GEEK4FOOD

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

Deliverable 4.2

GEEK4Food modules and pilots' syllabus

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CONTENT

1. Executive summary

Deliverable 4.2 is related to the design and development of the training modules (n. 3) developed in WP4 based on the outcomes of WP2, that will be later delivered as training pilots in WP5, Task 5.2..
It outlines the methodology employed in the project, starting from the task descriptions as laid out in the project work plan. Thereafter, it details the **GEEK4Food** approach to the design of modules and pilot syllabi, emphasizing how each element was structured to meet the project's goals.

For each module it is reported: its structure, including their duration and how these are aligned with the overall project framework; the target group (trainees), the mapping of content to ensure alignment with the learning objectives.

The modules' syllabi are provided in detail, highlighting the educational content, learning outcomes, and assessment strategies for each of them.

In the Annexes, the **content mapping files, syllabi, and module content** for three specific modules—"Eco-design of food packaging," "Optimised fermentation," and "Food waste valorisation in food product design"—are included to illustrate the project's curriculum in more detail.

2. Introduction

One of the GEEK4Food project's core goals is to design educational and training modules aimed at enhancing both graduates and experienced professionals in the upskill of their competences on green skills to drive sustainability and innovation in the food sector. It does so by anticipating future needs, designing forward-looking curricula, and ensuring these modules bridge gaps across industries to foster a more sustainable, circular and eco-friendly food system.
The project aims to support the creation of a workforce capable of contributing to the green economy, specifically in the context of food production and processing.
The term **"green" skills** refers to a set of abilities, personal and professional, along with values and knowledge that help individuals in contributing and supporting a sustainable and resource-efficient society development. When applied to the agri-food sector they refer to the enhancement of the natural resources, the development and optimisation of mild-, or innovative technologies with lower environment impact (energy, water, etc.) the identification of solutions to reduce the use of synthetic biomolecules and valorisation of waste and by-products.

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The GEEK4Food project aims to develop a frame of actions including the design and development of tools and educational initiatives that could be used to train, upskill and reskill the current and future generation of professionals and workforce, to support the transition towards a green and sustainable solutions agri-food system.

The forward-looking approach of the GEEK4Food project, supported by the Artificial intelligence-based GEEK4Food Skills (D2.1.) and Machine Learning tools, provided us trends on the green skills and jobs that allowed partners to identify topics and disciplines relevant for the design of training modules that anticipate future knowledge and abilities needs. In this context, it means designing training that will equip graduates and professionals with skills that will be relevant as food industry moves toward sustainability.

3. Methodology

3.1 Task description as presented in the project work plan

Task 4.3 and its deliverable D4.2 (***GEEK4Food modules and pilots' syllabus***) focus on the selection and optimisation of modern and disruptive training and educational methods for green and entrepreneurial skills and capabilities by piloting, demonstrating and translating innovative teaching methodologies and final identification of new content delivery standards.

Teaching methods and tools are not only learner-centred but personalised (with WP5), to respond to the fluidity of the marketplace needs. Skills such as decision making, critical thinking and independent problem solving are key competences and crucial outcomes, to respond to the increased demand for communication and organisational skills for all actors of the value chain.

GEEK4Food uses the European sustainability framework, as a reference tool, GreenComp can serve a wide range of purposes including curricula review; design of teacher education programmes; (self-) assessment/reflection, policy development, certification, assessment, monitoring and evaluation.

Innovative methodologies, including short experiential learning, micro-learning modules, will be piloted to strengthen existing international, national, regional and local efforts to capture and define sustainability competences. Built in means to measure impact will also be designed.

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

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According to the MS6 (*Matrix of modules for green skills*), three main areas/topics were identified for the following design and development of the modules and their delivery as pilots (WP5, D5.2.).

The selection of the three modules was based on the identification and analysis of the state-of-the art- of the green skills, that are becoming increasingly more important in the agri-food sector, and the project's scientific expertise on designing, developing and implementing the modules' topics.

