
7	Pollen	Dark Green	Oval, Smooth
8	Propolis	Light Green	Speckled Streaks
9	Bee Bread	Cream	Clustered, Oval
10	Bee Bread	White	Chalky, Wrinkled
11	Pollen	Yellow/Green	Shiny, Clustered
12	Pollen	Dark Yellow	Wrinkled, Raised
13	Propolis	Bright Yellow	Wrinkled, Oval
14	Raw Honey	Translucent	Shiny Streaks
15	Propolis	Cream, Opaque	Oval, Smooth, Flat
16	Pollen	Cream	Oval, Smooth, Flat

Wild Yeast Isolations – complex streaking

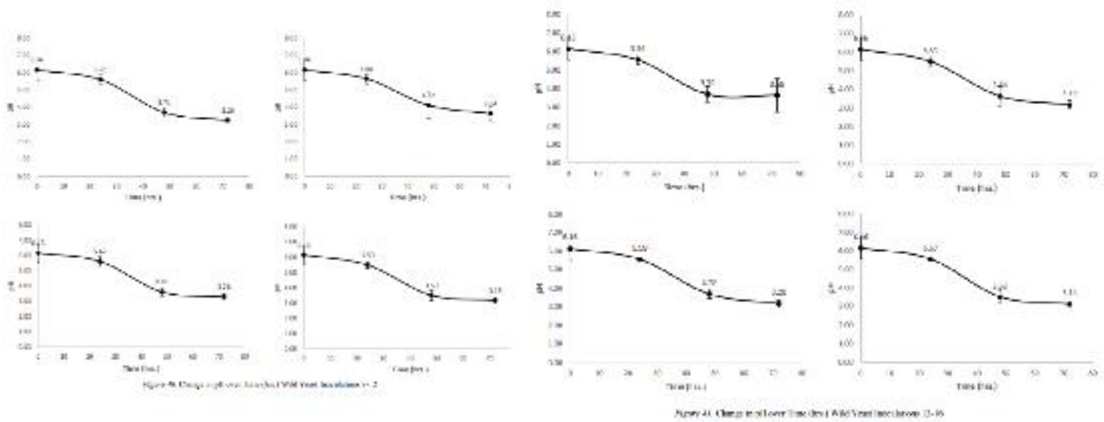


Wild Yeast Fermentation - Characterisation

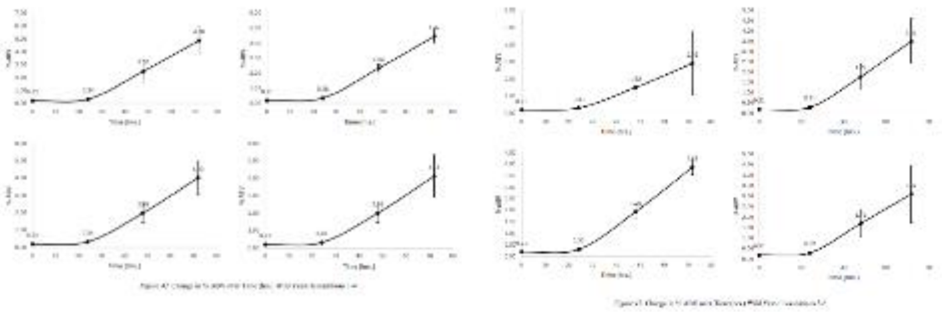
Wild yeast fermentation - pH



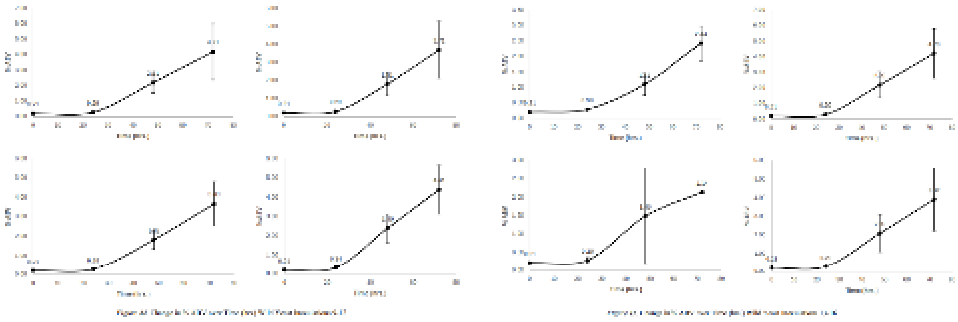
Wild yeast fermentation - pH



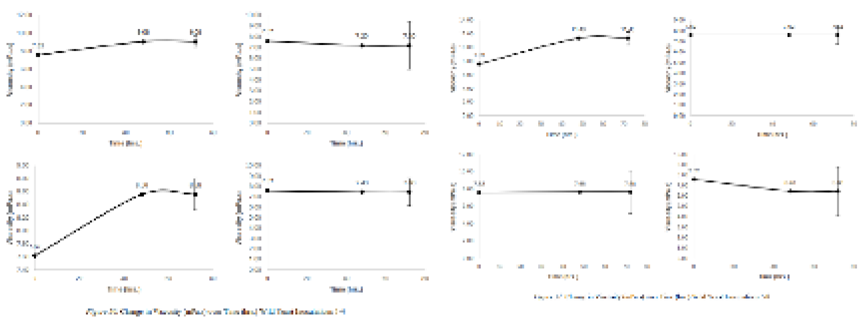
Wild yeast fermentation - %ABV



Wild yeast fermentation - %ABV



Wild yeast fermentation - Viscosity



Wild yeast fermentation - Colour

CIELab L, a*, b* colour analysis of laboratory Wort pre fermentation*

	L*	a*	b*
Wort	10.53	-0.60	7.51

Wild Yeast Inoculation	L*	a*	b*
1	29.75	-0.09	13.59
2	21.72	-0.20	9.55
3	23.90	-0.64	9.22
4	21.63	-0.15	10.83
5	18.98	-0.70	8.92
6	28.57	-0.40	9.20
7	22.37	-0.67	11.00
8	20.23	-0.52	10.37

Wild Yeast Inoculation	L*	a*	b*
9	22.16	-0.76	9.17
10	29.63	0.19	12.74
11	22.64	-0.51	10.14
12	25.71	-0.56	10.32
13	21.10	-0.85	9.11
14	24.68	-0.04	12.06
15	28.45	0.02	11.63
16	23.16	-0.14	10.68

Thank You

Questions?

Dr Graham O'Neill
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Food Scientist
Head of Food, Environmental Health & Safety

CUPRINS

- Cine suntem ?
- Dorjdie de panificatie
- Cluturi starter
- Intrebari

CINE SUNTEM ?


CINE SUNTEM ?
25
LESAFFRE
2024
Gust. Pasiune. Expertiză.
Împreună din 1999
Povestea a început în 1999, și, de atunci, am crescut constant,
devenind unul dintre liderii de piață și partener de încredere
pentru brutării, patiserii și producătorii industriali din România.
Investim constant în cercetare și dezvoltare pentru a oferi
produse și soluții de ultimă generație.
Oferim consultanță, asistență tehnică de specialitate și soluții
inovatoare, sustenabile, la cele mai înalte standarde de calitate.
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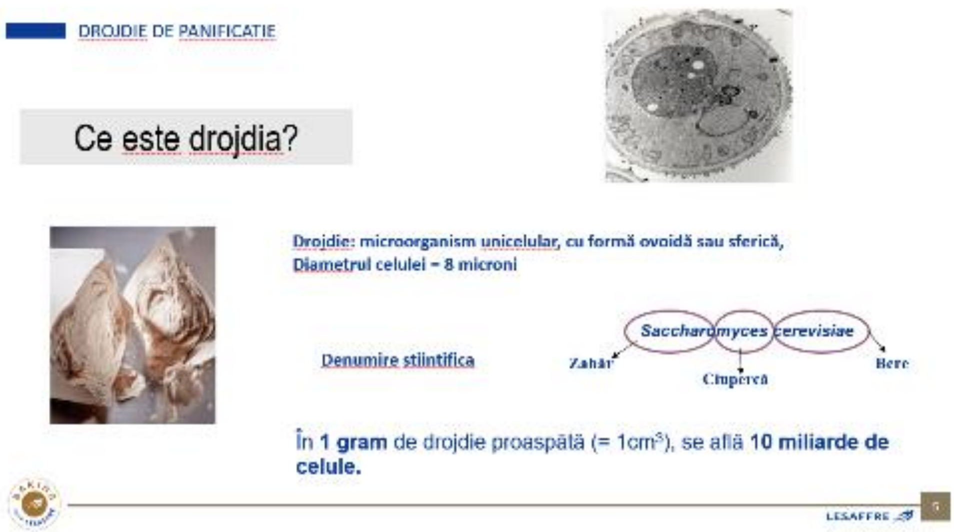
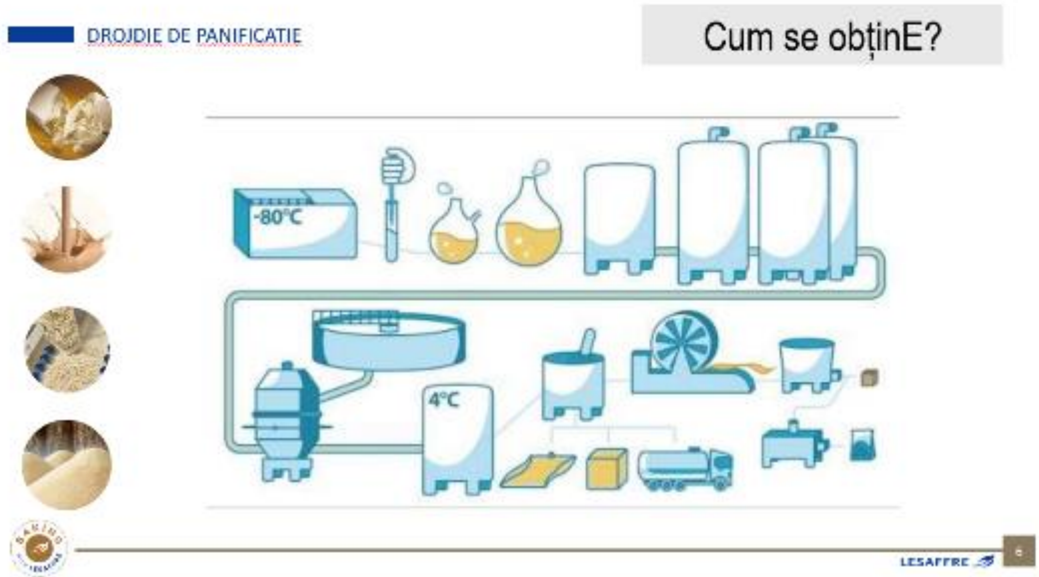

DROJDIE DE PANIFICATIE
Ce este drojdia?
Drojdie: microorganism unicelular, cu formă ovoidă sau sferică,
Diametrul celulei – 8 microni
Denumire stiintifica
Saccharomyces cerevisiae
Zahăr
Ciupercă
Bere
În 1 gram de drojdie proaspătă (= 1cm³), se află 10 miliarde de celule.
LESAFFRE


DROJDIE DE PANIFICATIE
Cum se obținE?
-80°C
4°C
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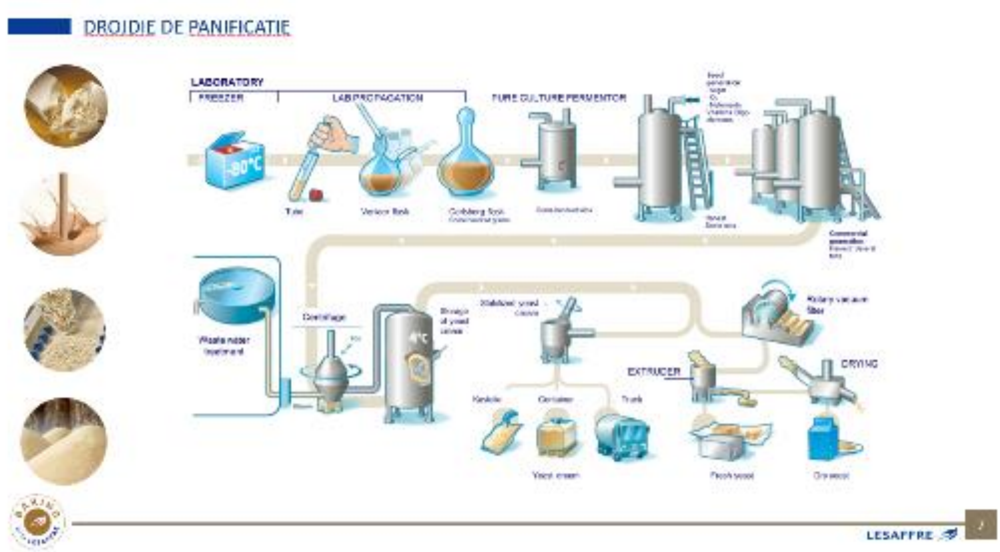
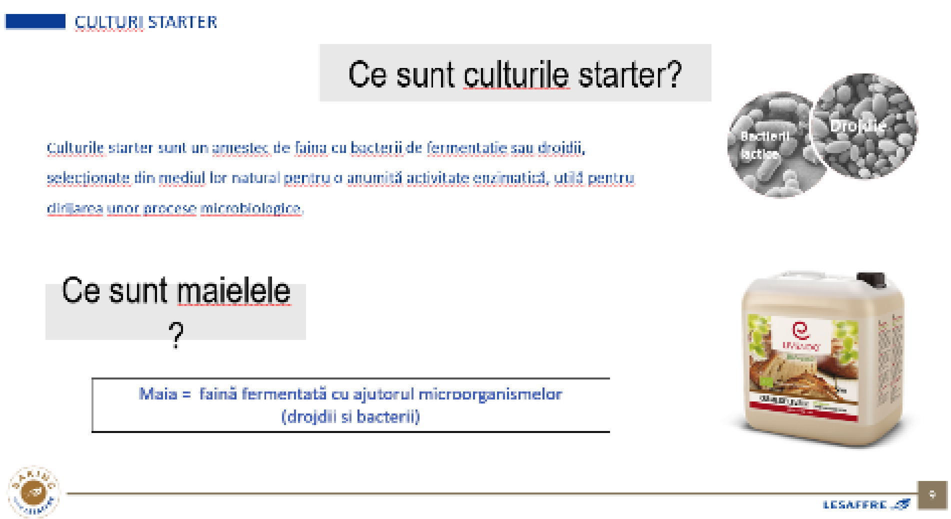

DROJDIE DE PANIFICATIE
LABORATORY
FREEZER
LAB PROPAGATION
PURE CULTURE FERMENTOR
-80°C
EXTRUDER
DRYING
LESAFFRE


DROJDIE DE PANIFICATIE
Drojdie comprimata
Utilizata in mod obisnuit de brutarii artizanali si industriali
Drojdie uscata instant
Combina usurinta in utilizare cu eficacitatea
Drojdie granulata
Potrivita pentru clientii industriali mari
Drojdie uscata
Eficienta chiar si in conditii climatice dificile
Drojdie lichida
Permite automatizare
LESAFFRE


CULTURI STARTER
Ce sunt culturile starter?
Culturile starter sunt un amestec de faina cu bacterii de fermentatie sau drojdii, selectionate din mediul lor natural pentru o anumită activitate enzimatică, utilă pentru dirijarea unor procese microbiologice.
Bacterii lactice
Drojdie
Ce sunt maielele ?
Maia = făină fermentată cu ajutorul microorganismelor (drojdii si bacterii)
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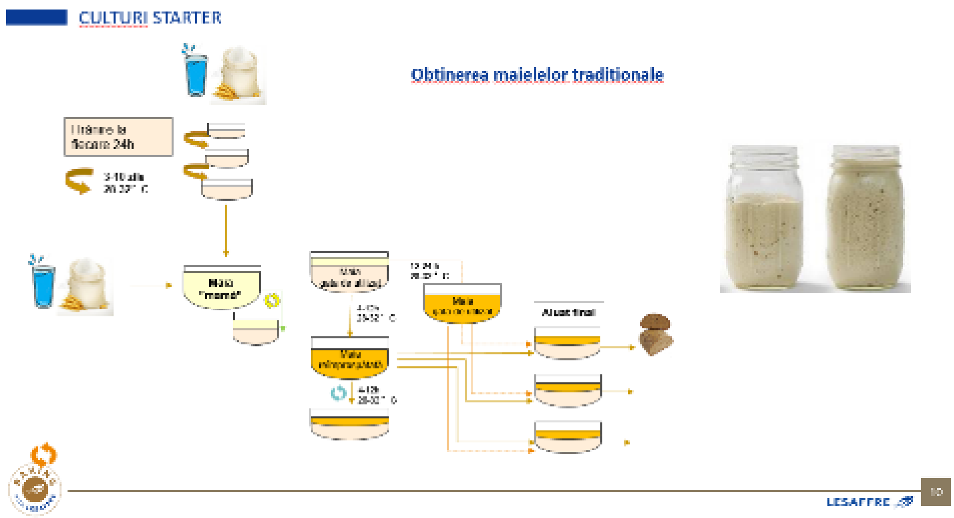
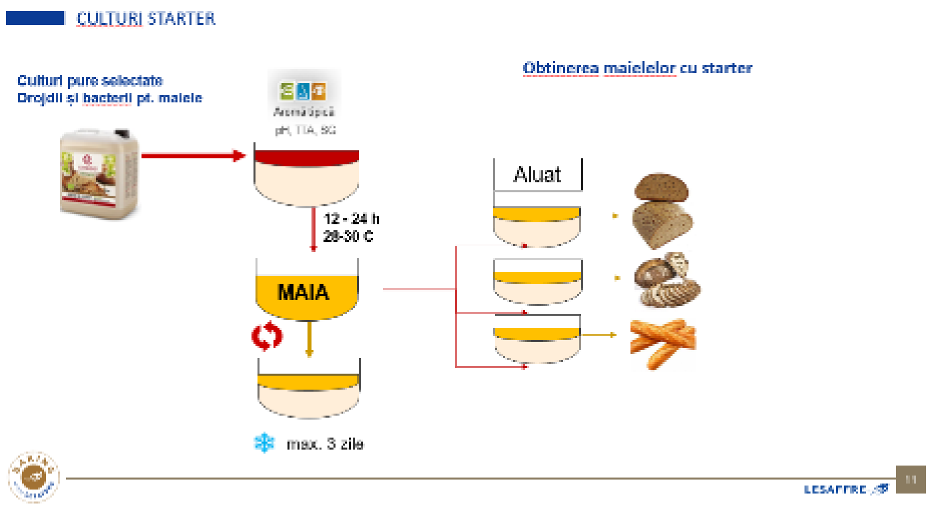
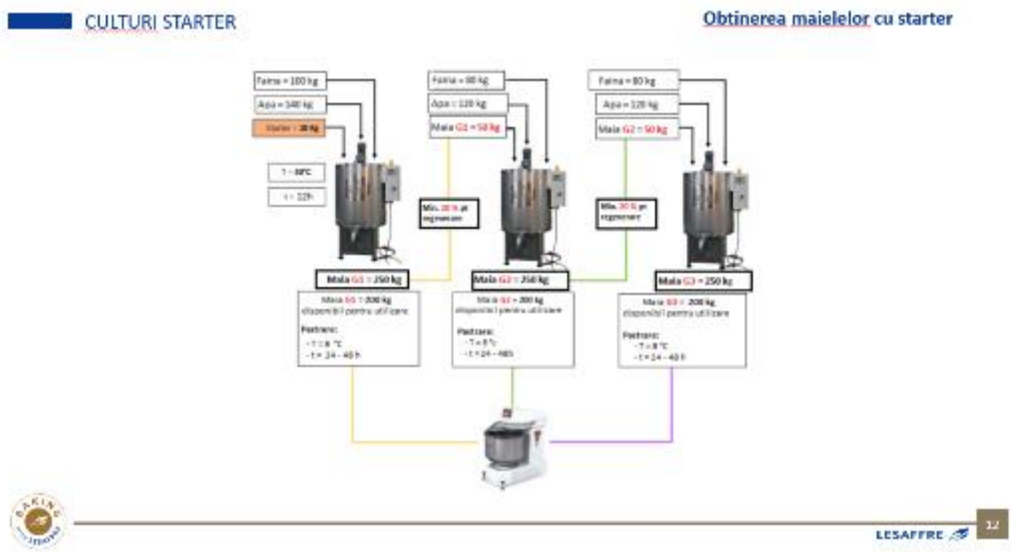

CULTURI STARTER
Obtinerea maielelor traditionale
Aluat final


CULTURI STARTER
Obtinerea maielelor cu starter
Culturi pure selectate
Drojdii și bacterii pt. maiele
12 - 24 h
28-30 C
MAIA
Aluat
max. 3 zile


CULTURI STARTER
Obtinerea maielelor cu starter


CULTURI STARTER
De ce se utilizeaza?
REOLOGIE & TEXTURĂ
Pâine cu secară, aluaturi dulci,…
AROMĂ & GUST
Folosită în pâine, patiserie, pizza, crește profilul aromatic
TERMEN DE VALABILITATE
Scăderea pH-ului, producție de acizi organici
BUNĂ STARE & NUTRIȚIE
Index Glicemic scăzut(low GI), avantaje nutriționale…
COMUNICARE / IMAGINE
Imagine tradițională și sănătoasă a produsului finit
REGLEMENTĂRI LEGALE
Mesaj pe eticheta, Marketing, aliniere cu tările care au deje o reglementare
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INTREBARI
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THANK YOU!

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Assessment questions

Practicality and scalability
How can advanced fermentation technologies (e.g., batch, feed-batch, continuous) and automation improve scalability and maintain efficiency across various applications?

Regulatory and logistical barriers
What are the key regulatory and logistical challenges in implementing optimized fermentation processes, and how can they be overcome to ensure safety and compliance?

Consumer trends and expectations
How can optimized fermentation align with consumer trends for sustainability and natural products while addressing concerns about safety and cost?

Environmental impact and circular economy
How does optimized fermentation contribute to reducing resource use and emissions while promoting circular economy principles in various industries?

Cost considerations
What are the cost advantages of optimized fermentation compared to traditional methods, and how can manufacturers ensure economic feasibility and ROI?

Technical and process efficiency
How do advancements in microbial engineering, real-time monitoring, and process automation enhance the efficiency and consistency of optimized fermentation processes?

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Multiple choice quiz

1. Which of the following fermentation processes is considered the most efficient but has a higher risk of contamination?
a) Batch fermentation
b) Feed-batch fermentation
c) Continuous fermentation
d) Solid-state fermentation

2. What is the main advantage of using food waste as a substrate in fermentation?
a) It eliminates the need for microbial strains.
b) It reduces greenhouse gas emissions and landfill waste.
c) It increases fermentation speed.
d) It makes bioreactors unnecessary.

3. Which of the following is an example of a product made using fermentation?
a) Bread
b) Yogurt
c) Vinegar
d) All of the above

4. What is a bioreactor used for in fermentation?
a) Mixing chemicals in a factory
b) Growing and controlling microorganisms for product production
c) Filtering water in industrial processes
d) Cooking food at high temperatures

5. Which microorganism is most commonly used in fermentation?
a) Bacteria
b) Yeast
c) Fungi
d) All of the above

6. What is a key advantage of fermentation compared to chemical processes?
a) It requires less energy and uses natural processes.
b) It can only be used for beverages.
c) It creates synthetic chemicals faster.
d) It doesn't use microorganisms.

7. Why is fermentation considered environmentally friendly?
a) It eliminates the need for packaging materials.
b) It uses renewable resources like agricultural waste.
c) It doesn't produce food.
d) It requires no microorganisms.

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Activity/Case-study 1

Identify alternative microbial-derived protein sources (biomass fermentation) to conventional ones. e.g. mycoproteins/single-cell proteins to vegetal/animal origin proteins.

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Scenario

- Conventional protein sources, such as animal-based proteins (beef, poultry, and fish) and plant-based proteins (soy, peas, and beans), have long been essential in global nutrition due to their high-quality amino acid profiles and widespread availability. However, their production often leads to significant environmental impacts, including high greenhouse gas emissions, land use, and water consumption, especially in the case of animal proteins. Furthermore, the ethical and sustainability concerns surrounding industrial livestock farming have driven interest in alternative protein sources.
- Mycoproteins and single-cell proteins (SCPs), derived from fungi and yeasts, respectively, present a promising sustainable alternative. These proteins require far less land, water, and energy compared to conventional animal protein sources, and they can be grown on agricultural waste or low-value substrates, reducing food system inefficiencies. However, challenges related to scaling production, nutritional profile and consumer acceptance of these alternative proteins still need to be addressed to fully replace traditional protein sources in the diet.
- Your company, **BioProTech**, has tasked you with developing a sustainable alternative protein source to traditional animal protein sources for a client, a mid-sized food company looking to adopt eco-friendly practices. The company currently sources animal proteins, including beef, poultry, and fish, for its products, which include ready-to-eat meals, burgers, and nutritional supplements. These conventional protein sources come with significant environmental impacts, such as high greenhouse gas emissions, water consumption, and land use.

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Task Overview

Working in different teams:

1. **Analyze the suitability of animal-origin proteins and SCPs for high-protein food industry,** considering nutritional profile (e.g. high-quality amino acid profiles) and compatibility with food ingredients, dietary supplements, or high-protein foods (burgers, protein powder supplements).
2. **Evaluate the environmental impact** and **costs** of both protein sources across their lifecycle (e.g., carbon footprint, water and energy consumption).
3. **Propose an alternative-protein source** tailored to the client's needs, identifying challenges and trade-offs.
4. **Develop a transition plan** for the client, considering economic feasibility, regulatory compliance, and consumer acceptance.

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Resources to be provided to the students

- Nutritional profile for animal-origin proteins (beef meat) and SCPs (fungi).
- Summary of LCA data for beef meat and fungi SCPs.
- Case examples of companies that transitioned to fungi-derived SCPs.
- Access to online tools for calculating material carbon footprints.

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For the tutor

Discussion Points Post-Case Study

- What are the limitations of SCPs as a replacement for animal-origin proteins in food industry?
- How can advancements in food biotechnology improve the adoption of sustainable practices?
- What role do consumer perceptions play in the success of alternative protein sources (SCPs) transitions?
- This case study is designed to equip industry professionals with the skills to evaluate and implement alternative-protein sources solutions in the high-protein food products sector, supporting innovation and sustainability.

Resources to be provided to the students

1. NUTRITIONAL PROFILE FOR ANIMAL-ORIGIN PROTEINS (BEEF MEAT) AND SCPS (YEASTS).

Meat is a fundamental component of the human diet, serving as a significant source of high-quality nutrients. It is particularly valued for its rich supply of essential proteins, lipids, vitamins, and minerals, which are critical for numerous physiological processes. The macronutrient profile of meat, characterized by its high biological value proteins and varied fat content, supports tissue synthesis, metabolic regulation, and energy provision. Additionally, its micronutrient composition—specifically B-complex vitamins, iron, zinc, and selenium—plays key roles in enzymatic reactions, oxygen transport, and immune function (Table 1).