The GEEEK4Food HEI partners brought together scientific knowledge and expertise to create educational modules that will help the development of the green skills identified in the mapping process.

The three GEEK4Food modules selected are:

1. **Eco-design of food packaging**
2. **Optimised fermentation**
3. **Food waste valorisation in food product design**

The design of the GEEEK4Food modules and pilots' syllabus is based on two foundational principles, their **modularity** and **homogeneity**, to ensure the program's success and relevance. Each module could be taken independently, and there might be some flexibility in the frame where they are delivered in terms of level of education (BSc, MSc, PhD, professional, Lifelong learning).

However, the modules would maintain a similar level of difficulty and would follow the same structure (described in the following sections), ensuring that the training has homogenous training approach.

1. **Homogeneity.** A homogenous training model suggests that the content and structure are consistent across all parts of the training program. In this context, it likely means that the same structure is applied to every unit or module within the selected GEEK4Food trainings, ensuring uniformity in how learners engage with the content, activities and assessment.
2. **Modularity.** A modular approach refers to design the training in separate, self-contained modules, where each module covers a specific topic or skill. These modules are structured in a way that makes the course easy to follow, flexible, and scalable. Each module might focus on specific learning objectives and typically contains multiple components or "chunks" of content that work together to achieve the goal. The modularity in this framework, recalls also the microcredentials approach.

   In this project, microcredentials, despite they were initially considered in the proposal, were not implemented as training methodology due to their limited recognition in real professional frameworks. The "modularity approach, thus, is expected to widen the potential use of the trainings in different contexts and educational environments.

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3.3 Modules' structure

To develop the GEEK4FFood modules' structure, the Higher Education Institution (HEIs) project's partners have considered some fundamental aspects:

1. **Balance between theory and practice**: the modules are designed to blend theoretical knowledge with practical application.
2. **Interactive elements**: the use of group work, discussions, and interactive exercises throughout the course's duration helps to keep learners engaged and facilitates peer-to-peer learning.
3. **Assessment and reflection**: the final assessment, whether a quiz or group presentation, ensures that learners leave the course having demonstrated their understanding and ability to apply what they've learned.
4. **Time management**: each section is carefully timed to ensure that learners stay engaged without feeling overwhelmed.

In summary, the GEEK4Food HEI partners have created a structured and uniform training model, by applying the same structure, as follows:

- **The challenge-based lecture**, which introduces the content through a real-world problem. The challenge-based lecture refers to a teaching approach that integrates real-world challenges or problem solving into the learning process. Instead of traditional lectures, a "challenge-based lecture" encourages students to actively engage with the content addressing a specific problem or challenge related to the subject. The challenge serves as the framework for exploring the learning material, encouraging critical thinking and the application of knowledge.
- **Three "content-related" lectures**, each of them focused on specific aspects and topics of the module for a more deep learning experience. These three content areas are likely key topics or themes that the modules aim to address. By dividing the module content into three lectures, learners can focus on smaller, manageable parts of knowledge and information, making the learning process less overwhelming. Each content area will be presented with its own set of key concepts. The lectures will be delivered by experts in the specific topic/sub-topic that will also guide the final discussion and, if possible, lead the case study activities.
- **Two case-study activities: they** provide opportunities for learners to apply what they've learned in practical ways. These are conceived as practical exercises/tasks designed to reinforce the learning and help learners in applying the concepts they've been taught. Including two case study activities in each module provides a balanced mix of theory and practice. These activities will help learners move beyond passive absorption of content to active participation, improving retention and skill development. Learners are encouraged to apply critical thinking, promote problem-solving, develop decision-making skills and contextualize presented theory.

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- **Refining and Discussion**: this final session offers an opportunity for learners to critically review, analyze, and improve the solutions or strategies they've developed during the case studies.
- **Assessment:** each module includes an assessment test to evaluate the learner's understanding and mastery of the content. It serves as a checkpoint to measure progress and to ensure that the learning objectives have been achieved. This type of session is designed to encourage problem-solving, reflection, and iteration.