According to European legislation, meat refers to the edible parts of livestock species such as cattle, pigs, sheep, and poultry. Various factors, including animal species, breed, diet, environmental conditions, and the anatomical origin of the cut influence the nutritional attributes of meat. For instance, lean meat cuts, such as chicken breast or turkey, provide higher protein concentrations and lower lipid content, whereas fatty cuts yield greater energy density due to elevated fat levels (R. S. Ahmad, Imran, Hussain, & nutrition, 2018).

Meat Cut	Protein (g)	Sat. Fat (g)	Fat (g)	Energy (kcal)	Vit. B12 (mcg)	Na (mg)	Zn (mg)	P (mg)	Fe (mg)
Chicken breast, raw	24.2	0.2	8.5	178	0.39	71	0.9	199	1.2
Beef, steak cuts, raw	21.0	1.9	4.5	123	1.9	59	1.7	167	1.3
Chicken, raw	22.8	0.6	1.9	113	0.70	78	1.4	202	0.7
Pork, chop, raw	18.1	10.8	31.7	353	1.1	60	1.8	190	1.4
Turkey, skinless, raw	19.9	1.8	7.1	136	1.9	42	1.5	209	2.1

The amino acid profile of beef meat represents a comprehensive and bioavailable source of essential and non-essential amino acids, which are fundamental for various physiological functions, including protein synthesis, enzymatic activities, and tissue repair. ***Beef is particularly valued for its high content of branched-chain amino acids*** (such as leucine, isoleucine, and valine) that are crucial for muscle metabolism, as well as lysine and methionine, which are vital for collagen formation and metabolic processes. The precise composition and concentration of these amino acids can vary among different beef cuts, reflecting differences in muscle composition and biochemical properties, thereby influencing the meat's nutritional and functional qualities. The table below presents the amino acid composition of different beef cuts (Chuck, Round, and Loin), highlighting variations in their nutritional profiles based on dry weight measurements (Wu et al., 2016).

Table 1. Amino acid profile of beef meat

Amino Acid	Chuck (mg/g dry weight)	Round (mg/g dry weight)	Loin (mg/g dry weight)
Essential Amino Acids (EAAs)			
Histidine	29.4	31.0	31.7
Isoleucine	38.4	40.5	41.1
Leucine	61.8	65.1	66.7
Lysine	66.6	70.4	72.0
Methionine	23.7	24.8	25.3
Phenylalanine	30.9	33.1	33.5
Threonine	34.3	35.8	37.0
Tryptophan	9.34	9.77	10.0
Valine	44.8	46.9	47.4
Non-Essential Amino Acids (NEAAs)			
Alanine	42.2	44.5	45.4
Arginine	47.9	51.0	52.4
Asparagine	30.3	32.9	33.4
Aspartate	37.7	40.3	41.1
Cysteine	10.1	10.8	11.2
Glutamate	68.9	73.8	75.1
Glutamine	46.8	48.5	49.9
Glycine	31.0	33.3	33.7
Proline	30.0	31.5	32.9
Serine	32.0	34.2	35.4
Tyrosine	27.1	28.9	30.1
4-Hydroxyproline	1.73	1.74	1.77

The term ***"single cell protein" (SCP)*** is widely regarded as the most accurate descriptor, as it refers to protein produced by single-celled organisms. Yeast, for example, has been shown to be capable of ***producing approximately 250 tons of protein*** within 24 hours. The concept of SCP was first introduced in 1968 during a meeting at the Massachusetts Institute of Technology (MIT), where researchers sought to identify a more precise term to replace previously used terminology, such as "microbial protein". Various microbial species, including algae, bacteria, fungi, and yeast can synthesize SCP. In addition to its high protein content, which ranges from 60% to 82% on a dry matter basis, single cell protein (SCP) also contains carbohydrates, nucleic acids, lipids, minerals, and vitamins (Sharif et al., 2021). Yeast for example is a good choice for SCP production as it grows rapidly on different sugars-rich feedstocks. Moreover, most yeasts are safe for consumption. The most common mycoprotein product on the market, Quorn^{TM}, has been produced since 1985 following 15 years of research and development (M. I. Ahmad, Farooq, Alhamoud, Li, & Zhang, 2022). ***Fusarium venenatum***, a fungus, has been cultivated in England for more than a decade to produce mycoprotein, commercially known as "Quorn." This product boasts a fibrous texture and is an excellent source of high-quality protein, including all essential amino acids. ***Fusarium venenatum***-derived mycoprotein comprises approximately 44% protein by weight on a dry basis, and its net protein utilization (NPU) is similar to that of milk.

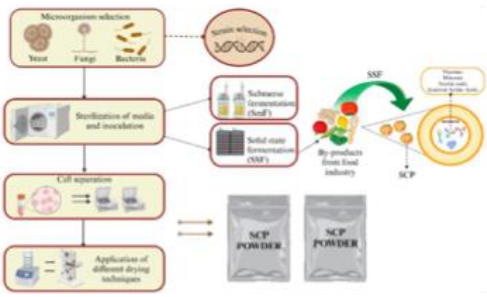

Fig 1. Schematic representation of the process for the production SCP (Source: Original)

The quantity and quality of single-cell protein (SCP) are influenced by the microorganism used and the culture conditions. For instance, ***the protein yield from microalgae can vary significantly, ranging from 30% to 80%***. SCP generally contains a higher percentage of protein compared to conventional food sources, such as soy (38.6%), fish (17.8%), meat (21.2%), and whole milk (3.28%). Table 2 presents a comparison of protein and amino acid content between conventional foods and SCP. SCP derived from *Haematococcus pluvialis* and *Saccharomyces cerevisiae* is a rich source of threonine (up to 7.41%) and tryptophan (up to 14.22%), both of which are considered limiting amino acids in milk and meat, respectively. ***SCP also provides essential amino acids such as methionine, threonine, and lysine, with lysine being deficient in cereals,*** suggesting that combining SCP with cereals could enhance the nutritional value of the food. Studies have shown that SCP protein can surpass the protein content of other sources, potentially offering health benefits to organisms that consume it. For example, supplementing the diet of *Jian carp* (Cyprinus carpio var. Jian) with the methanotroph *Methylococcus capsulatus* (Bath) significantly improved their mean final weight, rate of weight gain, specific growth rate, and serum antioxidant capacity while reducing malondialdehyde production, compared to fish fed soybean meal (Salazar-López et al., 2022).

Protein composition (%)	Meat (Beef)	Milk (Cow)	Fish (Carp, raw)	*Rhodopseudomonas faecalis* (Bacterium)	*Candida utilis* (Yeast) and *Brevibacterium lactofermentum* (Corynebacterium)	*Haematococcus pluvialis* (Microalgae)
TOTAL PROTEIN (%)	21.2	3.28	17.8	51.5	54.5	64.93
Essential amino acids (%)						
Isoleucine	2.41	0.12	2.71	3.7	3.45	2.58
Leucine	4.06	0.23	4.35	7.6	4.13	10.87
Lysine	4.45	0.13	5.16	5.6	25.00	11.05
Methionine	1.35	0.04	1.62	0.5	1.86	0.54
Phenylalanine	2.20	0.13	2.22	4.1	1.65	3.17
Threonine	2.29	0.08	2.59	0.3	3.93	7.41
Tryptophan	–	–	–	3.8	–	–
Valine	2.50	0.14	3.46	5.5	3.84	–
Histidine	1.70	0.06	2.00	1.9	0.79	1.84
Non-essential amino acids (%)						
Cysteine	0.64	–	0.66	1.0	–	1.19
Tyrosine	1.80	0.12	2.07	2.5	2.49	6.91
Arginine	3.16	0.05	3.21	1.1	3.35	21.44
Alanine	2.92	0.08	3.39	6.6	2.82	12.68
Aspartic acid	4.50	0.13	5.86	4.7	4.87	18.71
Glutamic acid	7.65	0.35	7.99	3.7	12.00	5.62
Glycine	2.43	0.04	2.73	6.1	3.87	28.12
Proline	1.89	0.15	2.08	5.4	2.74	9.96
Serine	2.02	0.10	2.45	3.7	1.24	7.70
Asparagine	–	–	–	–	–	6.67
Glutamine	–	–	–	4.3	–	6.83

2. SUMMARY OF LCA DATA FOR BEEF MEAT AND YEAST SCPS.

A nationwide Life Cycle Assessment (LCA) was initiated as part of the US Beef Sustainability Research Program to establish baseline environmental impact metrics and identify opportunities for improvement within the beef value chain. Primary cradle-to-farm gate inventory data were collected from the Roman L. Hruska US Meat Animal Research Center (USMARC), the largest agricultural animal research facility in the United States. The primary objective of this LCA was to establish a baseline for the environmental impacts associated with current practices throughout the US beef value chain. Specifically, the study aimed to quantify the sustainability impacts linked to the production and consumption of 1 kg of beef in a representative US system. The target audience for the results included stakeholders within the beef industry, consumers, and the broader public.

Table 2. Emission rates from fertilizer and manure application on feed crops used in US beef life cycle impact assessment

Emission Type	Rate
Runoff loss (corn fields only)	0.15 g P/kg P applied 0.60 g N/kg N applied
Air emissions (direct + corn crop residue)	0.20 g N2O/kg applied
N fertilizer leaching	30% of N applied
Leached N to N_2O-N	0.75% (2.25 kg N_2O-N/kg fertilizer N applied)
CO_2 from urea	200 g CO2-C/kg $(NH_2)_2CO$ applied
CO_2 from limestone	120 g CO_2-C/kg $CaCO_3$ applied
Volatilization of NH_3 from fertilizer-N	100 g NH_3/kg N applied

N2O-N = annual direct N2O-N emissions produced from soil amendment (urea or limestone) decomposition, kg N2O-N/year
CO2-C emission = annual C emissions from soil amendment (urea or limestone) decomposition, kg C/year

The Life Cycle Assessment (LCA) results (Table 3) for the beef value chain revealed that the feed and cattle production phases were the predominant contributors to most environmental impact categories. Key impact metrics included ***water emissions*** (7005 L diluted water equivalent per kilogram of beef [L eq/CB]), ***cumulative energy demand*** (1110 MJ per kilogram of beef [MJ/CB]), and ***land use*** (47.4 m^2 per kilogram of beef per year [m^2 a eq/CB]). Air emissions were quantified in terms of ***acidification potential*** (726 g SO_2 equivalent per kilogram of beef [g SO_2 eq/CB]), ***photochemical ozone creation potential*** (146.5 g C_2H_4 equivalent per kilogram of beef [g C_2H_4 eq/CB]), ***global warming potential*** (48.4 kg CO_2 equivalent per kilogram of beef [kg CO_2 eq/CB]), and ***ozone depletion potential*** (1686 µg CFC-11 equivalent per kilogram of beef [µg CFC-11 eq/CB]). Other metrics included ***abiotic depletion potential*** (10.3 mg Ag equivalent per kilogram of beef [mg Ag eq/CB]), ***consumptive water use*** (2558 L equivalent per kilogram of beef [L eq/CB]), ***and solid waste*** (369 g municipal waste equivalent per kilogram of beef [g municipal waste eq/CB]). ***In terms of relative contribution, the feed phase accounted for 0.93 of the human toxicity potential***

Table 3 Environmental impact metrics quantified in the life cycle assessment of US beef where 1 unit of consumer benefit (CB) is equivalent to 1 kg of consumed, boneless, edible beef in the USA

Impact	Units	Feed	Cow-calf	Finish	Packing	Case ready	Retail	Consumer	Restaurant
Abiotic depletion potential	mg Ag eq/CB	1.51	3.95	2.68	0.24	0.16	0.14	0.59	1.01
Cumulative energy demand	MJ/CB	988.0	11.6	6.0	1.4	8.3	6.6	29.3	48.4
Consumptive water use	L eq/CB	2506	11.9	11.2	3.7	1.9	1.7	6.8	14.0
Absolute consumptive water use	L abs./CB	5023	23.9	22.5	7.5	3.9	3.4	13.7	28.1
Human toxicity potential	norm. tox. pts.	0.93	0.034	0.027	0.003	0.002	0.001	0.001	0.002
Land use	m^2 a eq/CB	45.8	0.8	0.7	0.1	0.2	0.0	0.1	0.2
Acidification potential	g SO_2 eq/CB	127.4	359.2	210.7	2.6	1.7	2.3	7.8	13.9
Global warming potential	kg CO_2 eq/CB	7.42	28.51	6.39	0.55	0.27	0.46	2.01	2.83
Ozone depletion potential	µg CFC_{11} eq/CB	121.4	0.1	1.4	36.9	336.6	180.7	9.0	1008
Photochemical ozone creation potential	g C_2H_4 eq/CB	136.9	6.8	1.8	0.2	0.1	0.2	0.4	0.1
Solid wastes	g municipal waste eq/CB	91.3	101.4	21.5	45.1	7.0	10.1	25.3	67.3
Water emissions	L diluted water eq/CB	6127	17.9	2.4	126.1	484.9	2.2	198.8	45.9
Abiotic depletion potential	mg Ag eq/CB	1.51	3.95	2.68	0.24	0.16	0.14	0.59	1.01

This LCA is the first comprehensive assessment of its kind for beef production and has been third-party verified in accordance with ISO 14040:2006, ISO 14044:2006, and ISO 14045:2012 standards. A subsequent nationwide study of beef cattle production is currently underway, utilizing region-specific data to establish benchmarks at the regional level and identify opportunities for further improvements in the sustainability of US beef production (Asem-Hiablie, Battagliese, Stackhouse-Lawson, & Alan Rotz, 2019).

Yeast-based single-cell protein (SCP) produced using oat side-streams as feedstock (OS-SCP) demonstrates notable differences in environmental impact when compared to other protein sources. ***OS-SCP results in a 61% reduction in land*** use compared to conventional products such as soy protein concentrates. However, it exhibits higher environmental impacts across several categories, including ***global warming potential (205–754% increase)***, ***water consumption (166–1401% increase)***, ***freshwater eutrophication (118–333% increase)***, and ***terrestrial acidification (85–340% increase)***. When compared to other novel protein sources, such as yeast protein concentrate, methanotrophic bacterial SCP, and insect meal, OS-SCP shows a more significant environmental footprint. Nevertheless, OS-SCP also demonstrates a reduction in global warming (11% decrease) and freshwater eutrophication (20% decrease) compared to dry microalgae biomass(Kobayashi et al., 2023).

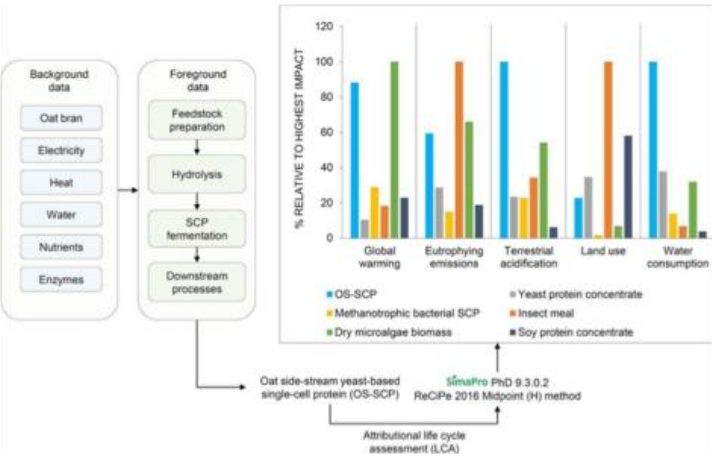

Figure 2. Comparative Environmental Footprint of OS-SCP vs. Other Novel Protein Sources

The production process for single-cell protein (SCP) derived from biomethane emerged as the dominant contributor in five out of six evaluated environmental impact categories: ecotoxicity (42.5%), global warming potential (39.2%), human toxicity—cancer (59.5%), human toxicity—non-cancer (48.3%), and water scarcity (70.1%). In contrast, the landfilling of rejected materials from the pretreatment stage was identified as the primary driver of freshwater eutrophication. Given the SCP production process's significant contribution to these impact categories, a detailed assessment of its operations is imperative. Analysis revealed that electricity consumption is the critical factor responsible for its environmental burden, contributing between 43.7% and 72.7% across five of the six impact categories, including ecotoxicity, eutrophication, global warming, and both cancer and non-cancer human toxicity.

To mitigate these environmental impacts, transitioning to renewable energy sources is strongly recommended. For instance, a study by Järviö et al. reported an 88% reduction in global warming potential for microbial protein production using autotrophic hydrogen-oxidizing bacteria (HOB) when hydropower replaced the conventional electricity mix in Finland. This highlights the transformative potential of integrating renewable energy into SCP production to reduce its environmental footprint (Fernández Gutiérrez, Argüelles, Martínez, Disla, & Lara-Guillén, 2022).

Table 4. Life Cycle Inventory for the single-cell protein to obtain 1 kg of protein from microorganisms (SCP)

Stage	Inputs	Outputs	Emissions to Air
Biowaste Pretreatment and Anaerobic Digestion	Biowaste: 71.4 kg FeCl3: 0.1 kg Polyelectrolyte: 0.04 kg Tap water: 28.8 kg Diesel: 0.09 kg Electricity: 12.0 MJ	Leftover biogas (to upgrade): 7.1 kg Solid fraction of digestate: 47.5 kg Liquid fraction of digestate: 39.2 kg Rejected materials to landfill: 6.4 kg	CH_4: 0.083 kg CO: 1.07 g CO_2: 0.296 kg NO_x: 1.96 g N_2O: 0.014 g SO_2: 6.00 × 10^{-3} g NH_3: 8.00 × 10^{-4} g NMVOCs: 0.156 g PM_{10}: 0.079 g $PM_{2.5}$: 0.079 g
SCP Production	Chemicals: 62.38 kg	Protein from microorganism: 1.00 kg Uniprotein (8% H2O) : 1.55 kg Wastewater to wastewater treatment plants: 8.6 kg CH_4: 0.057 g CO: 2.23 g CO_2: 1.019 kg NO_x: 5.08 g N_2O: 6.00 × 10^{-3} g NMVOCs: 0.15 g PM10: 0.051 g PM2.5: 0.051 g	

The term "Chemicals" includes biomethane, oxygen, water, natural gas, sodium hydroxide, and the sources of nitrogen, phosphorus and sulfur.

3. CASE EXAMPLES OF COMPANIES THAT TRANSITIONED TO YEAST-DERIVED SCPS.

Quorn

- Background: Quorn is a global leader in meat alternatives, producing mycoprotein-based products derived from fungal SCP.
- Transition Details: The company pioneered the use of fermentation to produce mycoprotein, which is cultivated from Fusarium venenatum, a type of fungus, and blended into various meat substitute products.
- Impact: Quorn's SCP-based products offer a sustainable protein source that uses significantly less water, land, and energy compared to traditional meat production, helping address climate change and resource scarcity.
- Web site: https://www.quorn.co.uk/mycoprotein

Quorn mycoprotein is a sustainable, meat-free protein source that is rich in dietary fiber and low in saturated fat. Its production begins not with livestock but with Fusarium venenatum, a natural, nutrient-dense filamentous fungus found in soil. The manufacturing process utilizes fermentation, a traditional biotechnological technique commonly employed in the production of bread, beer, and yogurt. Through controlled fermentation, Fusarium venenatum is cultivated to produce mycoprotein efficiently. The environmental advantages of ***Quorn mycoprotein are significant; its production generates 95% less CO_2 compared to conventional beef mince***, making it a highly sustainable protein option. This approach represents an innovative and eco-friendly solution to meet the nutritional needs of a growing global population while reducing the environmental impact of protein production.

Unibio Group

- Background: Unibio Group is a biotechnology company that focuses on producing sustainable protein using microbial fermentation, including yeast-based SCP.
- Transition Details: The company developed its proprietary U-Loop® technology, which converts methane into SCP for use as animal feed. Their product, Uniprotein®, offers a high-protein, sustainable alternative to traditional feeds like soy and fishmeal.
- Impact: By utilizing methane as a feedstock, Unibio significantly reduces land and water use, offering a lower-carbon solution to meet the growing global protein demand.
- Website: https://www.unibio.dk/end-product/protein/

Uniprotein® is a high-quality, protein-rich biomass containing approximately 72% protein, designed as a direct supplement for animal feed formulations. It is presented as a free-flowing, reddish-brown granule with a particle size range of 150–200 µm and features an extended shelf life. The production process ensures consistent product uniformity. Derived from a natural, non-genetically modified process industrialized by Unibio, Uniprotein® is produced through microbial fermentation using natural gas as the sole carbon and energy source. This method is environmentally sustainable, as the only by-product is clean water. Uniprotein® is free from toxins, dioxins, and heavy metals, owing to its highly controlled production environment and the exclusive use of food-grade minerals. Its innovative production process highlights its potential as a sustainable and safe alternative protein source for the animal feed industry.

4. ACCESS TO ONLINE TOOLS FOR CALCULATING MATERIAL CARBON FOOTPRINTS.

SIMAP (Sustainability Indicator Management & Analysis Platform)

Description: A comprehensive tool for assessing carbon footprints in supply chains, energy use, and material inputs. Institutions and companies often use it.

Website: https://unhsimap.org/

PlanBe.Eco Carbon Footprint Calculator

Description: PlanBe.Eco offers a user-friendly carbon footprint calculator designed to assess and mitigate environmental impacts. This platform caters to both individuals and businesses, emphasizing simplicity and actionable insights for sustainability goals.

Website: PlanBe

Carbon Trust Footprint Calculator

Description: Offers a user-friendly interface to calculate the carbon footprint of materials and products. It is designed for businesses and organizations seeking to estimate their emissions.

Website: https://www.carbontrust.com/en-eu

OpenLCA

Description: A free and open-source software for life cycle assessment (LCA). Users can model carbon footprints of materials and products using publicly available databases.

Website: https://www.openlca.org/

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Optimized Fermentation

Session 4:

Existing optimized fermentation products: Pros and Cons

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Agenda

1. **Optimized Food Fermentation Products**
2. **Real-World Examples of Optimized Fermentation Products**
3. **Advantages**
4. **Limitations**
5. **Future Trends of Food Fermentation**

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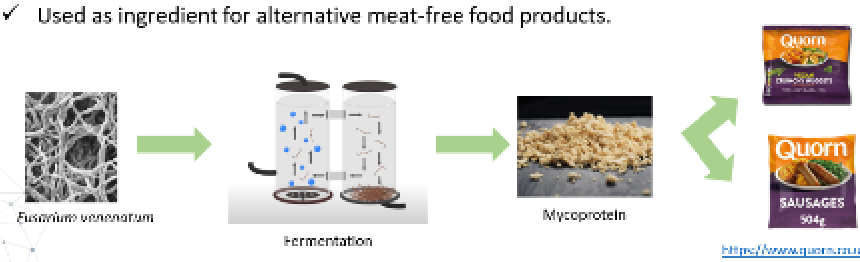
1. Optimized Food Fermentation Products

2. Real-World Examples of Optimized Fermentation Products

2.1. Mycoprotein-Based Products

Quorn:

- ✓ Alternative protein produced from *Fusarium venenatum;*
- ✓ Uses fungal biomass grown via fermentation on sugar-based substrates;
- ✓ Used as ingredient for alternative meat-free food products.



https://www.quorn.co.uk/

2.1. Mycoprotein-Based Products

Nature's Fynd

- ✓ Alternative protein produced from *Fusarium strain flavolapis;*
- ✓ The substrate used is often agricultural by-products;
- ✓ Developed for inclusion as an ingredient for food products such as meat, dairy, and flour alternatives.

https://www.naturesfynd.com/

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2.2. Seaweed or Algae-Based Products

ALGAMA

Algamafoods

- ✓ Use microalgae, such as Chlorella and Spirulina, to create sustainable proteins for use in beverages and snacks.
- ✓ Algama has been recognized with awards like the "Tech for Future 2024" prize for its innovative contributions to sustainable food production.

https://algamafoods.com/

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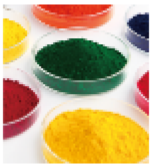
2.2. Seaweed or Algae-Based Products

DIC Corporation

DIC
Color & Comfort

- ✓ DIC produces food-grade natural pigments, particularly from microalgae, which are used as colorants in food and beverages.
- ✓ **Phycocyanin:** A natural blue pigment extracted from Spirulina, widely used in confectionery, beverages, and as a clean-label alternative to synthetic dyes.
- ✓ **Lutein and Astaxanthin:** Nutritional carotenoids derived from microalgae, used in dietary supplements and functional foods for their antioxidant properties.



https://www.dic-global.com/en/

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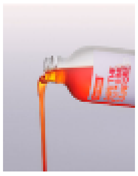
2.3. Alternative Oils

C16 BIO

C16 Biosciences

- ✓ A sustainable alternative to palm oil using optimized fermentation processes. The company leverages yeast strains to produce a palm oil substitute with a similar fatty acid profile, making it functionally equivalent to palm oil in various industries, including food and personal care.
- ✓ Their product, Palmless™, is produced by fermenting non-GMO oleaginous yeast, which can generate oils rich in palmitic acid—a key component of palm oil.



C16 Biosciences

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3. Advantages

- Increased yield and efficiency
- Cost effectiveness
- Consistency and quality control
- Environmental benefits
- Customization for novel products

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4. Limitations

- High initial investment
- Complexity in implementation
- Risk of contamination
- Dependence on precise parameters
- Potential for reduced genetic diversity
- Regulatory challenges

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5. Future Trends of Food Fermentation

- Precision fermentation
- Alternative substrates
- Expanded applications
- Sustainability and circular economy
- Advances in microbial engineering
- Clean label products
- Affordable alternatives
- Regional and cultural integration
- Regulatory and consumer acceptance

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Questions

1. What is one of the main benefits of optimized fermentation in the food industry?

A) Reducing production time for traditional food products

B) Reducing environmental impact by using alternative substrates

C) Increasing the price of fermented food products

D) Increasing the reliance on animal-derived ingredientes

2. Which of the following companies produces animal-free dairy products using optimized fermentation?

A) Geltor

B) Nature's Fynd

C) Algamafoods

D) Meati Foods

Project n.: 101087203

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Questions

3. Which of the following alternative substrates are being used in optimized fermentation processes?

A) Animal fat and muscle tissue

B) Plant sugars, agricultural waste, and CO_2

C) Raw animal byproducts

D) Only chemical compounds derived from synthetic sources

4. What is one of the primary advantages of optimized fermentation for food production?

A) It always produces products that are less expensive than traditional methods

B) It allows for the production of high-quality, sustainable ingredients without relying on animals

C) It is faster but less efficient than traditional fermentation

D) It increases the dependence on fossil fuels for production

Project n.: 101087203


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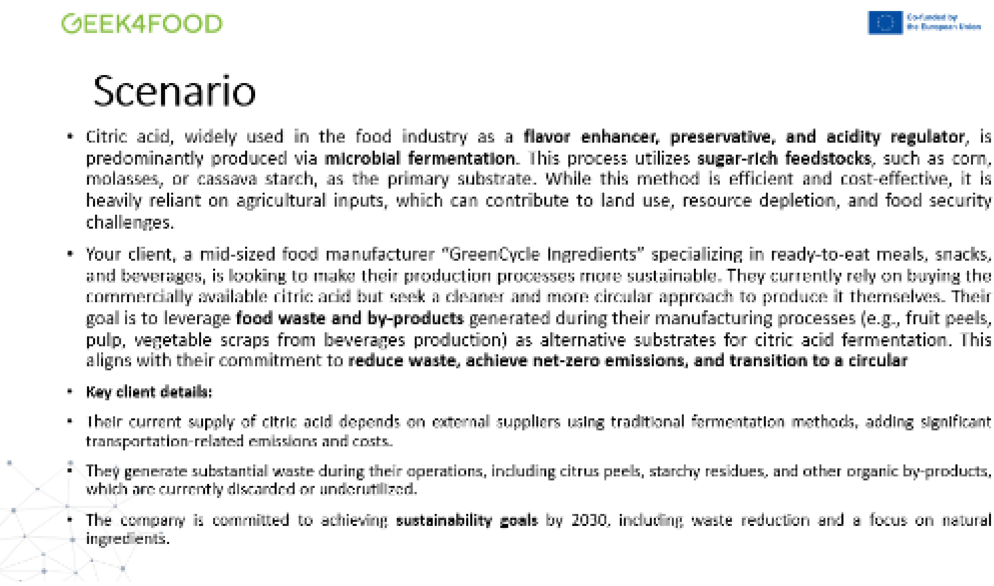
Activity/Case-study 2
Proposing an Innovative Solution for Controlled Fermentation-Derived Products
A Holistic Perspective on Applications, Environmental Impact, Raw Materials, and Cost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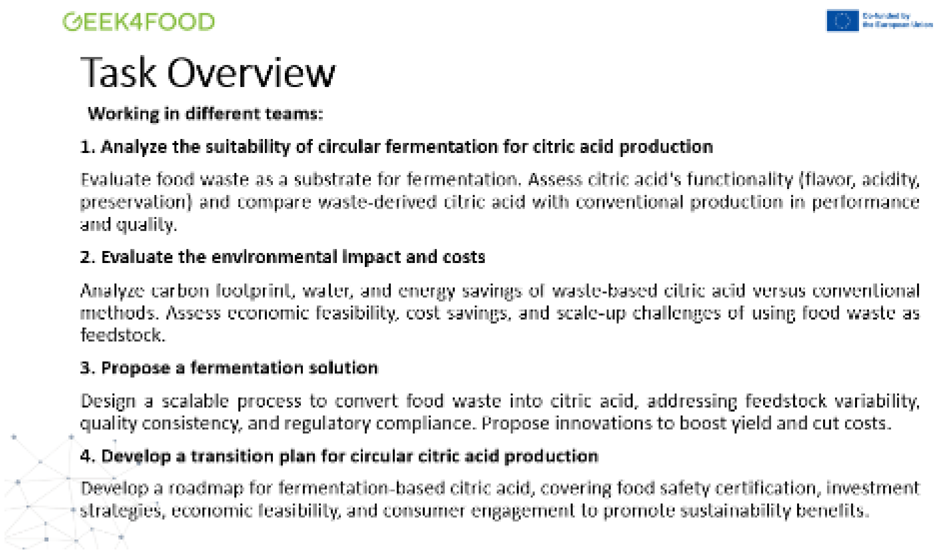
Scenario
Citric acid, widely used in the food industry as a flavor enhancer, preservative, and acidity regulator, is predominantly produced via microbial fermentation. This process utilizes sugar-rich feedstocks, such as corn, molasses, or cassava starch, as the primary substrate. While this method is efficient and cost-effective, it is heavily reliant on agricultural inputs, which can contribute to land use, resource depletion, and food security challenges.
Your client, a mid-sized food manufacturer "GreenCycle Ingredients" specializing in ready-to-eat meals, snacks, and beverages, is looking to make their production processes more sustainable. They currently rely on buying the commercially available citric acid but seek a cleaner and more circular approach to produce it themselves. Their goal is to leverage food waste and by-products generated during their manufacturing processes (e.g., fruit peels, pulp, vegetable scraps from beverages production) as alternative substrates for citric acid fermentation. This aligns with their commitment to reduce waste, achieve net-zero emissions, and transition to a circular
Key client details:
Their current supply of citric acid depends on external suppliers using traditional fermentation methods, adding significant transportation-related emissions and costs.
They generate substantial waste during their operations, including citrus peels, starchy residues, and other organic by-products, which are currently discarded or underutilized.
The company is committed to achieving sustainability goals by 2030, including waste reduction and a focus on natural ingredients.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Task Overview
Working in different teams:
1. Analyze the suitability of circular fermentation for citric acid production
Evaluate food waste as a substrate for fermentation. Assess citric acid's functionality (flavor, acidity, preservation) and compare waste-derived citric acid with conventional production in performance and quality.
2. Evaluate the environmental impact and costs
Analyze carbon footprint, water, and energy savings of waste-based citric acid versus conventional methods. Assess economic feasibility, cost savings, and scale-up challenges of using food waste as feedstock.
3. Propose a fermentation solution
Design a scalable process to convert food waste into citric acid, addressing feedstock variability, quality consistency, and regulatory compliance. Propose innovations to boost yield and cut costs.
4. Develop a transition plan for circular citric acid production
Develop a roadmap for fermentation-based citric acid, covering food safety certification, investment strategies, economic feasibility, and consumer engagement to promote sustainability benefits.

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Resources to be provided to the students

- **Chemical and functional profiles** - properties of citric acid and its applications in food products (e.g., preservation, flavor, and acidity regulation)
- **Raw material data** – composition and availability of food waste feedstocks
- **LCA** data for citric acid production
- **Case studies of circular fermentation for citric acid** - examples of successful food companies adopting waste-to-value solutions.
- **Access to analytical tools**
- **Regulatory guidelines**

Deliverables to be provided by the students

Each team will produce:

- A detailed report on their assigned aspect.
- A visual presentation summarizing key findings and proposed solutions.
- A collaborative proposal outlining a comprehensive fermentation-based solution.

Teacher's Role

- **Facilitator**: Guide students through the problem-solving process by posing questions and offering clarifications.
- **Evaluator**: Assess the feasibility, creativity, and thoroughness of proposed solutions.
- **Discussion Leader**: Encourage critical reflection on challenges, trade-offs, and potential advancements in fermentation technology.

Holistic perspective

A. Applications

Preservative for beverages, sauces, and processed foods.
Flavor enhancer in ready-to-eat meals, snacks, and confectionery.
Acidity regulator in baked goods, jams, and dairy products.
Suitable for industries seeking natural replacements for synthetic additives.

B. Environmental perspective

Reduces food waste by using by-products like citrus peels and pulp as feedstock.
Supports circular economy goals by minimizing reliance on virgin agricultural inputs.
Lowers greenhouse gas emissions compared to synthetic citric acid production.
Helps divert waste from landfills, reducing methane emissions.

C. Raw materials

Food Industry By-Products: Citrus peels, fruit pulp, and starchy residues.
Non-Food Industry Contributions: Organic waste streams suitable for fermentation.
Pre-Treatment Requirements: Enzymatic hydrolysis to convert waste into fermentable sugars.

D. Regulatory Requirements

Compliance with food safety standards (e.g., EFSA, FDA) for waste-derived ingredients.
Alignment with clean-label certification to meet consumer demand for natural products.
Upcoming regulations (e.g., EU Waste Framework Directive) supporting waste-to-value transitions.

E. Cost considerations

Cost comparison between traditional citric acid production (from sugar-rich crops) and waste-based fermentation.
Assessment of scalability for small- and large-scale manufacturers.
Evaluation of cost-efficiency improvements from integrated waste-to-value processes (e.g., reduced raw material costs).

F. Consumer perspective

Willingness to pay: Higher acceptance for natural, sustainable citric acid among eco-conscious consumers.
Safety assurance: Clear communication about the safety of waste-derived citric acid.
Sustainability: Market appeal driven by its role in reducing food waste and carbon footprint.

Interactive discussion/Stakeholder perspectives

Food manufacturers

- Does the innovation meet clean-label and sustainability demands from retailers and consumers?
- Can manufacturers market products as natural and eco-friendly while maintaining competitive pricing?

Environmentalists

- Does the shift toward waste utilization strengthen broader sustainability efforts?
- How does this solution influence consumer awareness about waste reduction and environmental impacts?

Regulators

- Are policies in place to support consumer-driven trends toward natural and sustainable ingredients?
- Can the innovation drive broader changes in waste management and resource efficiency?

Consumers

- Are consumers willing to pay a premium for waste-derived, eco-friendly products?
- How does this align with the growing demand for transparency and sustainability in food production?

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For the tutor

Discussion Points Post-Case Study

- What are the main challenges of using food waste as a substrate for citric acid fermentation?
- How can advancements in fermentation technology improve the scalability and efficiency of waste-based citric acid production?
- What strategies can help address regulatory and consumer acceptance challenges for waste-derived food ingredients?
- What are the economic and environmental trade-offs of transitioning to a circular fermentation model?
- How can companies collaborate across the value chain to maximize the benefits of circular fermentation?

Key Features of the Solution

1. Raw materials: utilization of food and agricultural waste feedstock:

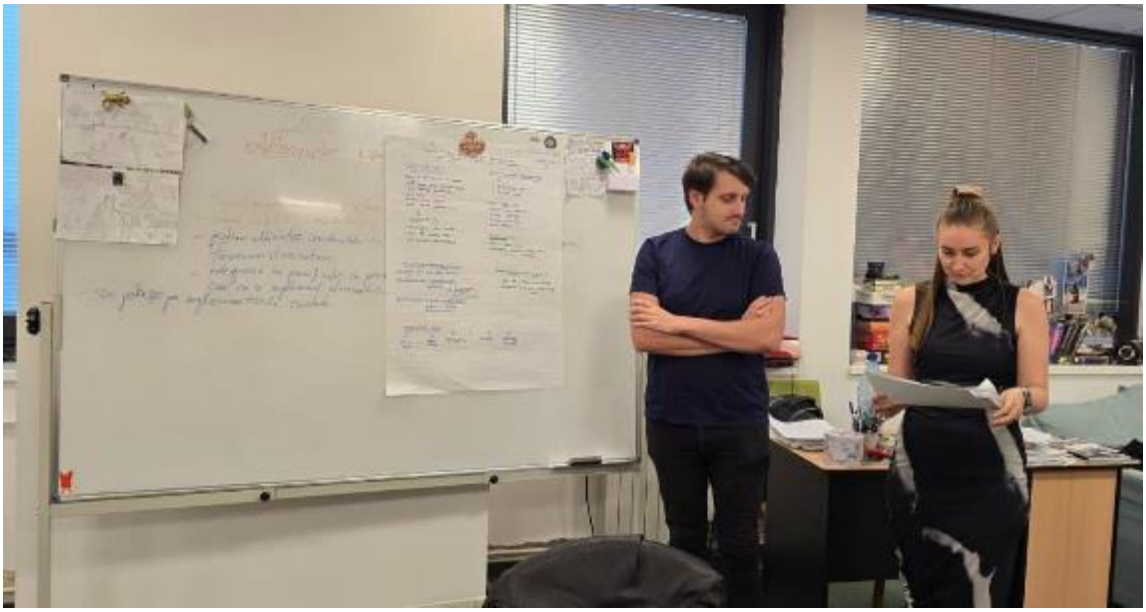
- Use of food production by-products such as citrus peels, fruit pulp, and starchy residues as fermentation substrates.
- Pre-treatment technology: deployment of green technologies to convert waste into fermentable sugars, ensuring optimal substrate quality.
- Environmental impact: reduces reliance on virgin agricultural inputs, diverts food waste from landfills, and minimizes methane emissions.

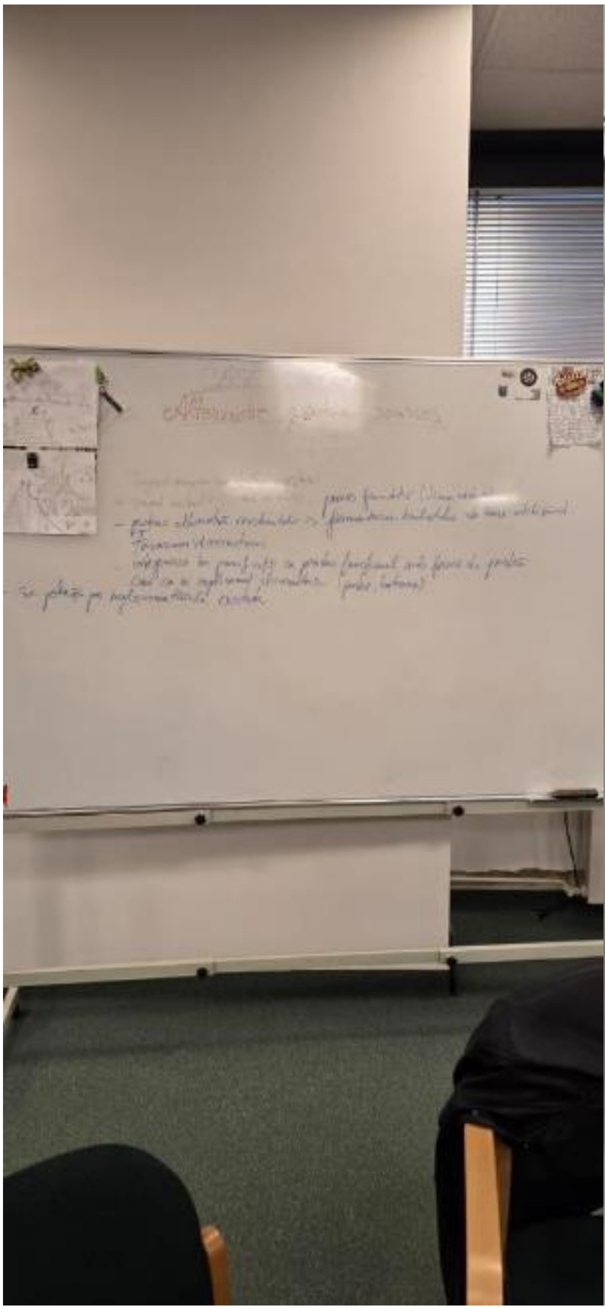
2. Process design: IoT-enabled automation

- Smart bioreactors: equipped with real-time sensors to monitor pH, temperature, nutrient levels, and product concentration during citric acid fermentation.
- Automated control systems: machine learning algorithms adjust fermentation parameters to optimize citric acid production efficiency.
- Scalability: modular designs support seamless scaling from pilot to industrial production for citric acid.

3. Circular economy: integrated downstream processing

- Energy recovery: capture of off-gases like CO_2 for reuse in beverage carbonation or other applications.
- Water recycling: advanced filtration systems recycle water used in the fermentation process to minimize waste.
- Waste minimization: residual biomass from fermentation repurposed as bioenergy or agricultural fertilizer, completing the waste-to-value cycle.





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Assessment
Multiple choice quiz

Safety and risk assessment of optimized fermentation process

1. What is the main purpose of fermentation in food production?
a) To produce alcohol for beverages
b) To enhance flavor, preserve food, and create useful by-products
c) To eliminate microorganisms from food
d) To increase the temperature of the food

2. Which of the following are examples of products made using fermentation?
a) Bread
b) Yogurt
c) Vinegar
d) Cheese

3. What is a bioreactor used for in fermentation?
a) Mixing chemicals in a factory
b) Growing and controlling microorganisms for product production
c) Filtering water in industrial processes
d) Cooking food at high temperatures

4. Which microorganisms are commonly used in fermentation?
a) Bacteria
b) Yeast
c) Fungi
d) Algae

5. What are the key advantages of fermentation compared to chemical processes?
a) It requires less energy and uses natural processes.
b) It eliminates the need for microorganisms.
c) It creates synthetic chemicals faster.
d) It uses renewable and sustainable resources.

6. What role does temperature play in fermentation?
a) It has no impact.
b) It affects the speed and efficiency of microbial activity.
c) It makes the fermentation process unnecessary.
d) It stops microorganisms from growing.

7. Why is fermentation considered environmentally friendly?
a) It eliminates the need for packaging materials.
b) It uses renewable resources like agricultural waste.
c) It reduces reliance on synthetic chemical production.
d) It produces no by-products.

Existing optimized fermentation products: Pros and Cons

1. What is one of the main benefits of optimized fermentation in the food industry?

1. Reducing production time for traditional food products
2. Reducing environmental impact by using alternative substrates
3. Increasing the price of fermented food products
4. Increasing the reliance on animal-derived ingredientes
5.

2. Which of the following companies produces animal-free dairy products using optimized fermentation?

1. Geltor
2. Nature's Fynd
3. Algamafoods
4. Meati Foods

3. Which of the following alternative substrates are being used in optimized fermentation processes?

1. Animal fat and muscle tissue
2. Plant sugars, agricultural waste, and CO_2
3. Raw animal byproducts
4. Only chemical compounds derived from synthetic sources
5.

4. What is one of the primary advantages of optimized fermentation for food production?

1. It always produces products that are less expensive than traditional methods
2. It allows for the production of high-quality, sustainable ingredients without relying on animals
3. It is faster but less efficient than traditional fermentation
4. It increases the dependence on fossil fuels for production

ANNEX 3: Content mapping file, syllabus and content of the module “Food waste valorisation in food product design”

1. Content mapping file

Type of content	Session’s Title	Partner responsible for content creation	Content's core duration	Indicative resources
Challenge-based lecture	Food waste: from what, what, what for and how: current and future sustainable strategies for valorisation	UNITE	30 min	https://food.ec.europa.eu/food-safety/food-waste_en Compr Rev Food Sci Food Saf. 2024;23:e70011. https://doi.org/10.1111/1541-4337.70011 Springmann et al., Nature, 2018, 562, 519 Wang et al. Nat Food (2025). https://doi.org/10.1038/s43016-025-01140-z https://op.europa.eu/en/publication-detail/-/publication/3803332e-2d1d-11ef-a61b-01aa75ed71a1/language-en
Content part 1 (or 2)	Technological functionalities of food waste for green ingredients design	UNITE	30 min	Galanakis, Trends in Food science and technology, 6 (2012) 68-87 Pittia & Gharsallaoui, Food waste recovery(pp. 155–170). Academic Press. https://doi.org/10.1016/B978-0-12-820563-1.00007-X
Content part 2 (or 1)	Biorefinery approches and innovative technologies for food ingredients	TUD/UNITE	30 min	
Activity based content – aiming systems approach, identify the problem	Activity/Case-study 1 (see below)	UNITE	activity's core duration: 30 min	
Activity based content –	Activity/Case-study 2 (see below)	UNITE	activity's core duration: 30 min	

aim to bring solutions				
Content part 3	Circular economy, industrial sustainability and social impact	TU Dublin	30 min	
Refining solution	Overview of the 2 case studies/discussion	(valorisation of food waste from food value chains, technological solutions)	15 min	
Learning outcome	"1. Understand the concepts of food waste recovery, technological functionality of waste biomolecules and their potential for valorisation along with the technological aspects 2. Understand the role of food waste recovery withing circular economy and the bioeconomy models and the link between the circular economy and social impact.			
Assessment method	"1. Group exercises (Case studies 1 and 2).			

2. Module's syllabus

Module's syllabus

Title: Food waste valorisation in food product design

General information	
Course	Food waste valorisation in food product design
Scope	Sustainability, Food waste, design thinking, food formulation, techno-functional properties
Language	English
Evaluation	Case studies/ multiple choice questions
Holders	Paola Pittia
Length	One day course
Didactic method	Lectures with activity-based content
Location	Online, or in class, or hybrid

Learning objectives

1. Understand the concepts of food waste recovery, technological functionality of waste biomolecules and their potential for valorisation along with the technological aspects
2. Understand the role of food waste recovery withing circular economy and the bioeconomy models and the link between the circular economy and social impact.
3. Identify potential food waste and side-streams for food ingredients and products development, based on technological functionality and technologies available.
4. Apply biorefinery and food technology concepts for food ingredients and products design.

Required skills

Learners need a multidisciplinary skill set, including unit food chemistry, food unit operations and processes, sustainability principles (circular economy, resource optimization, and waste-to-value systems), and the ability to valorise the techno-functional, nutritional and health properties in food product design.
Additionally, learners should develop process and product design along with innovation skills. The ability to integrate technofunctionality, sustainability, and cost in decision-making is critical, as is the capacity to analyze case studies, interpret process efficiency data, and ensure compliance with food safety and environmental regulations.
Strong communication and interdisciplinary collaboration skills and awareness of emerging trends in green technologies, sustainable processing, and biorefinery are essential. Basic knowledge of experimental design approaches, response surface methodology and statistical methods in food waste bioactives process optimisation and food product design is also beneficial.

Subjects

Challeng based lecture: Food waste: from what, what, what for and how: current and future sustainable strategies for valorisation.
Teaching session 1 : Technological functionalities of food waste for green ingredients design
Teaching session 2: Biorefinery approches and innovative technologies for food ingredients

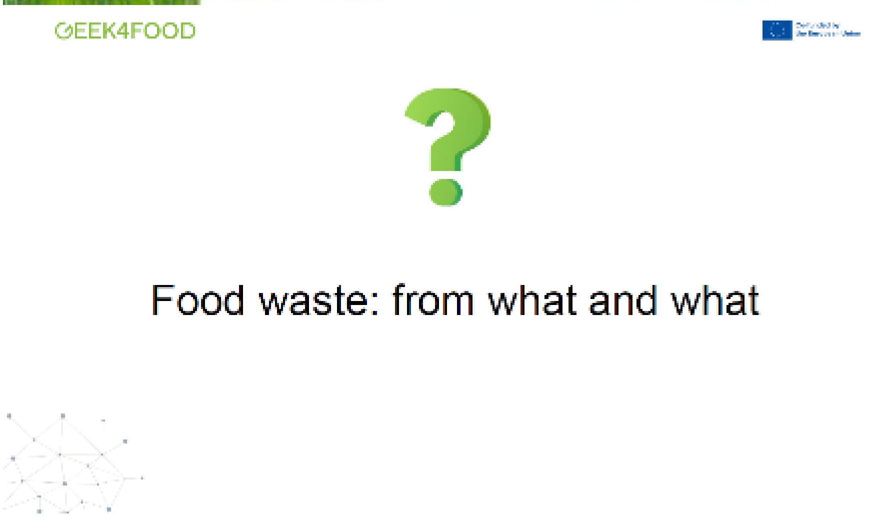
Case-study 1: Identify a specific food value chiain and related waste and side-streams to be valorised for innovative food ingredients and products based on their technological functionalities. E.g. From waste to value: the case of chocolate Case-study 2: Propose/describe a technological solution to develop/produce a food ingredient/product from holistic perspective (applications, environmental impact, raw materials, cost etc.). E.g. the case of mushrooms processing chain. Teaching session 3: Circular economy, industrial sustainability and social impact

Teaching methods
Lectures, case studies

Verification of learning
The achievement of the training objectives of the Food waste valorisation in food product design will be assessed through interactive methods, including multiple-choice questions and case study analyses. These assessments will evaluate the learners' ability to understand and apply the new knowledge on technological functionality of biomolecules, the potential of food waste as new second raw material for new products developmen, analyze and synthesize information, and make informed decisions in scenarios that mirror real-world conditions in food waste valorisation. Multiple-choice questions will test foundational knowledge, while case studies will challenge learners to solve problems related to process selection and optimization, scalability, and environmental impact. Practical exercises, such as real case studies and data interpretation, will measure their ability to effectively apply theoretical knowledge to operational contexts. These methods ensure a comprehensive evaluation of both conceptual understanding and practical skills.

Indicative resources
1. EC: Food waster (frameworks, standards for food waste): website link 2. Review: Makiso-Uruso et al., A comprehensive review of current approaches on food waste reduction strategies [Link 1] 3. Review: Springmann et al 2018. Options for keeping the food system within environmental limits [Link 2] 4. Review: Wang et al 2025. Food waste used as a resource can reduce climate and resource burdens in agrifood systems [Link 3] 5. Review: Galanakis C. 2012. Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications [Link 4] 6. Book Chapter: Pittia & Gharsallaoui, Food waste recovery [Link 5] 7. Review: Patel et al., 2024. Innovative biorefinery approaches for upcycling of post-consumer food waste in a circular bioeconomy context [Link 6] 8. Review: Fazle-Rabbi & Bin Amin, 2024. Circular economy and sustainable practices in the food industry: A comprehensive bibliometric analysis [Link 7]

3. Module's content



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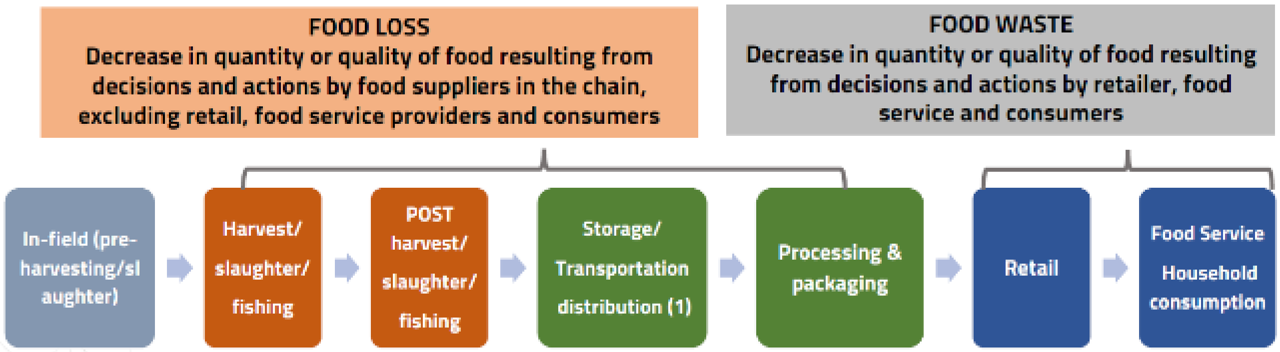
Food loss and waste (FLW)

Definitions and boundaries in the supply chain



Source: FAO, State of Food and Agriculture, 2019

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Food loss and waste

Definitions and boundaries in the supply chain

EU definitions

Food loss refers to **any food that is discarded, incinerated or otherwise disposed of along the food supply chain** from harvest/slaughter/catch up to, but excluding, the retail level, and is not used for any other productive use, such as animal feed or seed.

•**Food waste** refers to food that is discarded at the level of retailers, food service providers and consumers.
Food is wasted in many ways, e.g.

- Fresh produce that deviates from what is considered optimal (e.g. size, shape or colour) and is removed during sorting actions
  - Foods that are discarded by retailers or consumers when it's close to or beyond the best before date.
  - Unused or leftover food that is thrown out from households or restaurants.

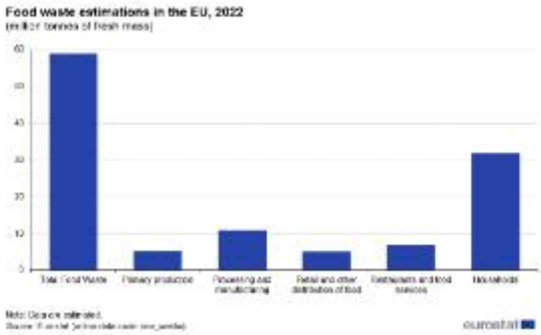
Food waste is discarded food and its associated inedible parts (such as bones or fruit cores). Food waste occurs at all **stages of the food supply chain, from farm to fork. However, the largest share is generated at consumption, which is a key area of focus for food waste prevention programmes.**

https://food.ec.europa.eu/food-safety/food-waste/frequently-asked-questions-reducing-food-waste-eu_en

GEEK4FOOD

FLW statistics

Statistics



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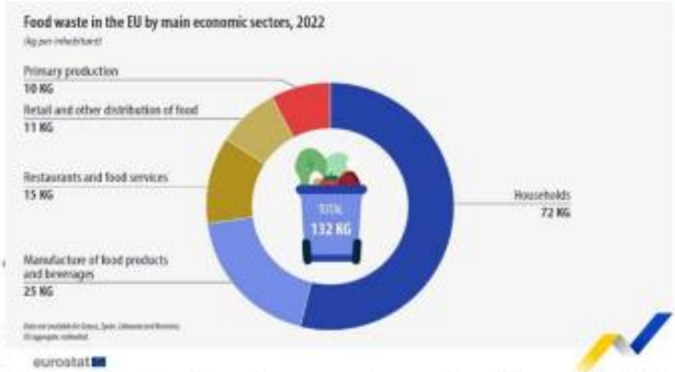
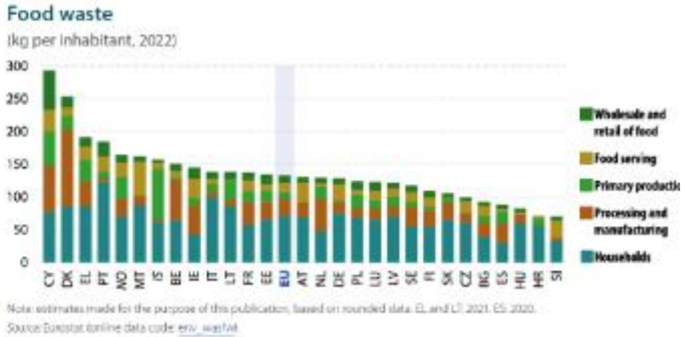
The total amount of food waste represents ca. 10% of the total food supply





https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

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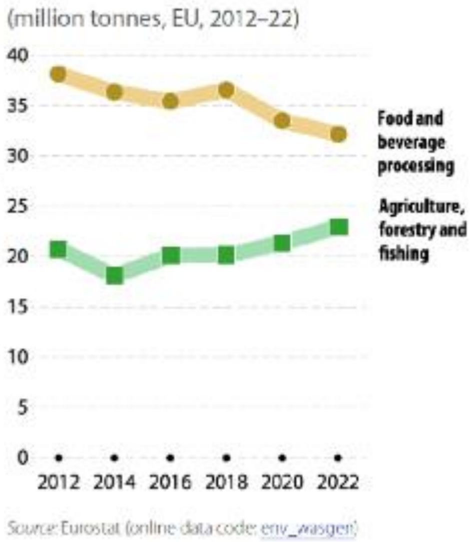
Food waste

Statistics

Reducing food loss and waste is an integral part of the *Farm to Fork Strategy action plan*. The figures presented in this section cover all types of waste generated in productive activities (including, among others, waste from food, feed, by-products and other plant or animal products). Agriculture, forestry and fishing and the processing of food, beverage and tobacco generated a combined 55.1 million tonnes of waste across the EU in 2022. Together these activities accounted for 2.7% of all waste from productive activities.

Across the EU, waste generated by food, beverage and tobacco processing fell overall by 15.7% between 2012 and 2022; with decreases each 2 years except in 2018. By contrast, the level of waste from agriculture, forestry and fishing increased each 2 years, other than a contraction in 2014; this waste stream increased 10.6% overall during the period under consideration

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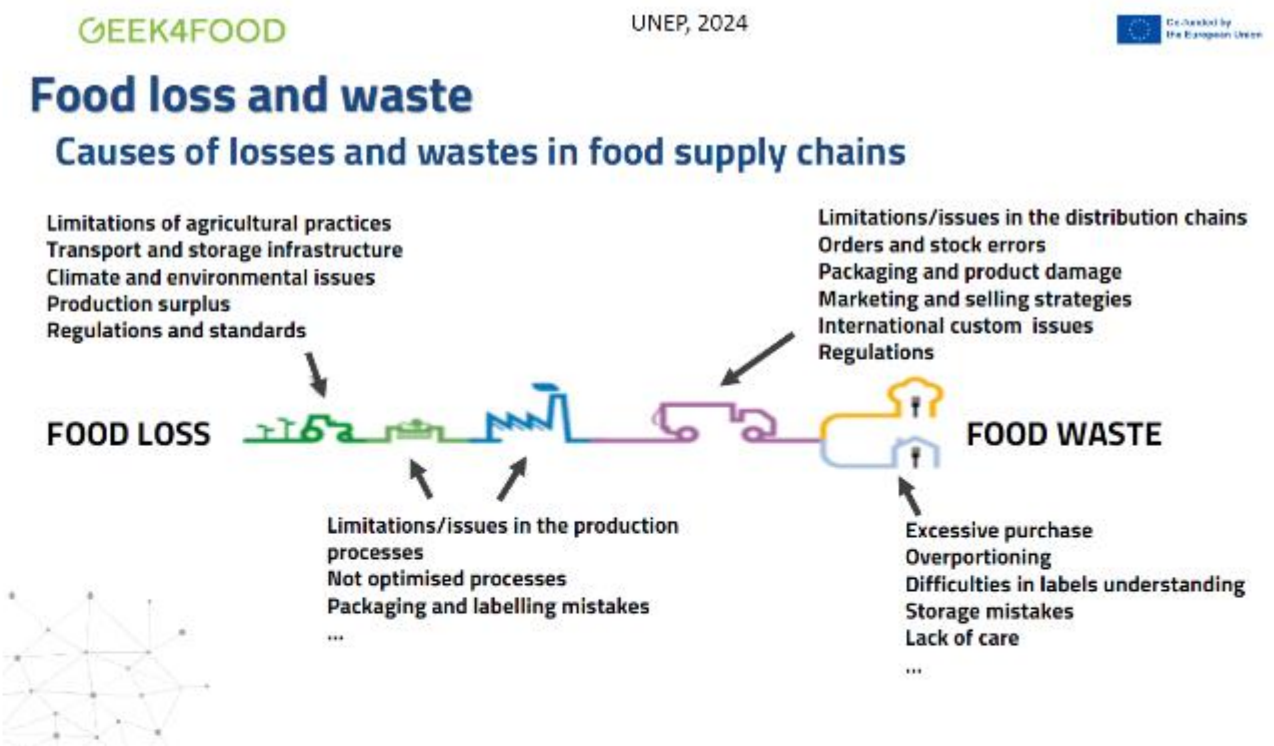
Food waste: why?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UNEP, 2024
Co-funded by the European Union
Food loss and waste
Causes of losses and wastes in food supply chains
Limitations of agricultural practices
Transport and storage infrastructure
Climate and environmental issues
Production surplus
Regulations and standards
Limitations/issues in the distribution chains
Orders and stock errors
Packaging and product damage
Marketing and selling strategies
International custom issues
Regulations
FOOD LOSS
FOOD WASTE
Limitations/issues in the production processes
Not optimised processes
Packaging and labelling mistakes
...
Excessive purchase
Overportioning
Difficulties in labels understanding
Storage mistakes
Lack of care
...

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Food loss and waste

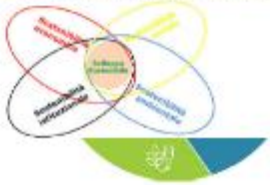
EU and International policies

SVILUPPO SOSTENIBILE

MODALITÀ DELLO SVILUPPO ECONOMICO MONDIALE IN GRADO DI ASSICURARE

"IL SODDISFACIMENTO DEI BISOGNI DELLA GENERAZIONE PRESENTE SENZA COMPROMETTERE LA POSSIBILITÀ DELLE GENERAZIONI FUTURE DI REALIZZARE I PROPRI".

United Nation



030 (EC, 2016)
h and innovation policy
form food systems and
veryone has enough
ile, nutritious food to
ealthy life.

)
t
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50.

systems fair, healthy and
environmentally-friendly.

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Food loss and waste

Impact

ETICAL AND SOCIETAL
Food waste → → no accessibility (food security)
Food surplus → → Malnutrition
Nutrients wastage → → lack of nutrients

FOOD LOSS

FOOD WASTE

ECONOMIC
Cost and value of the wasted food
Costs-opportunities of farming/land

ENVIRONMENT
Greenhouse gases
Water wastage
Environmental degradation
Energetic costs


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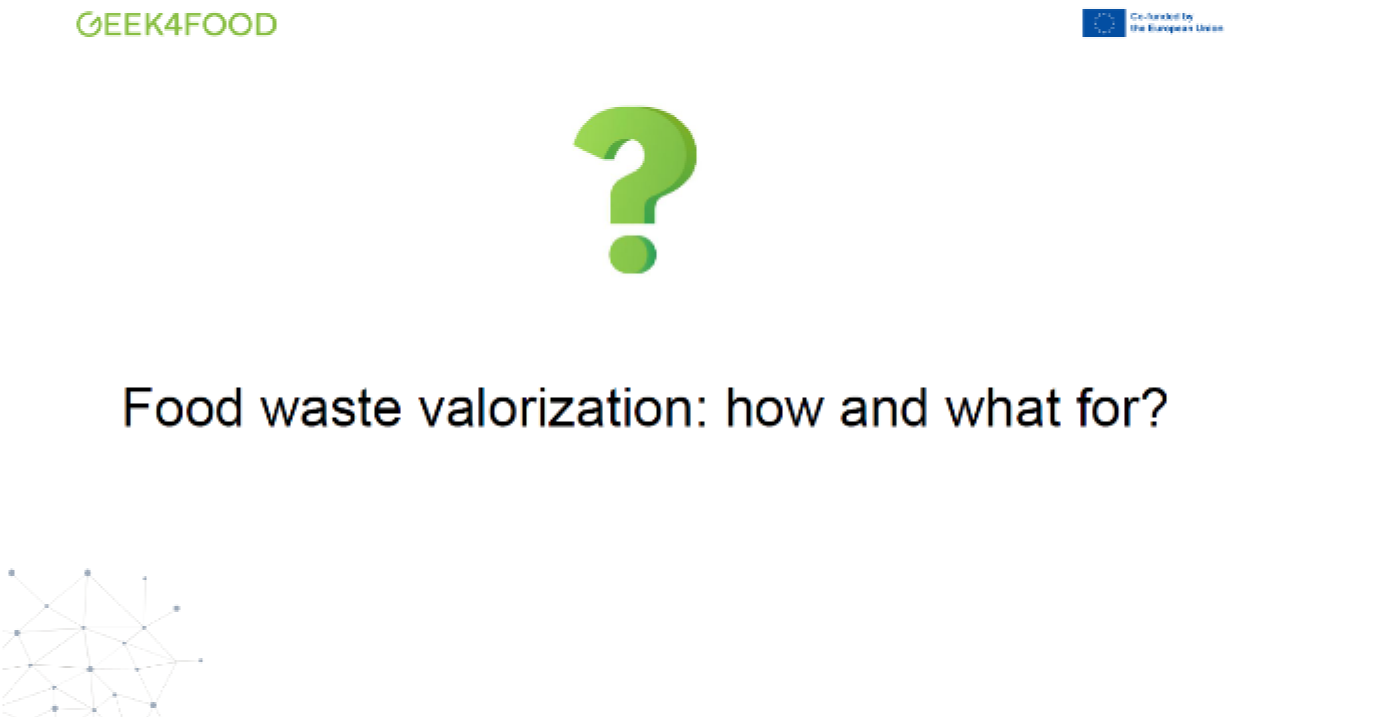
Food loss and waste
The magnitude
An estimated 13 percent of fo
supply chain, from after harv
reaching retail shelves in 202
An estimated 19 percent of fo
households, food services ar
the equivalent of 132 kg per ca
Households account for
%) of the food that is was
Around the world, each d
meals are thrown away ir
alone. (UNEP, 2024).
Total global food wastage (1.05 billion tons)
Household 631 million tons (60%)
Food service 290 million tons (28%)
Retail 131 million tons (12%)
Household Food Waste by Region (kg/capita/year):
Sub-Saharan African :93kg
Northern American: 76kg
Western Europe: 80kg
Latin America & Caribbean :95kg
Key Global Food Waste Statistics
FLP: Global and by food group
WORLD
13.3%
7.6%
12.4%
12.6%
0%
5%
10%
15%
20%
Source: F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Food waste valorization: how and what for?

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UNEP, 2024

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Food loss and waste

Causes of losses and wastes in food supply chains

Fig. 1. Sources and generation of food waste from various sector (UNEP, 2021).
Source: Di Fraia et al., 2024

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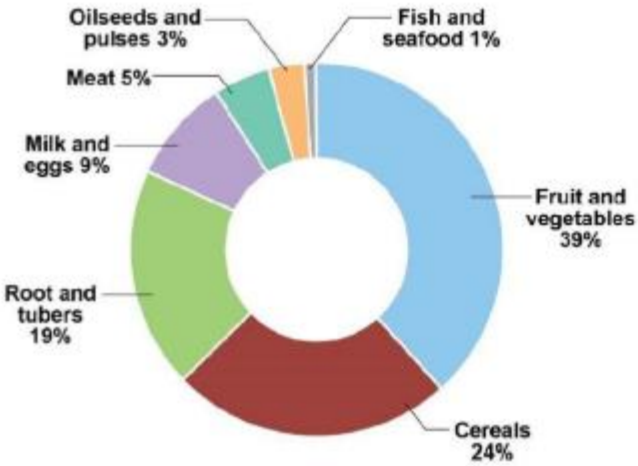
Food loss and waste

What?



Share of various global food waste.
Source: Roy et al, 2023

Fruits and vegetables are the major contributors to the total FW in different jurisdictions followed by cereals, root and tubers, milk, meat, and others.

However the generation of FW depends on the types of food, processing stages, and food supply chains, as well as the jurisdictions.]

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Food loss and waste

The complexity of FLW in processing (prior to retail)

- Quality vary at different processing steps (initial *vs.* end)
- Single ingredient vs. formulated products
- Formulated foods (complex recipies, multidomains,...)
  - complex composition
  - composition may vary
  - difficult to extract/separate individual compounds
- Packed vs. unpacked
- Wasted packaging?

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Food loss and waste: valorization paths

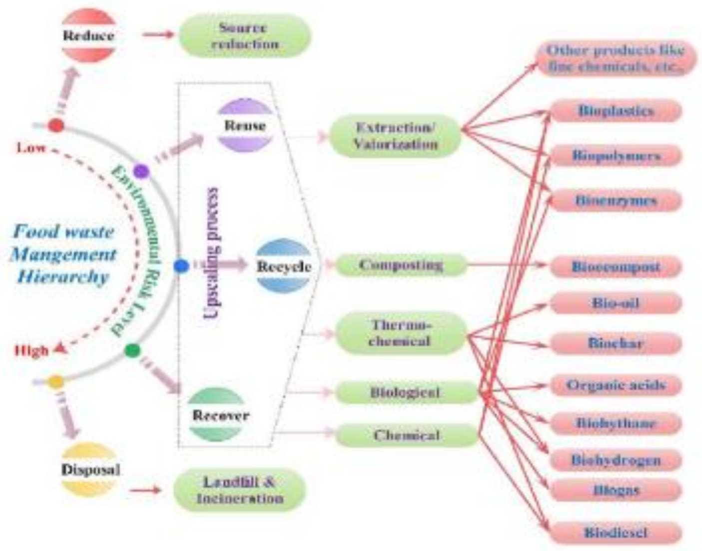


Fig. 2. Food waste management and upscaling process for biofuels and value-added products generation.

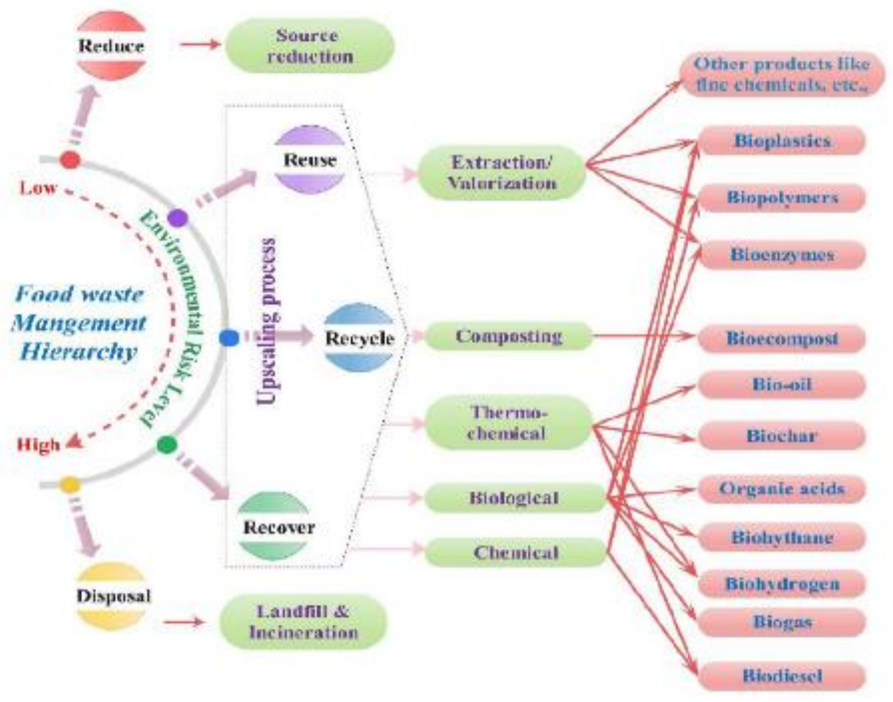
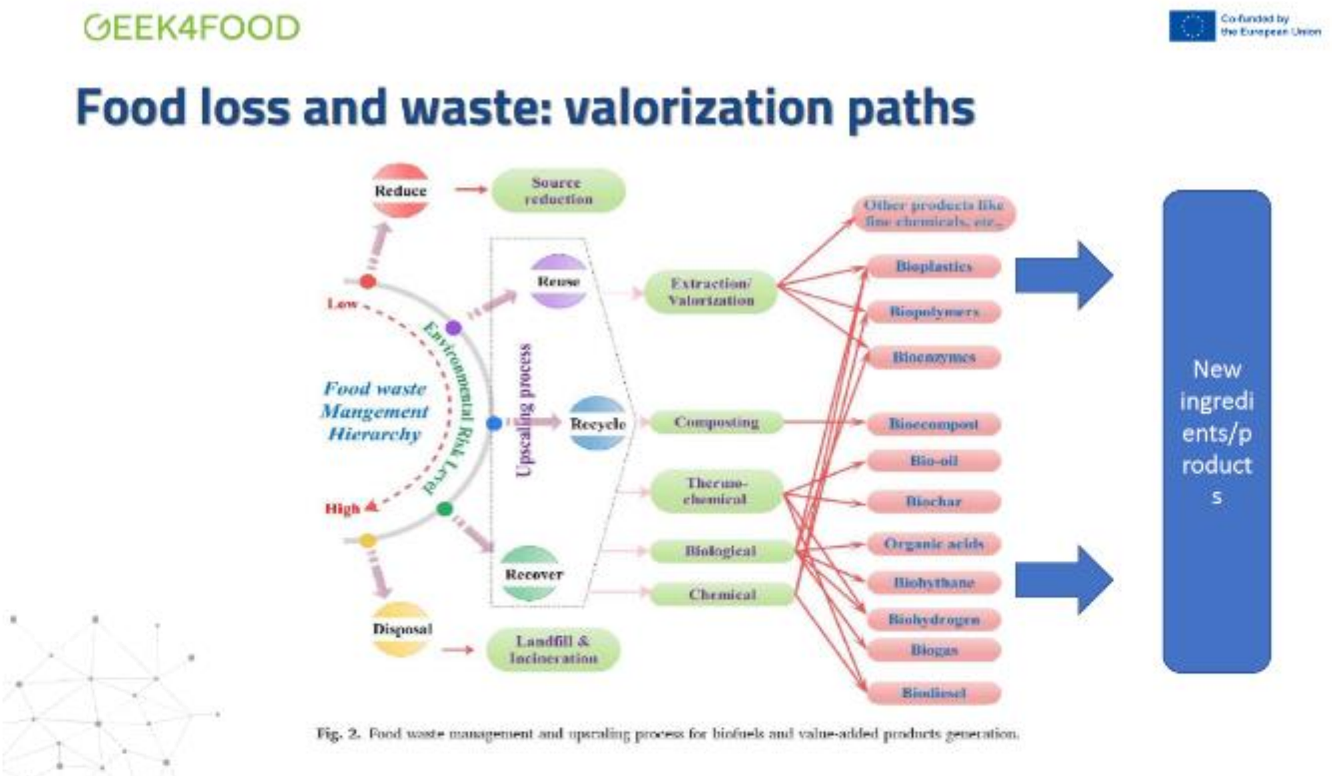


Fig. 2. Food waste management and upscaling process for biofuels and value-added products generation.



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Food loss and waste: prioritization of actions

FAO, 2019

Food-use-not-waste hierarchy:

- Emphasis is always placed on **prevention** and reduction of FW at source. Followed by **recovery & redistribution** of surplus food.
- Food waste, surplus food, scraps and byproducts can still be upcycled into food or valuable products or recycled through composting.
- The least favorable and most damaging option is disposal

Awareness raising and education of consumers is crucial for preventing food waste

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Recovery paths (bio-refinery) for FLW resources

Challenges

- COSTS
  - Each step has to consider plants, infrastructure, sta costs (and capabilities
  - CONVENTIONAL < costs than EMERGING
- SAFETY
  - Presence of contaminants (initial raw materials)
  - New generated compounds (e.g. Maillard reaction products, et.)
  - Legislation (food-grade, novel foods)
- TECHNOLOGIES
  - Availability
  - Optimisation
- STAFF
  - Knowledge, skills, capabilities

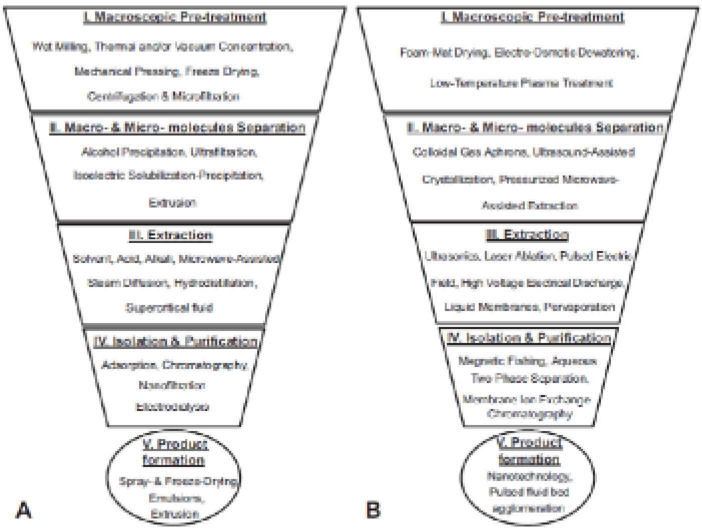

Fig. 1. Recovery stages of high-added value components from food wastes: (A) established and (B) emerging technologies.
Source: Galanakis , 2012

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Recovery paths (bio-refinery) for FLW resources

Strategy	Critical points	To be studied/developed/implemented
Reduce	….?	….
Upcycling: reuse (side-streams, waste, etc..)	• Quality and safety of the initial product • Suitability for the scope (individual raw material vs. formulated product)	• Understanding the technological performances • Definition of initial and final quality parameters • Identification and optimisation of technologies and/or formulations for the re-use (if needed) • Definition limits of the use
Up-cycling: recovery (biorefinery approaches)	• Quality and safety of the initial product • Costs	• Identification and optimisation of technologies • Understanding the technological performances of the biomolecules and process efficiency • Stabilisation technologies

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?

Food waste valorization: examples


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1. Duynie
DuyGrain® Upcycled Brewers Protein Concentrate
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Upcycled, plant-based, fibre rich, versatile and high in protein (DuyGrain®)
Obtained from Brewers' Spent Grains, co-product of the beer brewery industry; it mainly consists of the outside and protein parts of the barley.
Carrot Powder
From carrots from the food industry, co-product released during the processing of food grade carrots.
Made of: off-sized shapes or top and bottom pieces of carriots after washing or steam peeling
Sustainability savings on carbon footprint, water footprint and land use compared with conventional alternatives.
Upcycled Native Potato Starch
Obtained from off-sizes shapes EU, no-GMO potatoes
Suitable as thickener, structuring, etc…
https://www.duynie.com/en/food/products/


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1. Sweets Factory & University of Teramo (Reversed Incubator, www.askfood.eu)
askfood
Reversed Incubator
Company challenge:
Recovery of 2 by-products of of patisserie and bakery by-products:
- caramellised ground almonds
- meringue powder
Daily production, only partly upcycled
Issues: high presence of sugar and caramel (almonds)
Solution 1:
Formulation of a new dairy-dessert cream, high protein)
- cheesecake, filler for chilled pastries, croissant
Solution 2:
Re-formulation of a typical Italian cookie (nugat) made of the upcycled products

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Food loss and waste

VALORISATION

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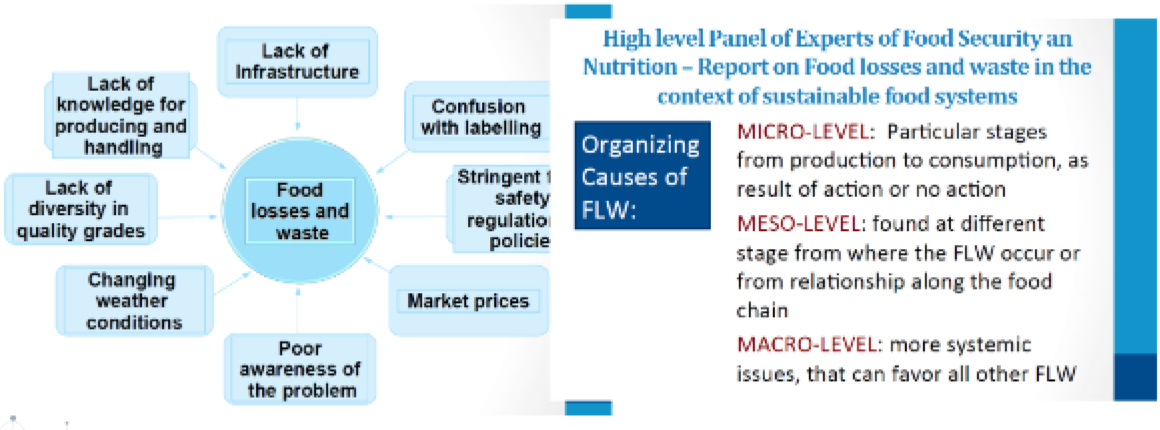
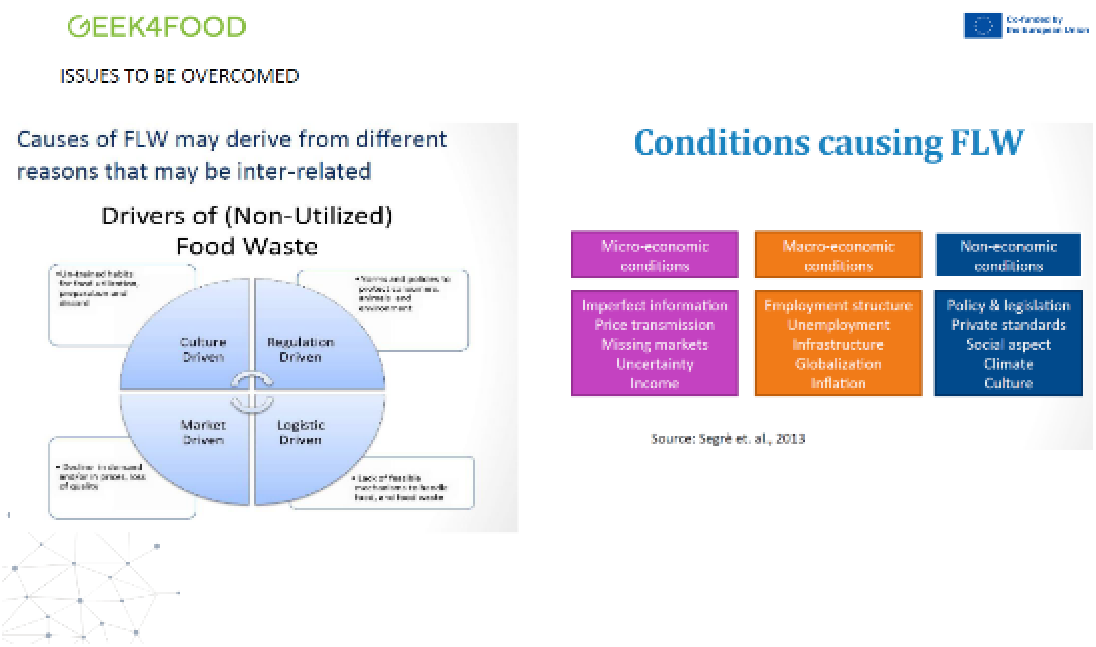
ISSUES TO BE OVERCOMED

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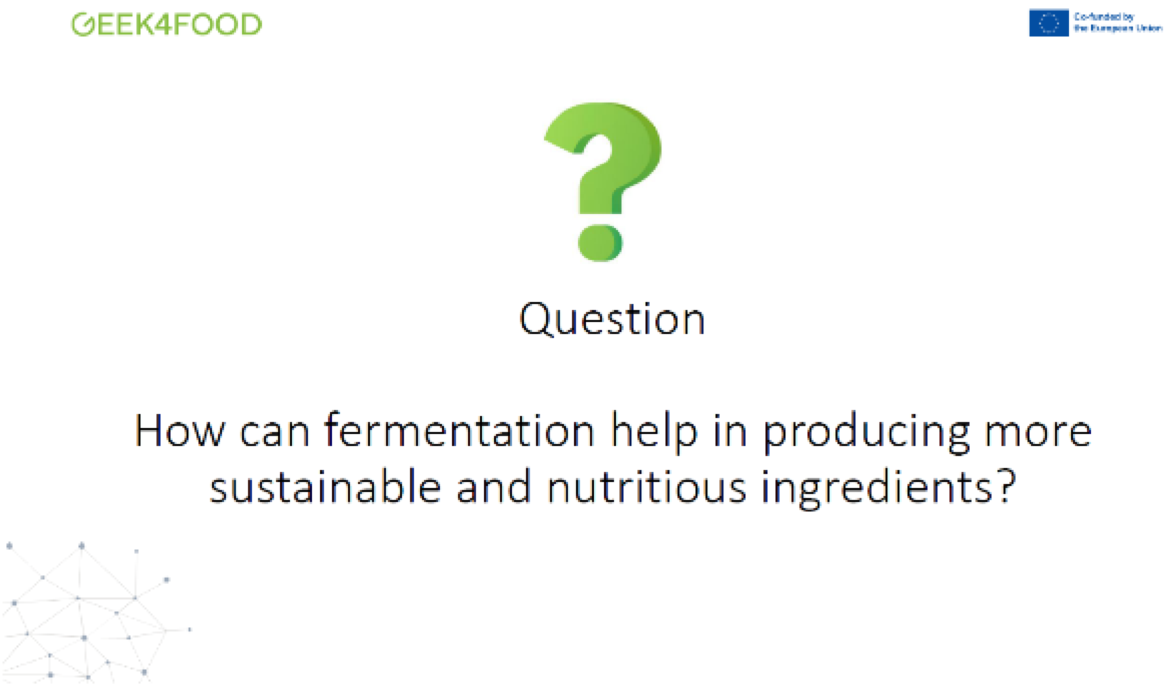
ISSUES TO BE OVERCOMED
Causes of FLW may derive from different reasons that may be inter-related
Drivers of (Non-Utilized) Food Waste
Culture Driven
Regulation Driven
Market Driven
Logistic Driven
Conditions causing FLW
Micro-economic conditions
Macro-economic conditions
Non-economic conditions
Imperfect information
Price transmission
Missing markets
Uncertainty
Income
Employment structure
Unemployment
Infrastructure
Globalization
Inflation
Policy & legislation
Private standards
Social aspect
Climate
Culture
Source: Segrè et. al., 2013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Question
How can fermentation help in producing more sustainable and nutritious ingredients?

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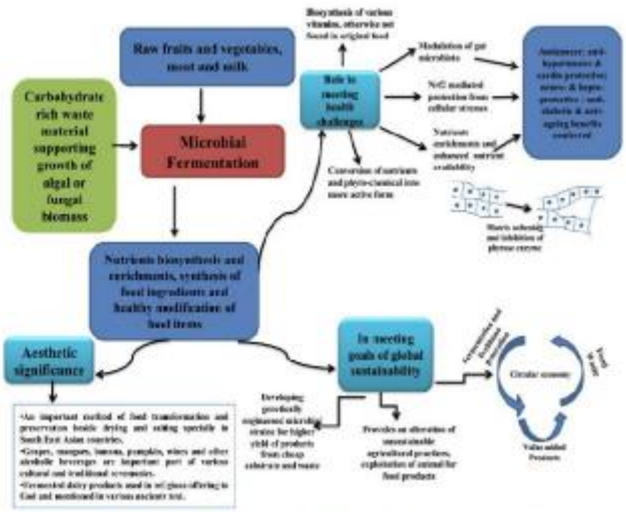
Discuss this diagram and consider the potential of fermentation.

Consider

- Fermented foods and health
- Fermented foods and the microbiome.
- Fermentation as a tool in valorization.



https://www.sciencedirect.com/science/article/pii/S016816052200137#f0005

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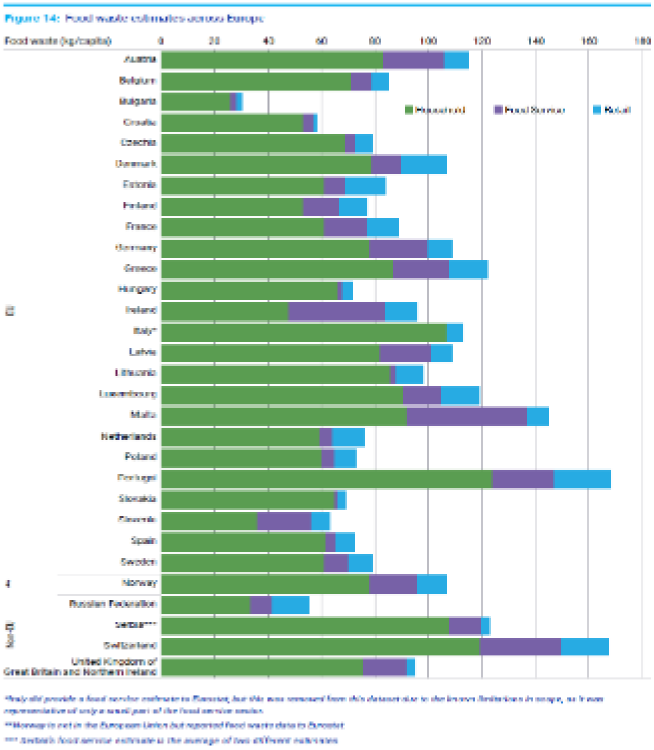
UNEP, 2024

Food waste

Statistics



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Case studies

https://foodtank.com/news/2024/04/companies-creating-upcycled-food-from-waste-products/

https://www.barry-callebaut.com/en/cacaofruit-ingredients-are-now-upcycled-certified

https://www.francescoselicato.it/birra-fatta-con-il-pane/

https://www.thegoodintown.it/biova-project-la-birra-che-nasce-dagli-scarti-del-pane-diventa-b-corp/

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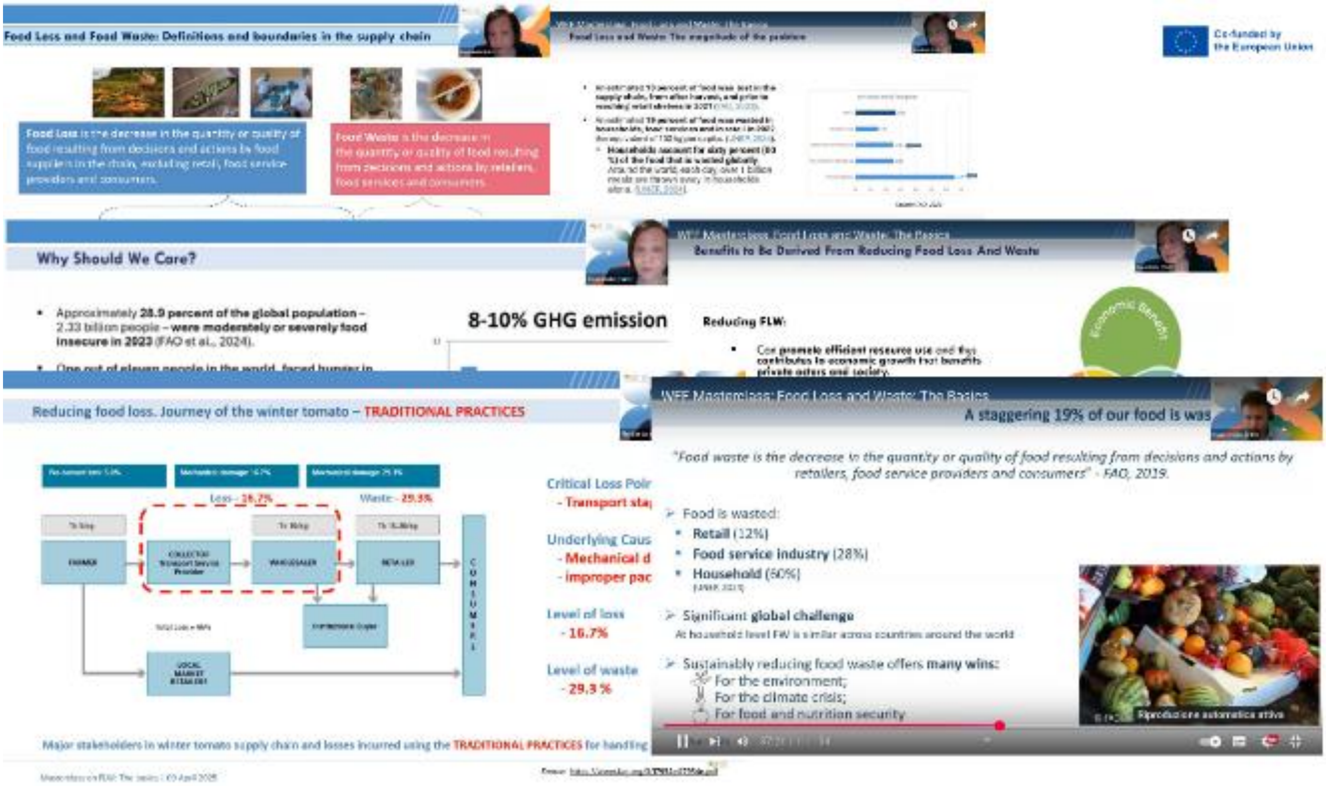
Confectionery upcycling

https://www.foodnavigator.com/Article/2024/05/16/how-fazer-makes-confectionery-with-upcycled-ingredients/

https://www.confectionerynews.com/Article/2025/03/05/upcycled-cacao-fruit-the-future-of-sustainable-chocolate-innovation/

https://www.candyrecycling.com/en/

https://refed.org/articles/guest-blog-combating-climate-change-through-upcycled-candy/ (candies from fruit and veg upcycled)
https://refed.org/stakeholders/manufacturers/


Food Loss and Food Waste: Definitions and boundaries in the supply chain
Why Should We Care?
8-10% GHG emission
Reducing FLW:
Benefits to Be Derived From Reducing Food Loss And Waste
Reducing food loss. Journey of the winter tomato – TRADITIONAL PRACTICES
Critical Loss Poir
Level of loss
- 16.7%
Level of waste
- 29.3 %
A staggering 19% of our food is was
"Food waste is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers" - FAO, 2019.
Food is wasted:
Retail (12%)
Food service industry (28%)
Household (60%)
Significant global challenge
Sustainably reducing food waste offers many wins:
For the environment;
For the climate crisis;
For food and nutrition security
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Prioritising actions towards food wast
Most preferred
Reduction at Source
Food Redistribution
Animal Feed
Industrial Uses and Fertilizers
Anaerobic Digestion
Composting
Incineration/ Landfill
Least preferred
FLW Prevention and Reduction
FLW Repurposing and Recycling
Incineration and Landfill
FAO, 2019
Food-use-not-waste hierarchy:
Emphasis is always placed on prevention and reduction of FW at source.
Followed by recovery & redistribution of surplus food.
Food waste, surplus food, scraps and byproducts can still be upcycled into food or valuable products or recycled through composting.
The least favorable and most damaging option is disposal
Awareness raising and education of consumers is crucial for preventing food waste
9 April 2025
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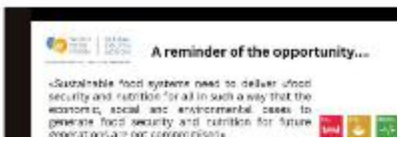
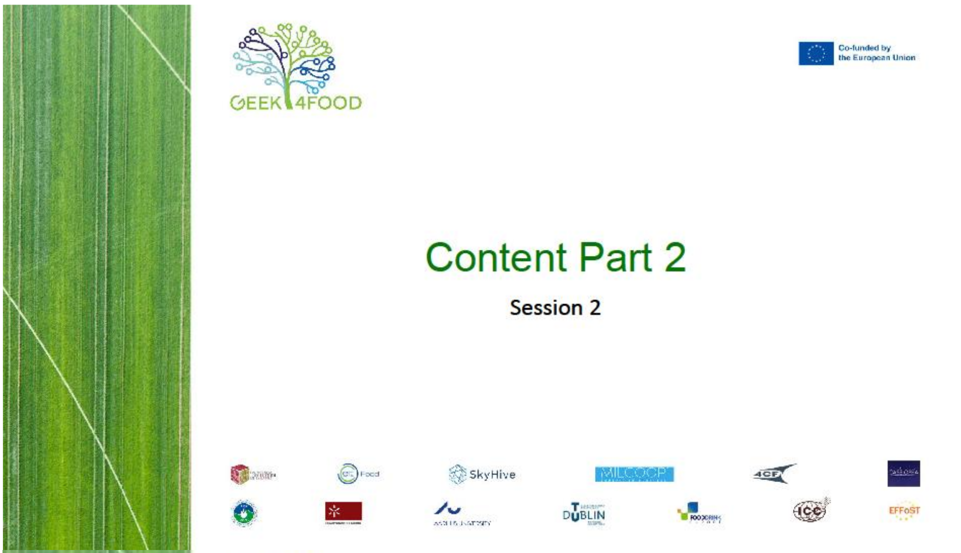

A reminder of the opportunity...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Content Part 2
Session 2
SkyHive
MILCOOP
DUBLIN
EFFoST


GEEK4FOOD
Technological functionalities of food waste for green ingredients design
DUBLIN


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'food ingredient' (definition)
any substance, including additives, used during the production of food, and present in the final product, in an unaltered or altered form.

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Quality and techno-functional properties of ingredients

Each ingredient/ (food, bio-) component may play a major role in determining the quality of the final product, i.e. it is characterised by a specific "functionality"

- nutritional
- technological
- sensorial
- health
- stability

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"techno-functionality» or technological functionality

"...*performing or being able to perform a function*...

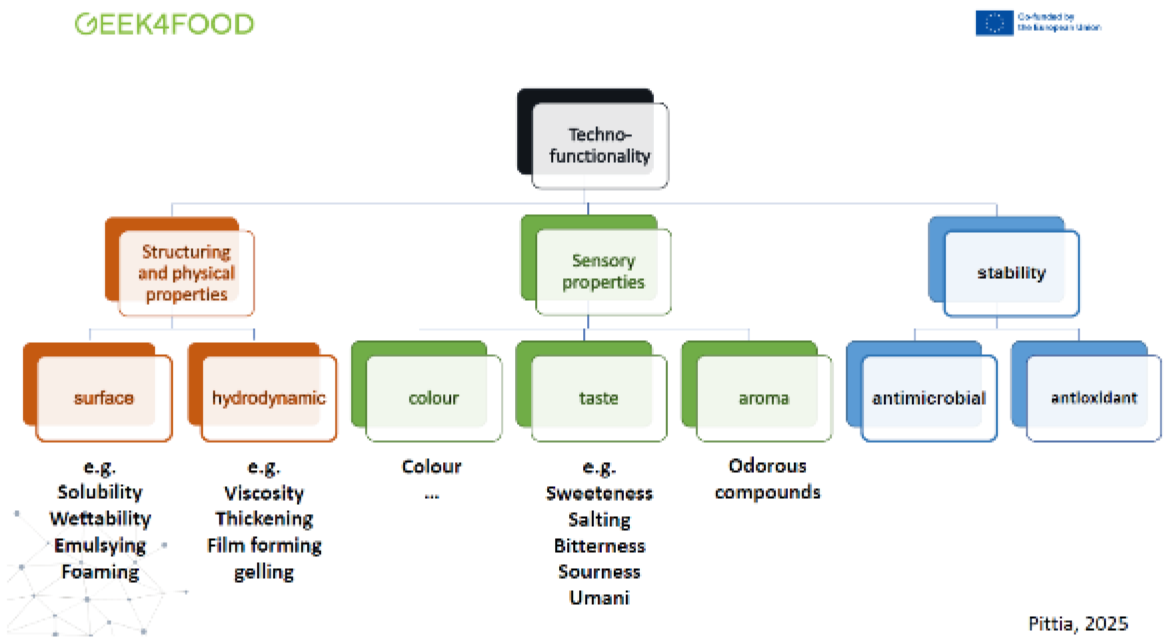
...

"each property of a food or food ingredient, excluded the nutritional ones, that influences its use and that is brought about from **how the different food components interact among them and/or the other components in the system.»**

(Mangino, 1984)

The **non-nutritional** characteristics of ingredients that influence their use and behavior during food processing and preparation.

These properties are crucial for creating specific food textures, viscosities, and structures and affect sensory acceptability and stability


GEEK4FOOD
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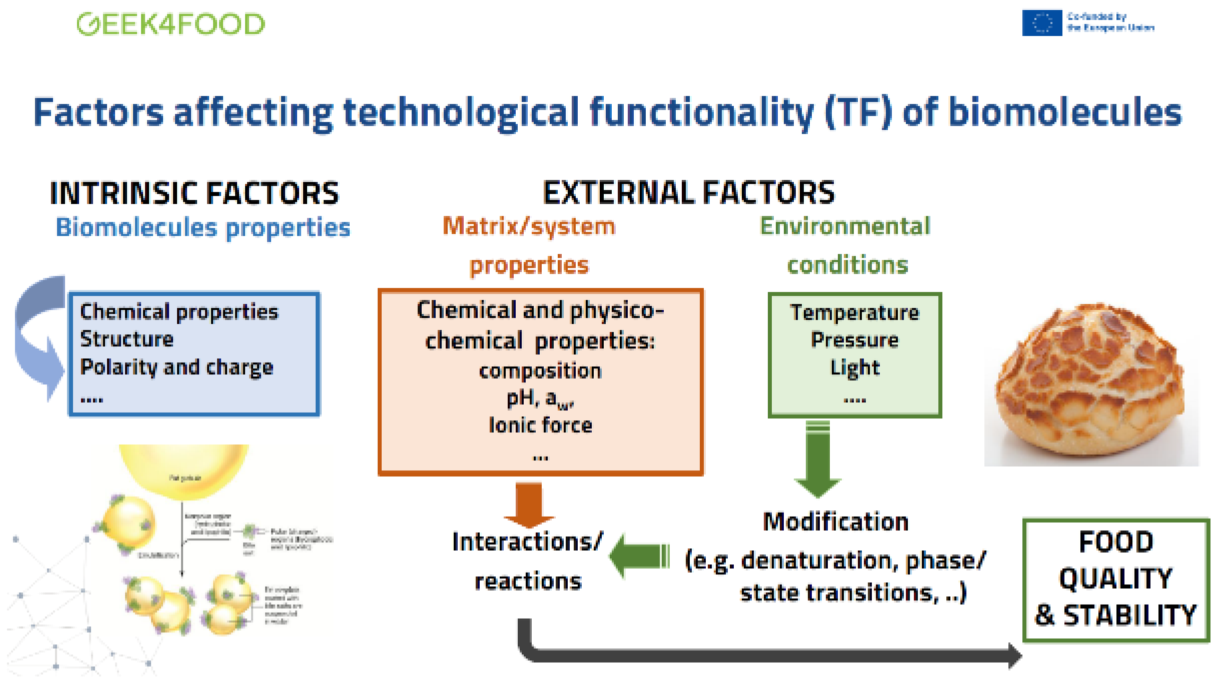
Techno-functionality
Structuring and physical properties
Sensory properties
stability
surface
hydrodynamic
colour
taste
aroma
antimicrobial
antioxidant
e.g.
Solubility
Wettability
Emulsying
Foaming
e.g.
Viscosity
Thickening
Film forming
gelling
Colour
...
e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani
Odorous compounds
Pittia, 2025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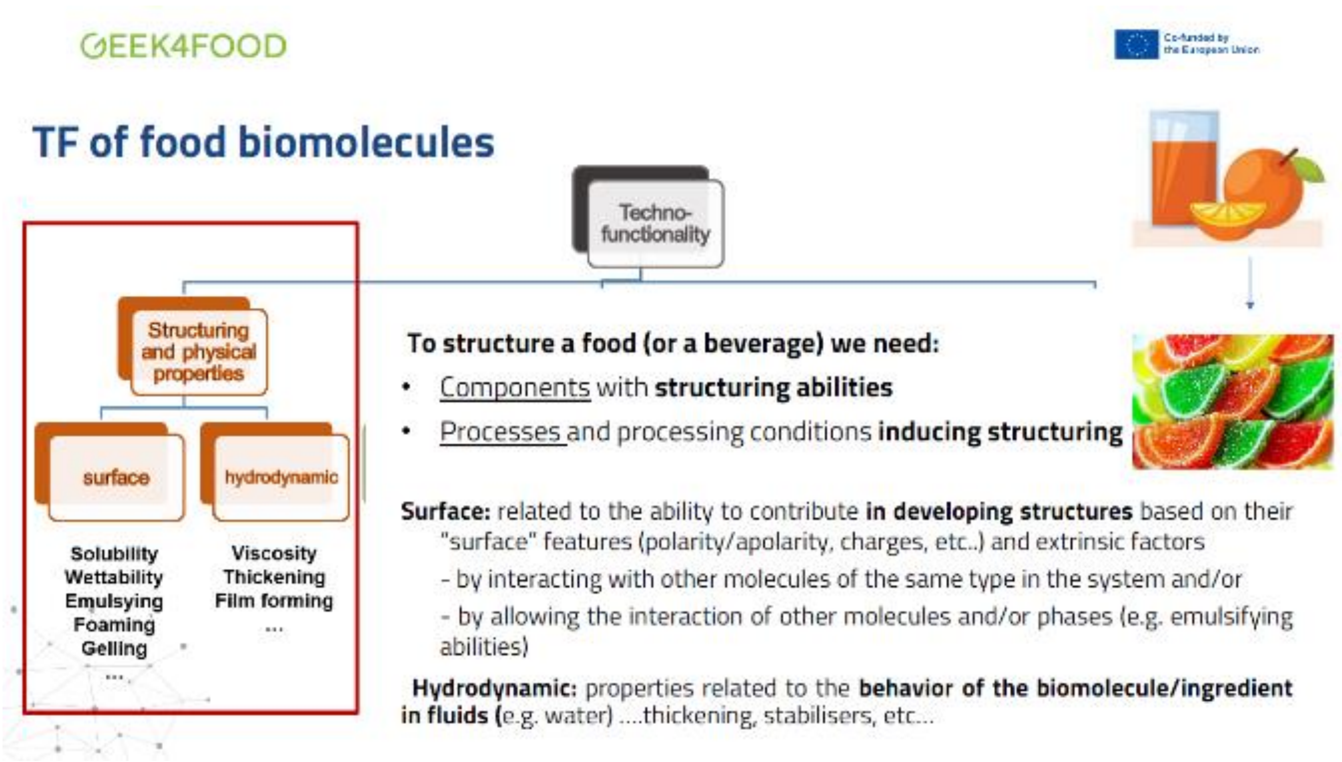
Factors affecting technological functionality (TF) of biomolecules
INTRINSIC FACTORS
Biomolecules properties
EXTERNAL FACTORS
Matrix/system properties
Environmental conditions
Chemical properties
Structure
Polarity and charge
....
Chemical and physico-chemical properties:
composition
pH, a_w,
Ionic force
...
Temperature
Pressure
Light
....
Interactions/ reactions
Modification
(e.g. denaturation, phase/ state transitions, ..)
FOOD QUALITY & STABILITY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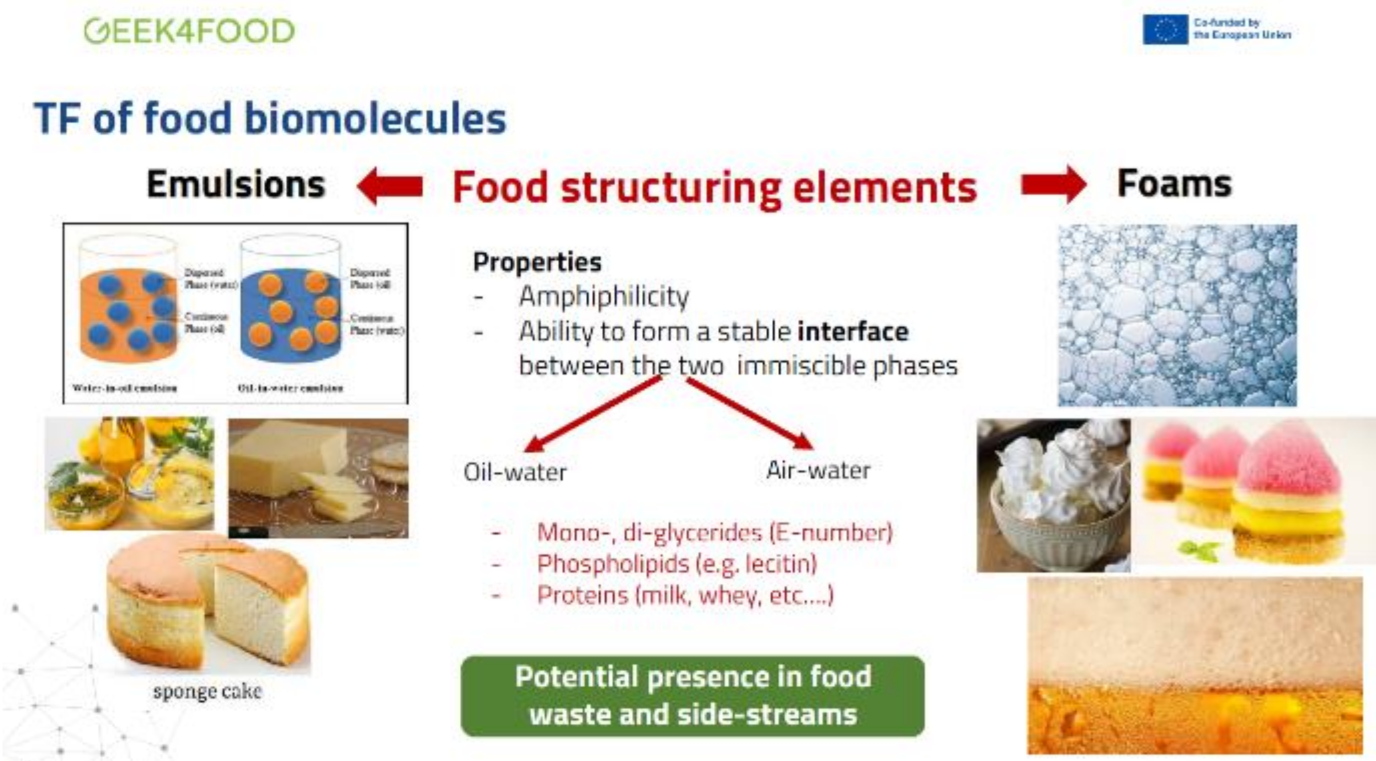
TF of food biomolecules
Techno-functionality
Structuring and physical properties
surface
hydrodynamic
Solubility
Wettability
Emulsying
Foaming
Gelling
…
Viscosity
Thickening
Film forming
…
To structure a food (or a beverage) we need:
• Components with structuring abilities
• Processes and processing conditions inducing structuring
Surface: related to the ability to contribute in developing structures based on their "surface" features (polarity/apolarity, charges, etc..) and extrinsic factors
- by interacting with other molecules of the same type in the system and/or
- by allowing the interaction of other molecules and/or phases (e.g. emulsifying abilities)
Hydrodynamic: properties related to the behavior of the biomolecule/ingredient in fluids (e.g. water) ….thickening, stabilisers, etc…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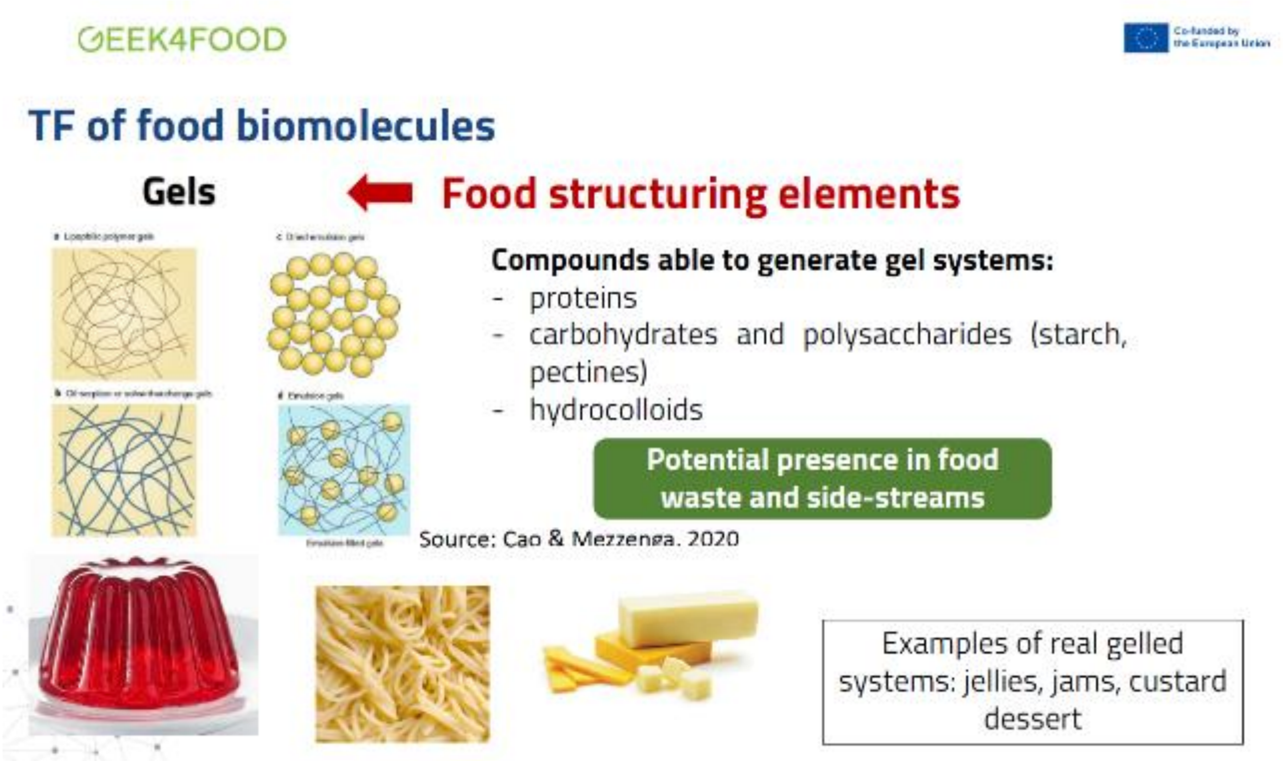
TF of food biomolecules
Emulsions
Food structuring elements
Foams
Water-in-oil emulsion
Oil-in-water emulsion
sponge cake
Properties
- Amphiphilicity
- Ability to form a stable interface between the two immiscible phases
Oil-water
Air-water
- Mono-, di-glycerides (E-number)
- Phospholipids (e.g. lecitin)
- Proteins (milk, whey, etc….)
Potential presence in food waste and side-streams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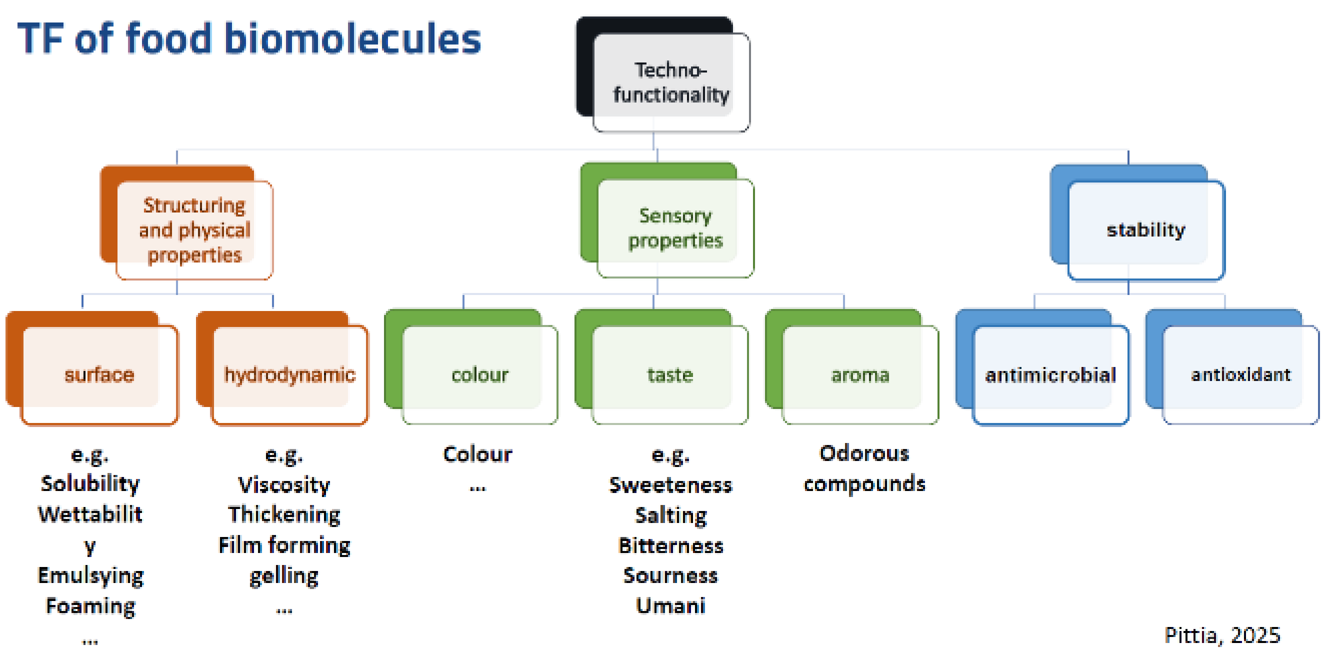
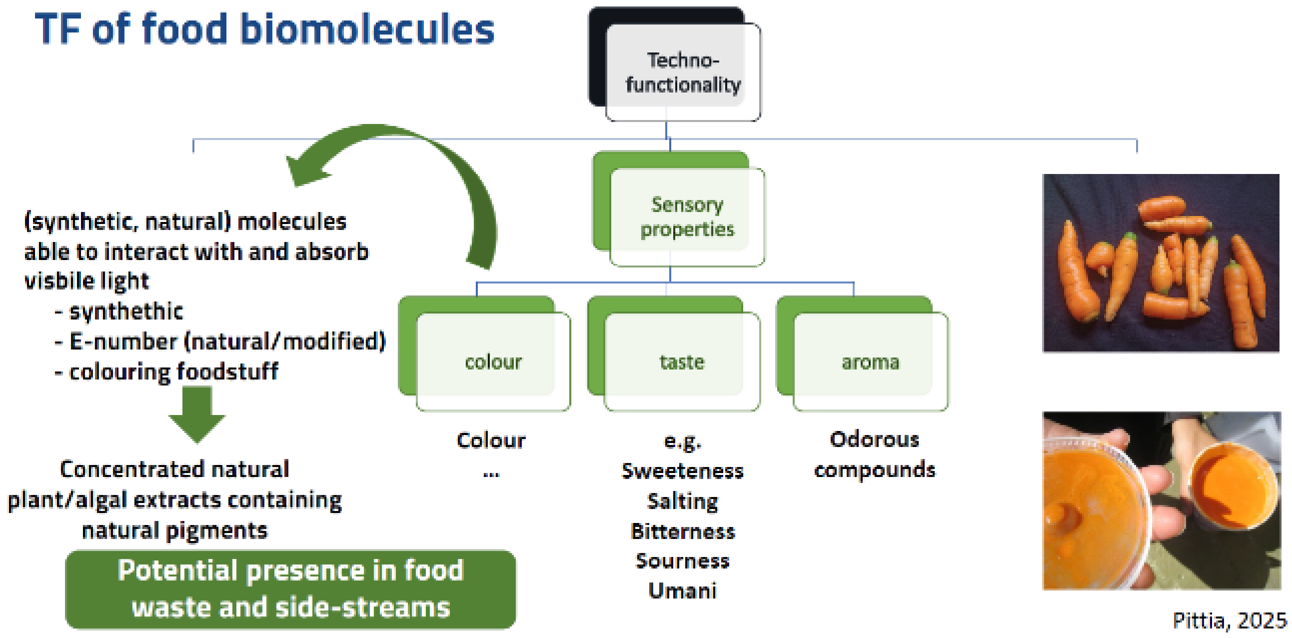
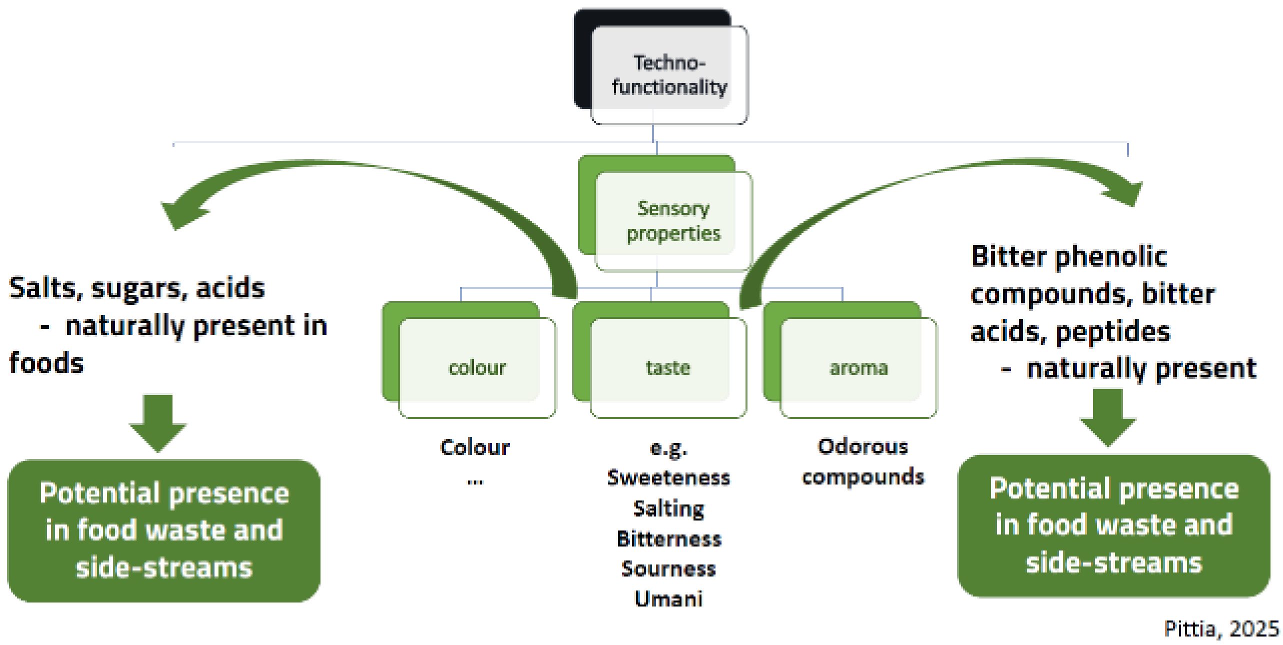
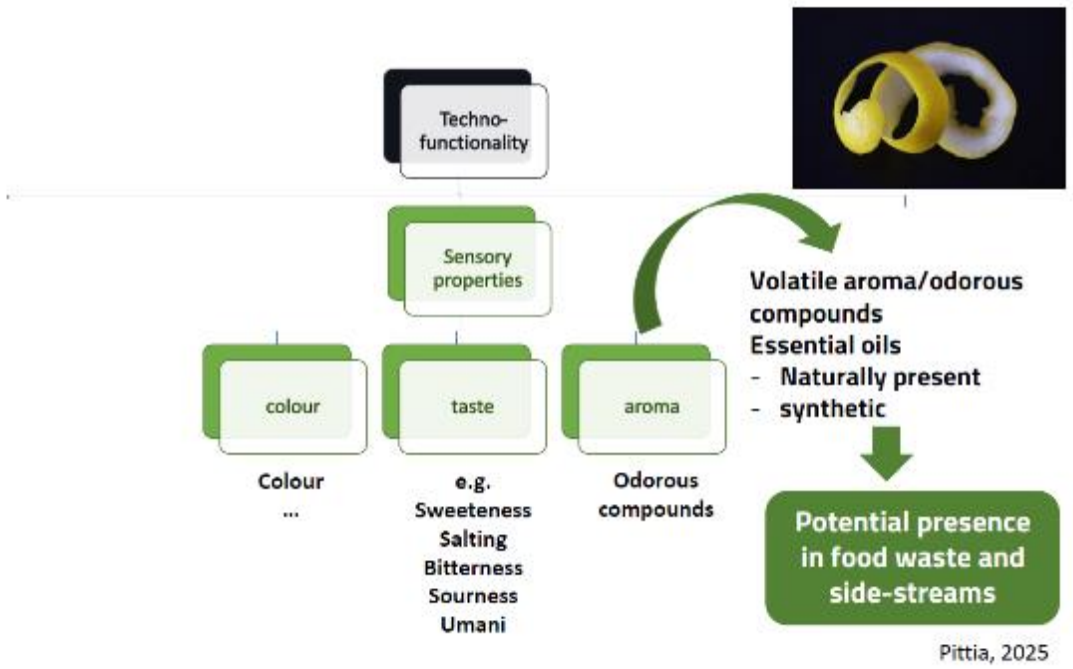
TF of food biomolecules
Gels
Food structuring elements
Compounds able to generate gel systems:
- proteins
- carbohydrates and polysaccharides (starch, pectines)
- hydrocolloids
Potential presence in food waste and side-streams
Source: Cao & Mezzenga, 2020
Examples of real gelled systems: jellies, jams, custard dessert


TF of food biomolecules
Techno-functionality
Structuring and physical properties
Sensory properties
stability
surface
hydrodynamic
colour
taste
aroma
antimicrobial
antioxidant
e.g.
Solubility
Wettability
Emulsying
Foaming
...
e.g.
Viscosity
Thickening
Film forming
gelling
...
Colour
...
e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani
Odorous compounds
Pittia, 2025


TF of food biomolecules
Techno-functionality
Sensory properties
colour
taste
aroma
(synthetic, natural) molecules able to interact with and absorb visbile light
- synthethic
- E-number (natural/modified)
- colouring foodstuff
Concentrated natural plant/algal extracts containing natural pigments
Potential presence in food waste and side-streams
Colour
...
e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani
Odorous compounds
Pittia, 2025


Techno-functionality
Sensory properties
colour
taste
aroma
Salts, sugars, acids
- naturally present in foods
Potential presence in food waste and side-streams
Colour
...
e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani
Odorous compounds
Bitter phenolic compounds, bitter acids, peptides
- naturally present
Potential presence in food waste and side-streams
Pittia, 2025



Antioxidants and anti-microbials:

- Natural (e.g. plant extracts, terpens, glucosinolates derivatives, alkaloids, essential oils, pure compounds)
- Peptides
- Enzymes
- *Synthetic (e-number, use in foods regulated by law)*

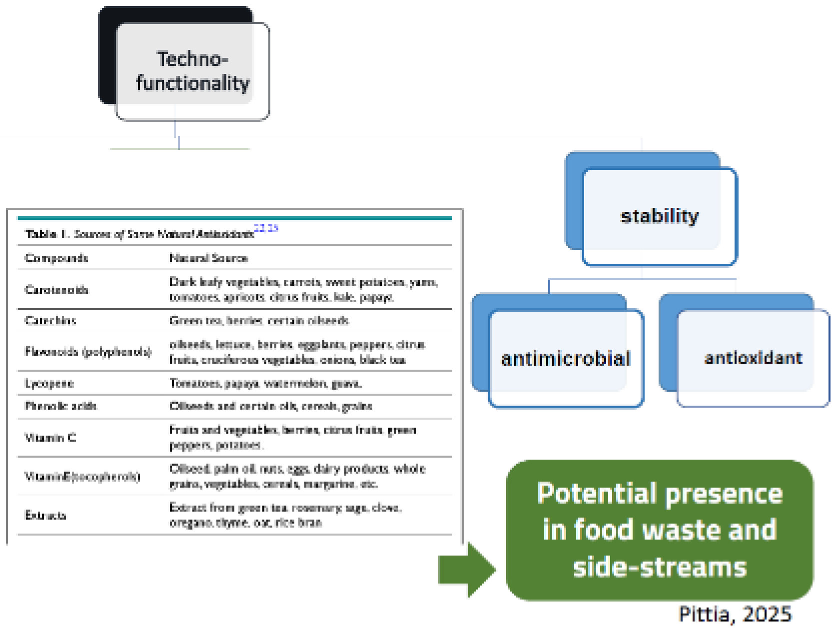
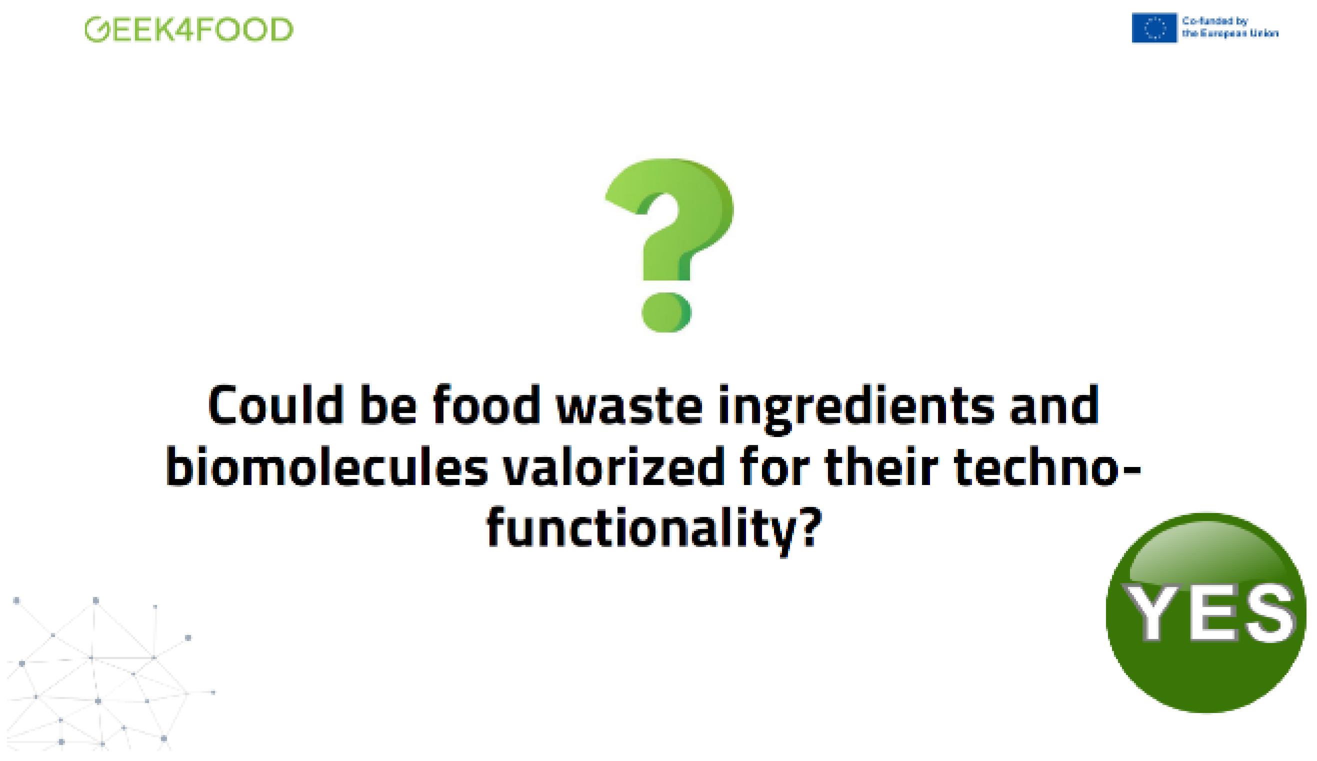


Table 1. *Sources of Some Natural Antioxidants*[22,23]

Compounds	Natural Source
Carotenoids	Dark leafy vegetables, carrots, sweet potatoes, yams, tomatoes, apricots, citrus fruits, kale, papaya.
Catechins	Green tea, berries, certain oilseeds
Flavonoids (polyphenols)	oilseeds, lettuce, berries, eggplants, peppers, citrus fruits, cruciferous vegetables, onions, black tea
Lycopene	Tomatoes, papaya, watermelon, guava.
Phenolic acids	Oilseeds and certain oils, cereals, grains
Vitamin C	Fruits and vegetables, berries, citrus fruits, green peppers, potatoes.
VitaminE(tocopherols)	Oilseed, palm oil, nuts, eggs, dairy products, whole grains, vegetables, cereals, margarine, etc.
Extracts	Extract from green tea, rosemary, sage, clove, oregano, thyme, oat, rice bran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Could be food waste ingredients and biomolecules valorized for their techno-functionality?
YES


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Could these raw materials, food waste and side-streams processing products become food ingredients (or additives?)
YES

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Issues and challenges

1. LEVEL OF PROCESSING

- **basic/minimal:** sanitisation, stabilisation (es. such)
  e.g. powders, extracts…
  High level of compositional complexity
  Use: bulking agents, colouring, flavouring …

- **advanced/biorefinery approaches** (extraction, isolation, purification)
  - different levels

From simple solid-liquid separation (see above) to pure compounds/extracts (obtained by complex sequence of process stages) with specific techno-functionality

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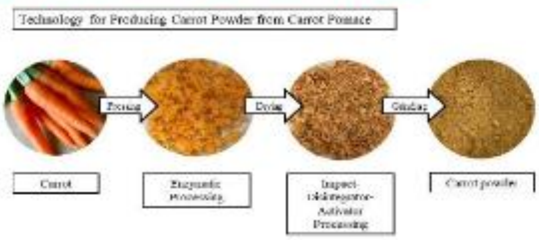
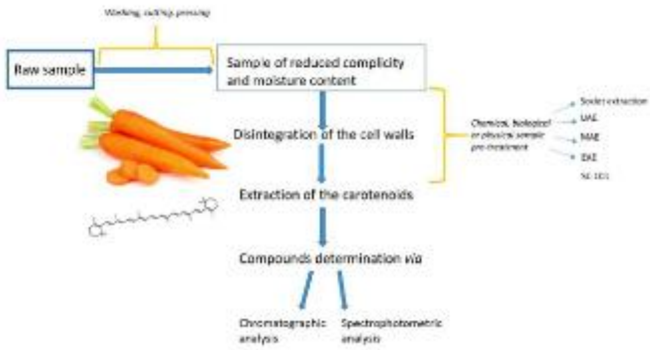
Issues and challenges



Baskovtceva et al., 2023
Carrot pomace
Use of Enzymes to enhance content of b-carotene in carrot powder

High health potential powder
Medium-impact processing



Mi¸ekus et al, 2019
Green Chemistry Extractions of Carotenoids from Daucus carota L.

Pure compound
High-impact (sustainable) processing

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Food waste and side-streams: Technological functionality of biomolecules obtained from food waste (Pittia, 2018)

Compound	Origin/source of waste and by-products	Solubility	Technological/quality functionality
Pectins	Fruit and vegetable peels, pomaces	Water	Gelling and structuring Surface activity
Proteins	Meat (animal), Fish Milk (whey), Eggs Vegetables (legumes) (micro-)algae, seaweeds , Seeds	Water, Amphyphylic behaviour	Emulsifying and foaming activity, Gelling and structuring Binding (aroma, lipids) Antioxidant properties
Peptides and aminoacids	Meat (animal), Fish, Milk Vegetables, Seeds	Water Amphyphylic behaviour	Solubility, Emulsifying and foaming activity Bioactivity, Health properties
Oligosaccharides	Fruit and vegetables	Water	Solubility Healthy properties
Polysaccharides	Fruit and vegetables	Water	Water holding and binding properties Gelling and structuring
Hydrocolloids and gums	Vegetables, seeds	Water	Gelling and structuring Water holding capacity
Oils and fats	Meat, Fish, Seeds	Oil	Structure forming, Binding (aroma, proteins) Sensory properties
Phenolic compounds	Plant and fruit peels, pomace, and extracts	Water-to-oil depending on chemical structure and molecular weight	Antioxidant , Health properties Surface activity Sensory properties (colour and taste)
Phytochemicals	Plant extracts	Water-to-oil depending on chemical structure and molecular weight (Some) amphiphilic behavior	Solubility, Surface activity , Emulsifying properties Healthy properties
Pigments	Plant and fruit extracts, Algae and seaweeds residues, Meat (myoglobin)	Water-to-oil depending on the compound	Colour and sensory properties
Flavour compounds and essential oils	Plant and fruit extracts	Water-to-oil depending on the compound	Aroma and sensory properties

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Issues and challenges

2. SAFETY AND REGULATIONS

a. **waste and side-streams may**:

- have high level of microbial and chemical contamination
- highly prone to degrade (enzymes, chemical reactions, microbial growth)

  → **stabilisation, sanitisation**

b. Valorisation of biomolecules not used for food purposes

- approval required to become food grade according to the (EU) «novel foods» regulations

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Issues and challenges

3. COSTS and ECONOMIC benefits

- Each process/step has specific costs (end environmental impact)
- Evaluate the availability of technologies + need of process optimisation
- Need to evaluate costs/benefits in relation to the added-value and technological potential of the final product

4. SKILLS and Human Capital COMPETENCES

- Food waste and side-streams management and processing skills
- Sustainability and green skills


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Waste valorisation in food product design
Session 3: Biorefinery approaches and innovative technologies for food ingredients
SkyHive
DUBLIN
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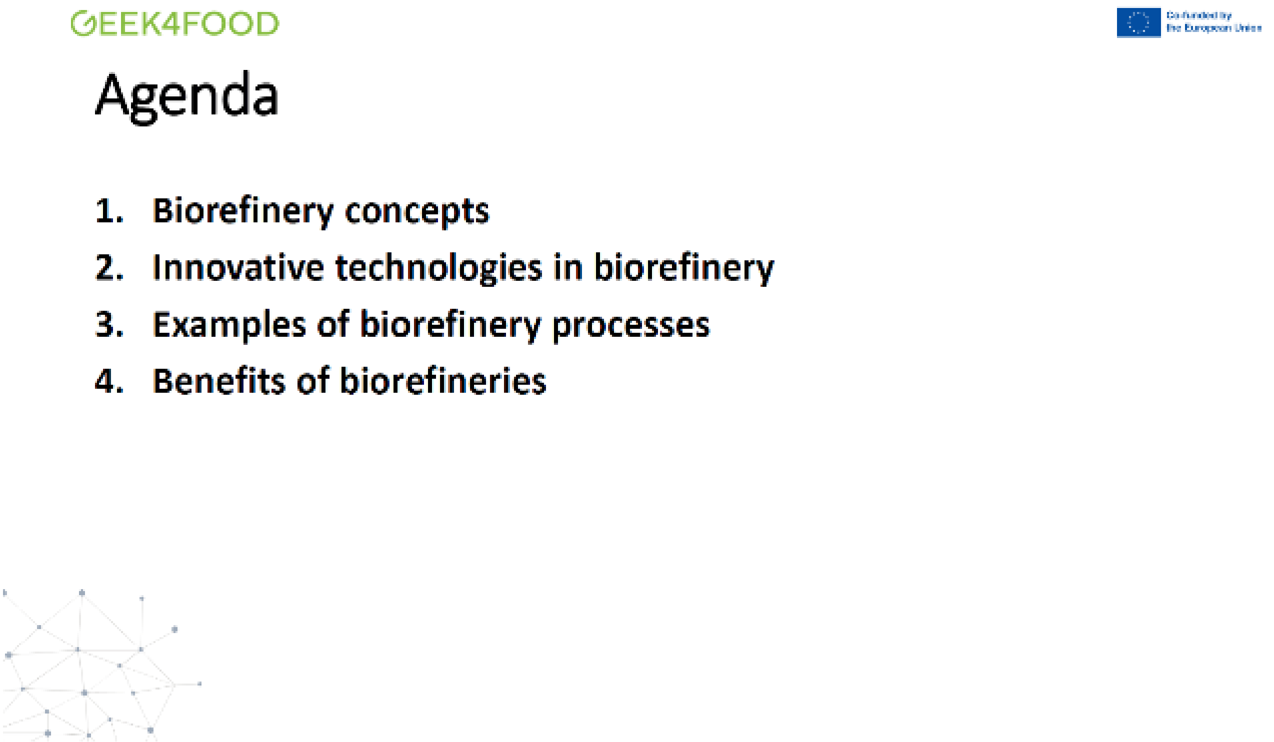
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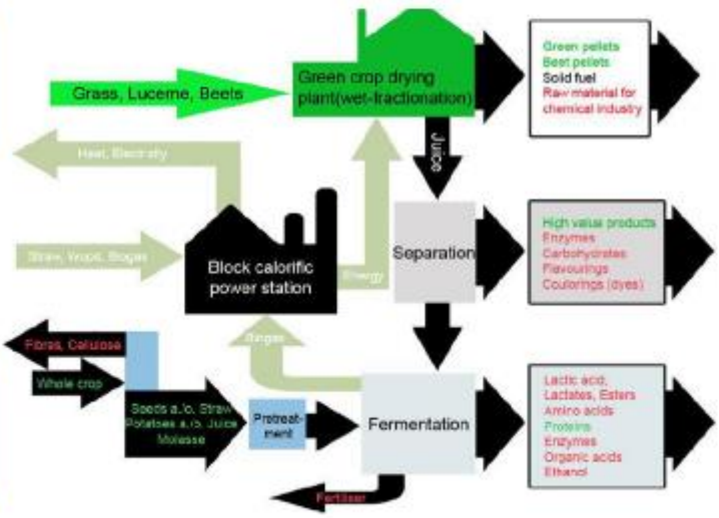
Agenda
1. Biorefinery concepts
2. Innovative technologies in biorefinery
3. Examples of biorefinery processes
4. Benefits of biorefineries

Why biorefineries

- Overproduction of biomass
- Alternative sustainable utilisation.
- Example: Biorefinery Ireland is to design, construct and operate a commercial green biorefinery in Ireland using herbaceous biomass such as grass, immature cereals, legumes and sugar beet as feedstock; and produce energy, biofuels and high value biochemicals with food, feed and industrial applications.
- **One of the instruments to improve the sustainability of the food system.**

1. What is a Biorefinery?

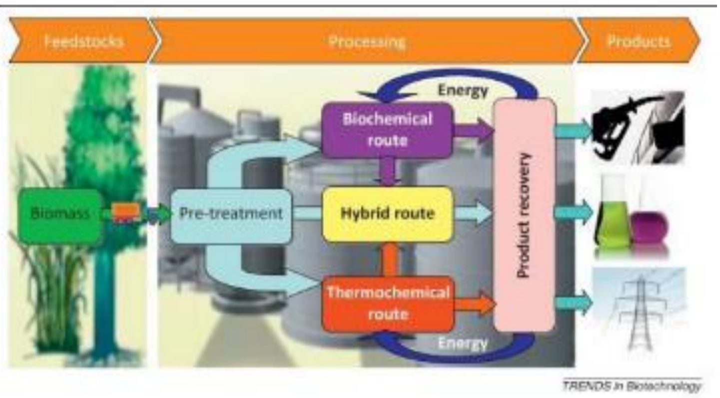
- Biorefineries leverage renewable biomass (e.g. food waste)
- Produce a range of added value products, including food ingredients, through innovative technologies and integrated processes.
- Biorefineries offer a sustainable alternative to traditional manufacturing, reducing waste, and creating new economic opportunities.



1. Biorefinery approaches associated to food systems

Integrated Biorefineries:

- Combine various conversion processes (thermochemical, biochemical, biological) to maximize resource utilization and produce a spectrum of products.



https://doi.org/10.1016/j.tibtech.2013.10.009

1. Biorefinery approaches associated to food systems

Food Waste Biorefineries:

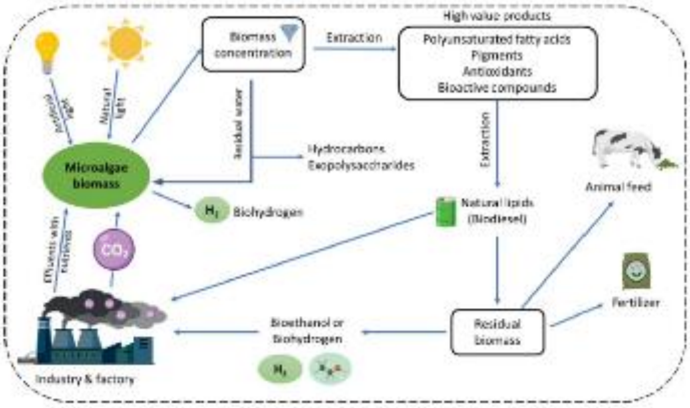
- Specifically address food waste streams, converting them into valuable ingredients like biofuels, chemicals, and bio-based materials.

https://doi.org/10.1016/j.biortech.2017.07.176

1. Biorefinery approaches associated to food systems

Microalgae Biorefineries:

- Focus on cultivating microalgae for high-value compounds such as pigments, vitamins, and polyunsaturated fatty acids.



https://doi.org/10.1016/j.ecmx.2022.100323

2. Innovative technologies

Enzymatic Conversion:

Utilize enzymes to break down complex biomass components into simpler, more usable forms, aiding in the extraction of valuable ingredients.

Fermentation:

Employ microorganisms to ferment biomass into products like alcohols, organic acids, and biogas.

Anaerobic Digestion:

Break down organic matter in the absence of oxygen to produce biogas, a renewable energy source.

Hydrothermal Carbonization:

A thermochemical process that converts biomass into a carbon-rich solid (biochar) and a liquid phase containing valuable chemicals.

Advanced Extraction Techniques:

- Develop methods like high hydrostatic pressure, ultrasound, and microwave-assisted extraction for efficient and environmentally friendly ingredient recovery.

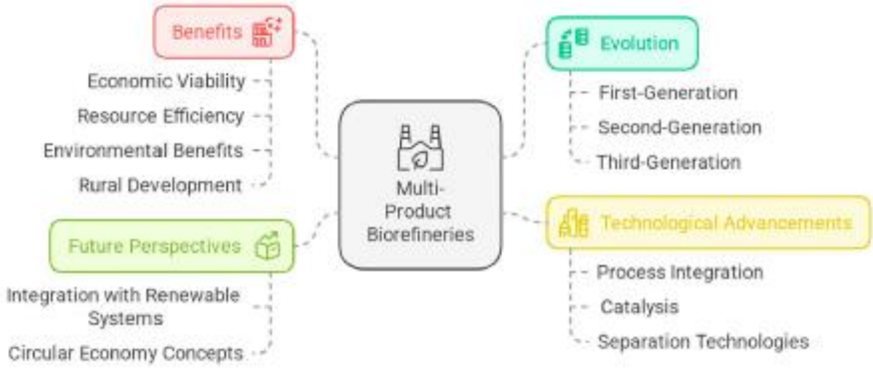
3. Examples of Food Ingredients Produced Through Biorefineries

Polyphenols and Polysaccharides:	• Extracted from plant and animal sources, these compounds offer various health benefits.
Fucoidan and Beta-glucans:	• Recovered from seaweed, these ingredients possess beneficial properties like antioxidant and immunomodulatory effects.
Alginates:	• Derived from seaweed, they are used in food processing as a thickening agent and stabilizer.
Prebiotics:	• Derived from agro-industrial sources, they enhance gut health and contribute to the development of functional foods.
Microalgae-based Products:	• Spirulina, a type of microalgae, is a rich source of protein, vitamins, minerals, and antioxidants, offering a sustainable food and feed source.

4. Benefits of Biorefineries

Sustainable Resource Management:	Circular Economy:	Enhanced Resource Efficiency:	Development of Functional Foods:
• Utilizes renewable biomass, reducing reliance on fossil fuels and minimizing waste.	• Promotes the closed-loop recycling of resources, minimizing environmental impact and creating new economic opportunities.	• Maximizes resource utilization and minimizes waste generation, contributing to a more sustainable and efficient food industry.	• Enables the production of food ingredients with enhanced health benefits, addressing the growing demand for functional foods.

4. Multi-product biorefineries: evolution, benefits, and future



https://doi.org/10.20935/AcadEnergy7605

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Waste valorisation in food product design

Session : Circular economy, industrial sustainability and social impact

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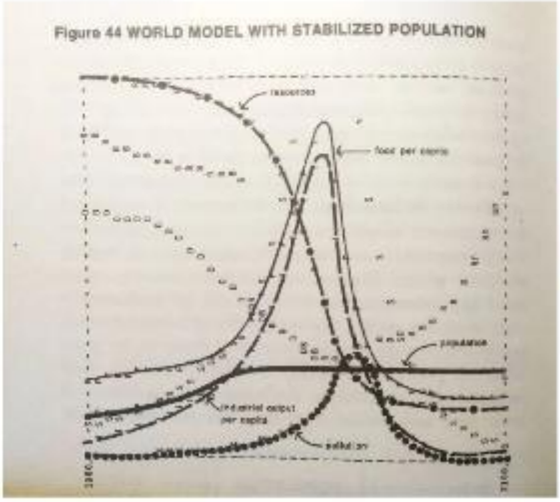
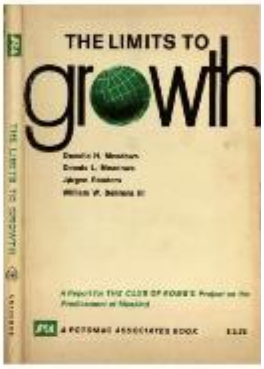
Agenda

1. **The limits of growth.**
2. **Principles of the circular economy.**
3. **Industrial sustainability.**
4. **Social impact of the circular economy.**

1. The Limits of growth. Club de Roma 1972.

- World has interconnected systems
- If growth trends continue unchanged there is a large possibility of an overshoot of the carrying capacity of the Earth in the next 100 years





1. From a linear to a circular economy

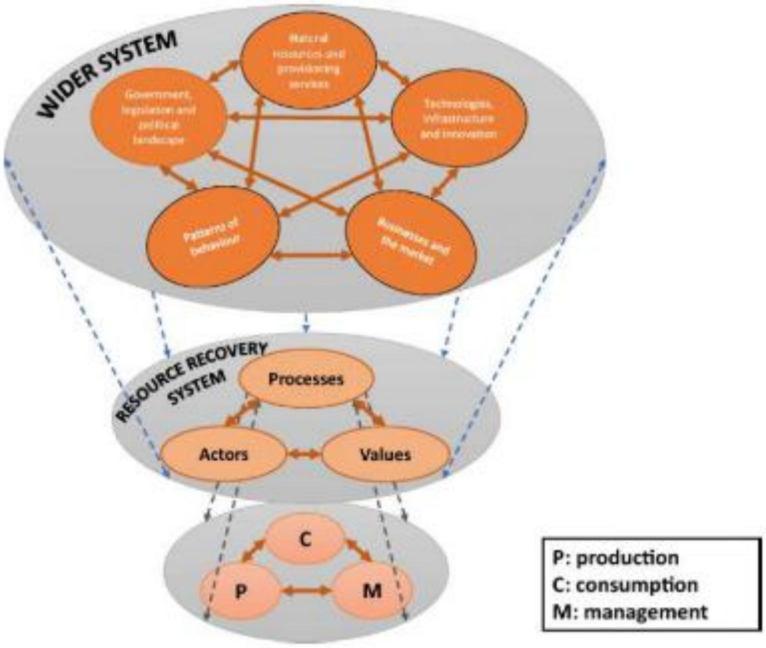
https://umaine.edu/sustainability/2021/04/25/food-waste/

2. The Circular Economy model

2. Principles of circularity

Reduce:	Reuse:	Recycle:	Recover:	Design for Circularity:
• Minimize the use of raw materials and energy in the production process.	• Extend the lifespan of products through repair, refurbishment, and re-purposing.	• Recover valuable materials from end-of-life products and use them in new production cycles.	• Extract energy from waste materials through incineration or other processes.	• Develop products and systems that are designed to be easily repaired, reused, and recycled.

2. Circularity and Systems Thinking



https://link.springer.com/article/10.1007/s11356-020-11725-9

3. Circularity and industrial sustainability

Resource Efficiency: Circular economy practices encourage industries to use resources more efficiently, reducing the demand for raw materials and energy.

Waste Reduction: By designing products for durability, reparability, and recyclability, industries can significantly reduce waste generation.

Innovation: Circular economy initiatives can drive innovation in product design, manufacturing processes, and business models, fostering new industries and creating economic opportunities.

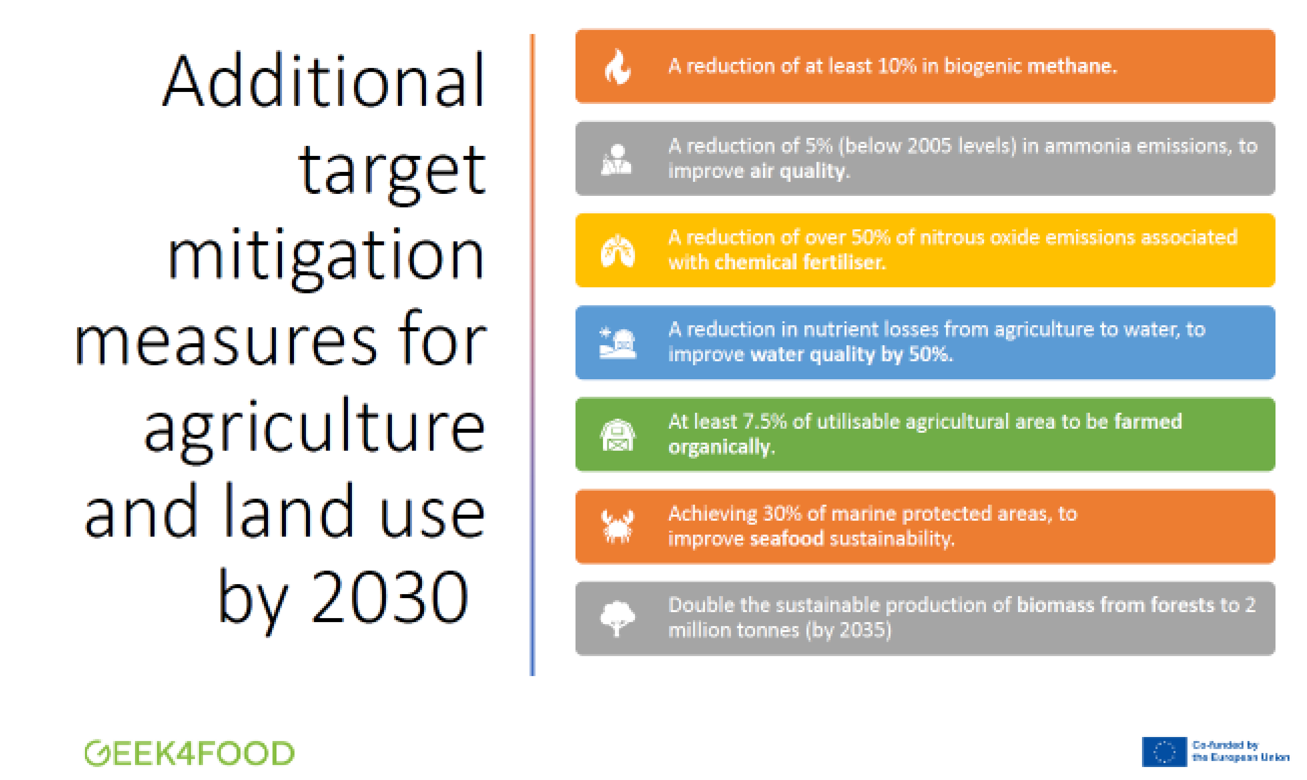
Climate Change Mitigation: Reducing waste and resource consumption through circular practices can lead to a reduction in greenhouse gas emissions, contributing to climate change mitigation efforts.

4. Changing the system. Climate KIC Deep Demonstration Transforming Ireland Agrifood system

4. Seven Social Impact Areas of the Deep Demonstration for Ireland

- 2050 focus
  - Vision 2050: re-imagine Ireland's land and agri-food system
  - Grow the sector through innovation and investment in new value chains
  - Implement circular bio-economy models at regional or multiple value chains level
- 2030 focus
  - Diversify incomes through carbon farming and nature credit frameworks
  - Produce and certify climate-neutral beef
  - Accelerate emission reduction and sustainability in dairy farms
  - Grow and diversify the tillage sector

https://www.climate-kic.org/wp-content/uploads/2023/03/EIT-Climate-KIC-Ireland-Land-Agri-Food-Systems-Map.pdf


Additional target mitigation measures for agriculture and land use by 2030
A reduction of at least 10% in biogenic methane.
A reduction of 5% (below 2005 levels) in ammonia emissions, to improve air quality.
A reduction of over 50% of nitrous oxide emissions associated with chemical fertiliser.
A reduction in nutrient losses from agriculture to water, to improve water quality by 50%.
At least 7.5% of utilisable agricultural area to be farmed organically.
Achieving 30% of marine protected areas, to improve seafood sustainability.
Double the sustainable production of biomass from forests to 2 million tonnes (by 2035)
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Activity/case study 1
From waste to value:
the case of chocolate
SkyHive
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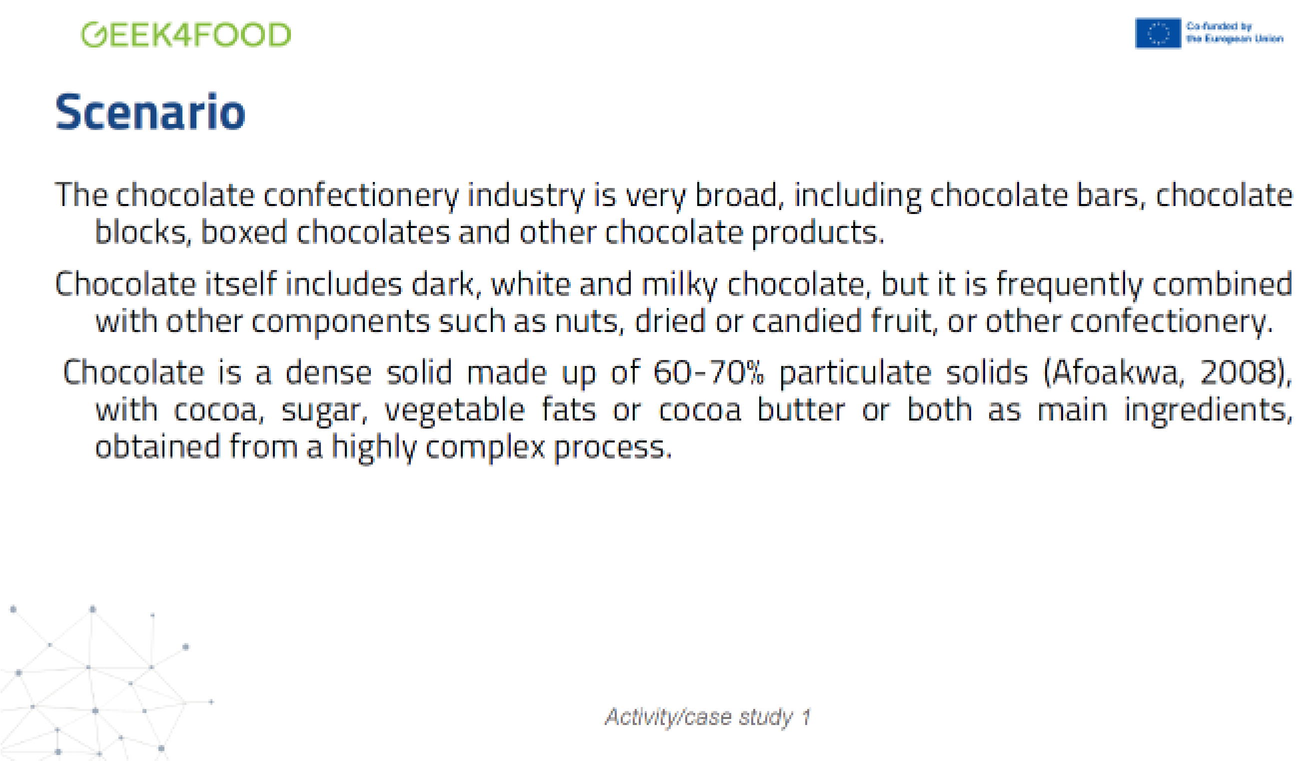
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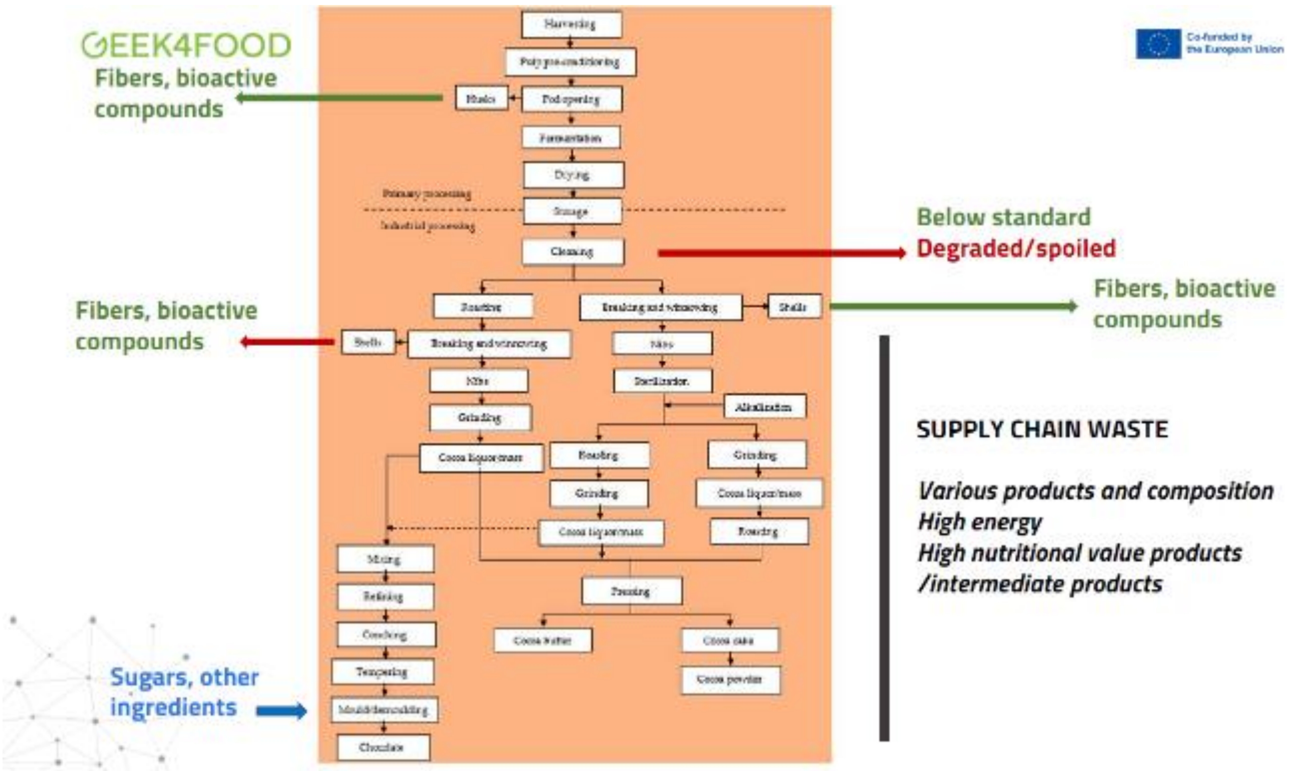
Scenario
The chocolate confectionery industry is very broad, including chocolate bars, chocolate blocks, boxed chocolates and other chocolate products.
Chocolate itself includes dark, white and milky chocolate, but it is frequently combined with other components such as nuts, dried or candied fruit, or other confectionery.
Chocolate is a dense solid made up of 60-70% particulate solids (Afoakwa, 2008), with cocoa, sugar, vegetable fats or cocoa butter or both as main ingredients, obtained from a highly complex process.
Activity/case study 1

GEEK4FOOD

Confectionery products	Raw materials	Product chemical composition	Nutritional content
Chocolate	Sucrose, Cocoa, Vegetable fat/ Cocoa butter, Milk, Lecithin	Free fatty acids, Polyphenols, Lactose, Protein, Potassium, Magnesium, Copper, Iron	Energy 507 calories Water 1.1% Carbohydrates 57 g/100 g Protein 4.2 g/ 100 g Fats 35.7 g/100 g

Activity/case study 1



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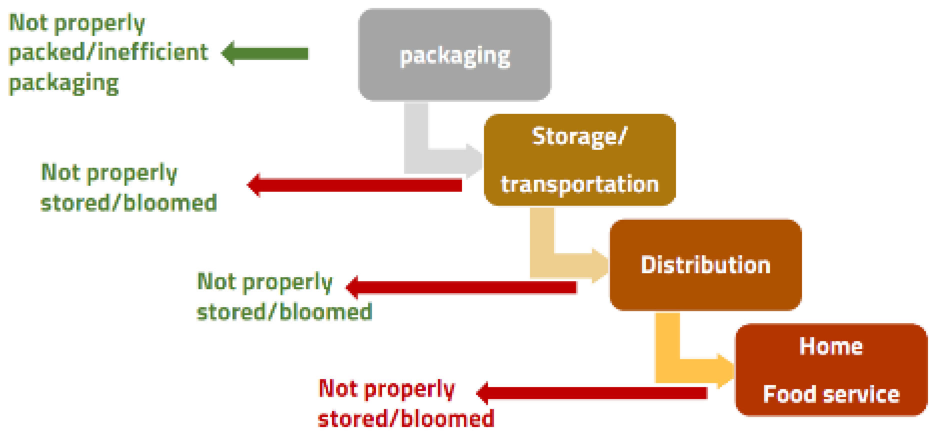
After chocolate production



Activity/case study 1

GEEK4FOOD

Defective beans (germinated, insect-damaged, etc…) : ca. 5%

The waste stream(s) consists of:

- un-used raw materials,
- wastes from the pre-processing stages (e.g. forming chocolate)
- production wastes in the form of chocolate mass.

In the production chain (ca. 2%):

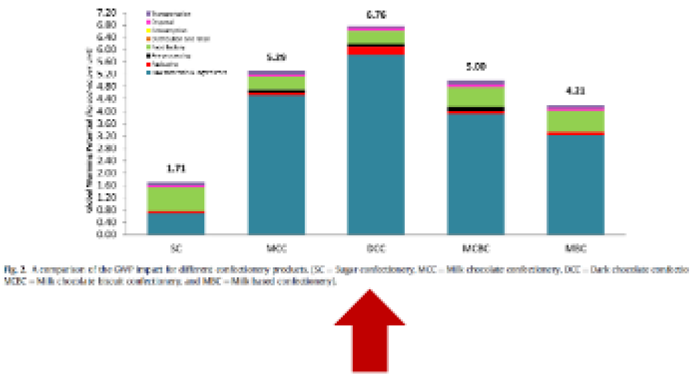
- products that are misshapen or do not meet specifications
- waste generated when the high-speed production lines are interrupted or fail, when there is a change of product production
- Wasted material that cannot be re-worked/re-processed into product.

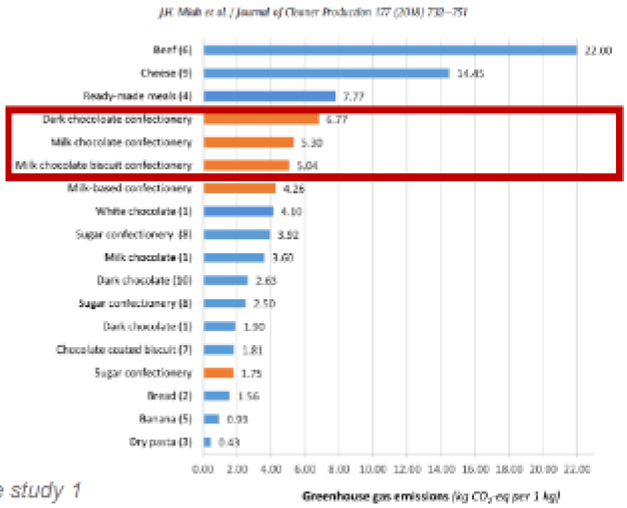
AFTER PACKAGING: ca. 5.7% of chocolate products become waste products (= disposal, to landfill as food waste)

Activity/case study 1

GEEK4FOOD

Co-funded by the European Union





Source: Miah et al., 2018

Activity/case study 1

GEEK4FOOD

Co-funded by the European Union

Question 1

FROM THE FULL PROCESS DIAGRAM, IDENTIFY THE POTENTIAL OF

- **UP-CYCLING**
- **RECOVERY**

of the wasted products/intermediate products.

Activity/case study 1

GEEK4FOOD

Co-funded by the European Union

Question 2

FROM wasted products/intermediate products, IDENTIFY THE POTENTIAL of the wasted products considering their potential technological properties

Activity/case study 1

Case Study 2. Mushroom production and the circular economy

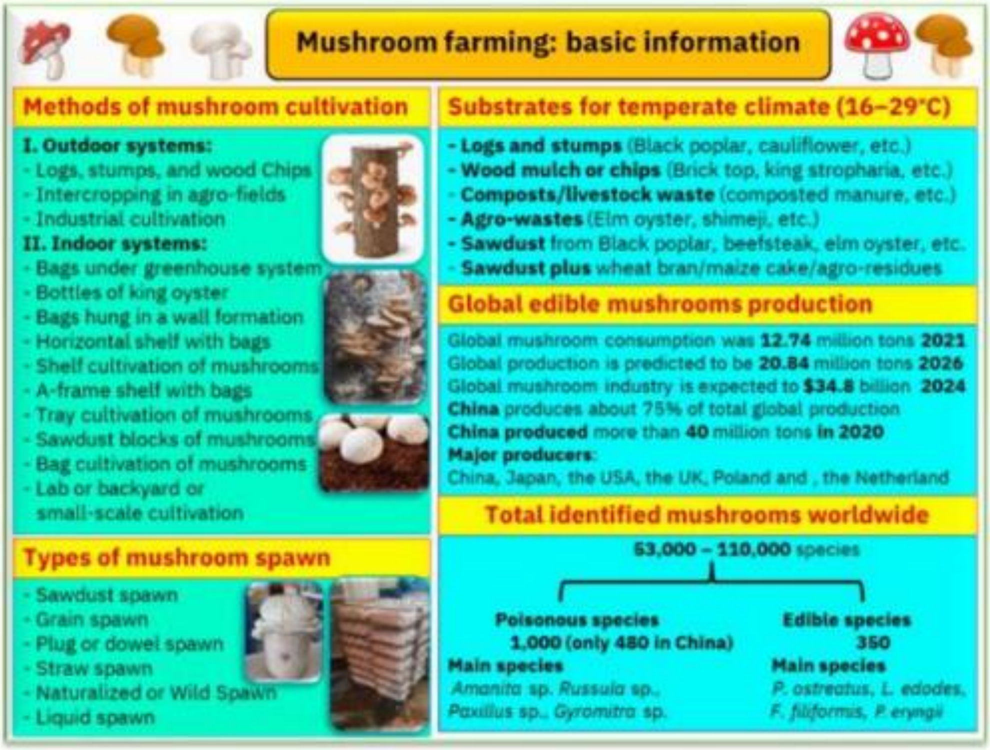
Jesus Frias, Technological University Dublin

Objectives

1. To identify the circularity components in mushroom production and propose potential increments.
2. To understand the systems related to mushroom production.

Mushroom farming fundamentals

From DOI: 10.3390/foods12142671



Activity 1 Mushroom production and circular economy (15 mins)

Discuss the following increments in cricularity of the edible mushroom production chain from DOI: https://doi.org/10.18011/bioeng.2024.v18.1241

Table 1. Relationship between the Circular Economy and the edible mushroom production chain.

Circular Economy aspects	Description	Interview
Refuse (R0)	Avoid the use of non-renewable and toxic materials from the outset	The producer does not use chemical pesticides in his production, seeking alternative bio-inputs if necessary
Rethink (R1)	Redesign processes to maximize efficiency and minimize waste	Producer implements sustainable cultivation techniques, but faces challenges in some aspects to make the process more sustainable
Reduce (R2)	Reduce consumption of natural resources and energy	Efficient use of water and energy through a semi- artesian well and solar panels, but there are limitations in reducing plastic packaging
Reuse (R3)	Reuse products and components whenever possible	Reuse growing substrates for compost and manure, large bags of substrate as garbage bags
Repair (R4)	Repair products to extend their useful life	Cultivation equipment undergoes constant preventive maintenance and was built by the producer (humidifier, fan)
Renovate (R5)	Renovate old products for continuous use	Adaptation and construction of equipment used in production
Remanufacturing (R6)	Remanufacturing products to restore their functionality	Products that have not been marketed are used to produce antipasto or mushroom quibbles, these are not marketed
Redefine (R7)	Redirect materials to new uses	Used substrates are redirected to compost and manure
Recycling (R8)	Recycling materials to create new products	Recycling organic waste into compost and manure, but recycling plastics is still a challenge
Recover (R9)	Recover energy from waste through processes such as incineration	Energy recovery is not practiced due to a lack of infrastructure.

Identify three potential more effective and the more feasible potential improvements of circularity.

Activity 2 Mushroom sector as part of circular economy (15 mins)

From https://www.interregeurope.eu/good-practices/mushroom-sector-as-part-of-circular-economy

Discuss this good practice and identify the key elements of the circular economy that are associated to the integration of mushroom production.

About this good practice

In Castilla-La Mancha there is an agricultural-based economy specializing in wine production, cereals, olives, etc. In the 70s, people looked for complementary activities to reinforce the economy. Connected to that, in Villamalea the production of mushrooms was developed, using straw from cereal production and locally available chicken manure.

From the end of the 90s until the present day, this complementary activity has created a steady business based on mushrooms, linked to a logistics and distribution network to supply the supermarkets and retailers of the country. In consequence, and due to the specialization of the business and the cooperation between the different companies, Villamalea has substantially improved the local economy.

The mushrooms are one of the main agents responsible for decomposing the dead organic material. This practice takes advantage of the ability of mushrooms to make use of secondary products obtained from agriculture and farming (straw, chicken manure) which create a specific compost ready to produce mushrooms. At the ends of the growing period, mushrooms have not used up all the nutrients of the substrate. For this reason, this material is ideal for adding to the fields as fertilizer, because it improves the water holding capacity of the soil. It is rich in nitrogen, humus, and other minerals and nutrients and it does not contain heavy metals or the seeds of competitor grass.

Resources needed

The company set up as an agricultural cooperative was recognized as an organization of fruit and vegetable producers. Thank to that, they benefits from European funds (FEOGA), and has around 50 mushroom facilities, 2 compost yards, warehouses, specific logistics and more than 800 direct employee.

Evidence of success

It provides a solution for some residual materials, such as straw, chicken manure, etc., transforming them into mushrooms. In the composting process employment is required and also many people are needed to pick mushrooms in the farms, so it provides a living for one thousand families in the region.

The current volume of compost is 130,000 tons per year, producing around 35 M kg of mushrooms, and generating 87 M kg of spent mushroom compost with a total turnover of 70 M€ per year.

Potential for learning or transfer

In every part of the world there are different kinds of residual materials coming from agricultural and other food industries, and most of these products can be composted, to get a substrate ready to produce mushrooms.
Therefore, this experience of good practices can easily be exported to other regions, which translates into economic wealth and circular economy boost in line with current policies.

Further information: **Website**

Good practice owner

You can contact the good practice owner below for more detailed information.

Organisation: **Champinter Cooperative Society - Sociedad Cooperativa Champinter,** Spain Castilla-La Mancha

ANNEX 4: Participant feedback - Eco-design of food packaging

Diego Quispe Sayago · 3rd+ + Follow
Estudiante en Universidad Nacional de San Cristóbal de Hu...
1mo · Edited ·

Grateful for an incredible seminar on Eco-Friendly Food Packaging

I am beyond grateful to have had the opportunity to attend the Eco-Design Food Packaging online training on 28 April.
As we all know, the need for sustainable packaging solutions has never been more urgent. From reducing plastic waste to embracing biodegradable and compostable alternatives, it's clear that we have the power to make a significant impact on our planet.
A huge thank you to the speakers, panelists, and organizers for providing such a rich learning experience and for driving forward a cause that is close to my heart.
Special thanks to Department of Food Science, AU FOOD and the Geek4Food Project for bring us a space to conect and learn with proffesionals from diferents countries around the world.

CERTIFICATE
OF PARTICIPATION

GEEK4FOOD

THIS CERTIFICATE IS PRESENTED TO

Diego Quispe Sayago

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia	Mario Roccaro	Milena Corredig
GEEK4Food Coordinator	GEEK4Food co-coordinator	Professor of Food Technology
Teramo University	EIT Food	Aarhus University

AARHUS UNIVERSITY

Iqra Liaqat 👉 Queen Elizabeth Commo... · 2nd **+ Follow** ···

Looking for PhD position

1mo · 🌐

🌱 Proud to share my latest learning milestone! 🌍

I recently completed the online training module on "Eco-design of Food Packaging"held on 28 April 2025, organized by GEEK4Food and co-funded by the European Union 🇪🇺.

This training deepened my understanding of sustainable food packaging strategies, circular economy principles, and the role of innovative eco-design in reducing environmental impact across the food value chain.

Grateful to the trainers and institutions behind this initiative:
#GEEK4Food (Green Education for Evolving Knowledge in Food)
#EIT #Food
#TeramoUniversity
#AarhusUniversity

Special thanks to @PaolaPittia, Mario Roccaro, Milena Corredig for their leadership and insights throughout the program.

🌿 Looking forward to applying these principles in research and practice to contribute toward sustainable food systems!
#Sustainability #FoodPackaging #EcoDesign #GEEK4Food #EITFood #FoodTe


CERTIFICATE
OF PARTICIPATION

GEEK4FOOD

THIS CERTIFICATE IS PRESENTED TO

Iqra Liaqat

In recognition of participation and commitment to the 'Eco-design of Food Packaging'

Hellen Renata · 2nd
Food R&D Analyst | Master in Food Science and Technolog...
1mo ·

+ Follow ···

Yesterday I participated in the online training module Eco-design of Food Packaging, promoted by the Geek4Food project and co-funded by the European Union.
The course addressed sustainable strategies for food packaging design, highlighting the importance of innovation aligned with environmental responsibility.
It was also a great space for exchanging ideas with participants from different countries.
Grateful to the team involved for this opportunity!

CERTIFICATE
OF PARTICIPATION

GEEK4FOOD

THIS CERTIFICATE IS PRESENTED TO

Hellen Renata

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia
GEEK4Food Coordinator
Teramo University

Mario Roccaro
GEEK4Food co-coordinator
EIT Food

Milena Corredig
Professor of Food Technology
Aarhus University

AARHUS UNIVERSITY

Rukmini Brahmachari · 1st
Doctoral Researcher in Food Sustainability | Postharvest & Horticulture | ...
1mo ·

Short update!
I recently took part in an online training on Eco-Design for Food Packaging hosted by Geek4Food in collaboration with Aarhus University! 🌱
The session brought together participants from various backgrounds and offered a well-rounded introduction to sustainable packaging principles. For me, it served as both a refresher and a chance to gain insights into recent developments in the field. One highlight was a case study on fruit and vegetable packaging—a topic I had explored in depth during my master's studies, which made the experience even more engaging.
Grateful for the opportunity to deepen my understanding of eco-design and explore its real-world applications. Looking forward to more such insightful learning experiences in the context of fresh produce supply chains! 🍎📦
#SustainablePackaging #EcoDesign #GEEK4FOOD #FoodPackaging #FreshPr

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Rukmini Brahmachari

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia
GEEK4Food Coordinator
Teramo University

Mario Roccaro
GEEK4Food co-coordinator
EIT Food

Milena Corredig
Professor of Food Technology
Aarhus University

AARHUS UNIVERSITY

Dr. Melike Nur Tosun · 2nd
Food Engineer/Microbiologist
1mo ·

+ Follow ···

I had the opportunity to both reinforce what I already knew and gain new perspectives through the "Eco-designed of Food Packaging" training. The content was multifaceted, covering everything from the environmental impact of food packaging to safety, from design principles to material selection.
In addition to topics such as sustainability, material safety, and migration, the training highlighted the importance of considering intentionally and non-intentionally added substances (IAS and NIAS) in packaging within the framework of risk assessment and eco-design approaches.
The use of case studies to support theoretical knowledge made the training more engaging and memorable. Many thanks to everyone who contributed.

Geek4Food Milena Corredig Ilke Uysal Unalan EMMANOUIL TSOCHATZIS Konstantina Ntrallou PAOLA PITTIA Mario Roccaro


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OF PARTICIPATION

THIS CERTIFICATE IS PRESENTED TO

Melike Nur Tosun Demir

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia, GEEK4Food Coordinator, Teramo University
Mario Roccaro, GEEK4Food co-coordinator, EIT Food
Milena Corredig, Professor of Food Technology, Aarhus University

Tran Ngo · 2nd
Research Scientist @ VTT
1mo ·

+ Follow ···

It was a great opportunity to deepen my knowledge in ''Eco-design of Food Packaging'' through Geek4Food training. Thank you for it. The training is insightful for the development of our eco-design framework for circular food packaging within STOPP PROJECT.


CERTIFICATE
OF PARTICIPATION

THIS CERTIFICATE IS PRESENTED TO

Tran Ngo

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia, GEEK4Food Coordinator, Teramo University
Mario Roccaro, GEEK4Food co-coordinator, EIT Food
Milena Corredig, Professor of Food Technology, Aarhus University


Thuseinthan Inpabalan MSc.Eng(Aarhus), MBA(U... · 1st
International Experience to solve and manage real-world projects | #...
1mo ·
Happy to share that I recently took part in the GEEK4Food / AU Food training session, a great opportunity to connect, learn, and explore the intersection of food systems, innovation, and research!
Big thanks to Milena Corredig and the organizing team for a well structured and insightful session. Grateful for the chance to engage with such a dynamic group of peers and experts.
Looking forward to applying these learnings, especially regarding the training and knowledge platform and joining more events like this in the future!
#GEEK4Food #AUFood #LifelongLearning #ResearchAndInnovation #Sustaina
Geek4Food Aarhus University
#2CN10
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OF PARTICIPATION
GEEK4FOOD
THIS CERTIFICATE IS PRESENTED TO
Thuseinthan Inpabalan
In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025
On 28 April 2025, Aarhus University FOOD proudly hosted the online ...more
GEEK4FOOD
2. Eco-design and sustainable packaging
You and 50 others
1 comment · 4 reposts
Celebrate
Comment
Repost
Send
Give your good wishes...
Most relevant
Temitope Akinyemi · 2nd
(edited) 1mo
It was quite an intensive training and worth my time. I would like to appreciate Milena Corredig and others @GEEK4Food who designed the curriculum of the training. Thank you so much.
Like · 4 | Reply

Remigio Graziani · 1st
PhD candidate in Private and Agrifood law
1mo ·

I'm thrilled to have participated in the Eco-design of Food Packaging training module organized by the GEEK4FOOD project and supported by Aarhus University, Teramo University, and EIT Food.

It was a truly enriching experience, especially from the perspective of a PhD student in agri-food law. Exploring the intersections between sustainable packaging, innovation, and legal frameworks offered valuable insights into the future of food systems.

Once G4F, forever G4F!
Geek4Food Università degli Studi di Teramo EIT Food Aarhus University

#GEEK4FOOD #EcoDesign #FoodPackaging #AgriFoodLaw #PhDLife #Sustair

CERTIFICATE
OF PARTICIPATION

GEEK4FOOD

THIS CERTIFICATE IS PRESENTED TO

Remigio Graziani

In recognition of participation and commitment to the 'Eco-design of Food Packaging' online training module, held on 28 April 2025

Paola Pittia

Mario Roccaro

Milena Corredig

Feedback received via email, after the cerifications were sent to trainees:

1. *Thank you very much for your kind message and for sending the Certificate of Attendance.*
   It was a pleasure participating in the GEEK4Food/AU Food training session. It was insightful and enriching. Thank you once again for the warm welcome and the excellent organization. I hope to join more of your events in the future.

2. *Thank you so much for sending me the certificate. I sincerely apologize for not replying earlier and for not completing the questionnaire. Unfortunately, due to family matters, I was only able to return to work today.*
   I am truly grateful to you, to Professor Corredig, and to the fantastic team at Aarhus. Please accept my apologies once again, and I very much look forward to participating in future G4F activities.

3. *Thank you for the warm message and for organizing the GEEK4Food/AU Food training session. I truly appreciated the valuable insights and knowledge shared during the event. I'm grateful for the Certificate of Attendance.*
   I was wondering if it would be possible to access the PPT files from the training session? That would be really helpful for future reference.
   Looking forward to future events and potential opportunities for data sharing or collaboration.

4. *Thank you for organizing the GEEK4Food/AU Food training session. It was a truly informative and engaging experience, and I'm grateful for the opportunity to take part. I hope to join another training in the future and continue learning through these great initiatives.*

5. *Thank you for your email and the attached Certificate of Attendance. I received it with thanks.*
   I appreciate the opportunity to attend the GEEK4Food/AU Food training session. It was a pleasure to participate, and I found the experience to be quite valuable.

6. *Thank you very much for the certificate.*
   It was indeed an interesting session providing valuable insight into the current work being done in the field of eco-design for food as well as the true timeline of it all.
   Hope to find more such sessions in the future!

7. *Thank you for your kind words and for the opportunity to participate in the GEEK4 Food/AU training session. I found the experience to be valuable and insightful, and I appreciate the knowledge and skill shared during the training.*
   I have received the certificate of attendance!
   Thank you very much once again, and I look forward to participating in future events!

8. *Thank you for the certificate. The certification increases my motivation. More importantly, the training was really enjoyable and productive.*
   I hope I will have the opportunity to meet again in future events.
   Thanks again for everything.

ANNEX 5: Event brochure and poster - Eco-design of food packaging


Eco-design
of food packaging
28 April 2025 | 13:00 - 17:00 CET | Online
Organised by Aarhus University, Denmark
GEEK4FOOD
AARHUS UNIVERSITY
Co-funded by the European Union

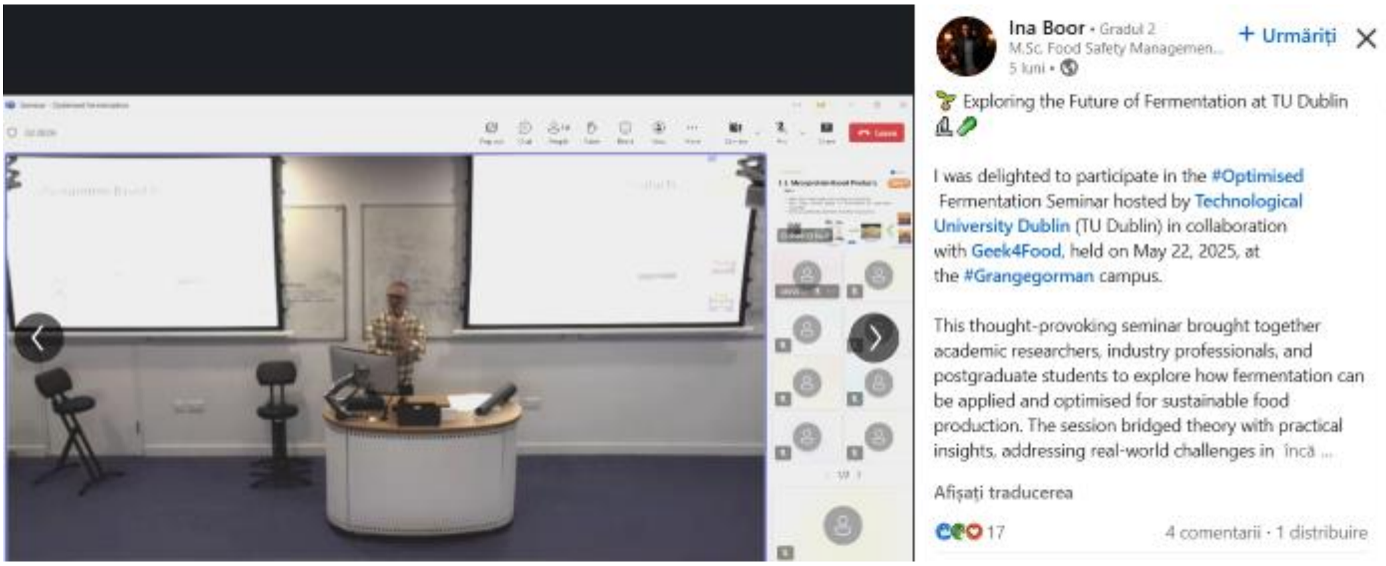
ANNEX 6: Group picture - Optimised fermentation in USAMV Cluj-Napoca

ANNEX 7: Event brochure and poster - Optimised fermentation in USAMV Cluj-Napoca


Optimised
fermentation
5 May 2025 | 09:00 - 13:00 EEST | On-site
Designed for
Postgraduate students, and junior and senior professionals from industry.
Learning objectives
- Understand the fundamentals of optimised fermentation, including choosing microorganisms and bioreactor settings for specific food ingredients.
- Compare optimised fermentation with traditional methods, focusing on the technological improvements.
- Learn about the regulations related to optimised fermentation products.
- Develop innovative and sustainable optimised fermentation processes.
Learn more and enrol now
GEEK4FOOD


Optimised
fermentation
22 May 2025 | 14:00 - 17:00 Irish time | On-site & Online
Organised by TU Dublin, Ireland
enrol now
GEEK4FOOD
DUBLIN

ANNEX 8: Participant feedback - Optimised fermentation TUD



ANNEX 9: Group picture – Optimised fermentation TUD

ANNEX 10: Event brochure and poster – Optimised fermentation TUD

ANNEX 11: Event brochure and poster - Food waste valorisation in food product design


Waste valorisation
in food product design
6 June 2025 | 10:00 - 15:30 CEST | Online
Organised by Teramo University, Italy, in collaboration with TU Dublin, Ireland
enrol now
GEEK4FOOD
DUBLIN
Co-funded by the European Union