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

Table 1: *GEEK4Food modules' structure*

This design ensures consistency, clarity and depth, and allows for flexibility in how the content is delivered and engaged with. It's a learner-centric approach that encourages active participation, problem-solving and continuous feedback. The GEEK4Food modules are independent, but they all contribute to achieving the same overall educational goals, using a consistent approach.

3.3.1 Modules' duration

Each of the three GEEK4Food modules has been designed to be delivered in maximum **one day**, with 30-minute sections. This duration has been optimised for an online delivery and in this case the time is optimised short enough to maintain attention and focus, yet long enough

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to delve into concepts and ideas and is ideal for learners who may not have the time to commit to longer, multi-day training programs but still want to gain key skills and knowledge quickly. Additionally, each module will be focused and concise, with emphasis on the most critical concepts, hands-on activities and opportunities for engagement. Each 30-minute core section leaves room for the instructor to add a brief introduction at the start to set the context for that part of the course. It offers time for a Q&A session at the end that gives participants a chance to ask questions and clarify any doubts, ensuring that they fully understand the material before moving on to the next section.

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

For alternative modalities of delivery of the training module with the same content and structure, the timing can be adapted and modified. In particular, the time dedicated to the case studies can be modified, e.g. prolonged, especially if real case studies are discussed and experienced moderator could be also involved in these sessions to enhance the discussion among trainees.

4. Target group

The design process of the GEEK4Food modules required the identification of the target group. Identifying the target group for the GEEK4Food modules is crucial not only about knowing who

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the users will be; it is also relevant to designing the learning experience that meet specific needs, preferences and contexts.
There are several key reasons why targeting the right audience, and they are:

- **Relevance of content.** Different target groups have different levels of prior knowledge, interests and needs. By identifying the target group, the GEEK4Food modules are designed with content that is specifically relevant to that group. Furthermore, understanding the target group's needs helps the design process to focus on solving real-world problems.
- **Optimized learning outcomes**. The GEEK4Food modules' design needs to ensure that it incorporates formats and activities that best match the learners' preferences and needs, making it more likely to be engaging and informative. When the design aligns with the target group's interests and challenges, learners are motivated, can actively participate in the learning process and take the knowledge beyond the module into their practice.
- **Improved behaviour impact.** One of the main goals of the GEEK4Food educational modules is to change attitudes or behaviours, whether it's teaching food sustainability practices or develop innovative and sustainable design solutions. Understanding the target group allows for the design of strategies that are more likely to resonate with the audience and encourage them to adopt new behaviours. The target group's real-life experiences can be used in the relevant case studies.

In short, by focussing on a specific target group, the GEEK4Food modules' design process ensures that the learning experience is not only informative but also relevant, accessible and impactful, leading to higher engagement, better learning outcomes and a more significant potential for behaviour change.
In this frame and in the perspective of delivering the trainings (WP5) the GEEK4Food consortium decided to target **junior and senior agri-business professional** to enhance the agri-business sector both strategic and operational levels.
By addressing the needs of professionals at different stages in their careers, the GEEK4Food consortium can support innovation's drivers, effective knowledge transfer and overall capacity of the sector's strength to meet current and future challenges. This approach aims to create a balanced, sustainable and resilient agri-business ecosystem, leading to long-term benefits for both professionals and the industry at large.

5. Content mapping files

For the development of the GEEK4Food modules the HEI partners used content mapping files. The content mapping files serve as a blueprint for organising, aligning and structuring the training content in a way that ensures it meets learning objectives, adheres to instructional design principles and supports effective learning outcomes. In essence, the GEEK4Food

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content mapping ensures that every piece of content (whether it's a case study, or training content) is directly linked to specific learning objectives. This alignment ensures that the training is focused and purposeful, helping learners achieve the desired knowledge or skills at each stage of the program.

In defining the learning outcomes and their corresponding descriptors, the GEEK4Food HEIs partners used the **Bloom's Taxonomy**, which outlines six levels of cognitive learning. These levels represent a progression of increasing complexity:

1) **Remembering**,
2) **Understanding**,
3) **Applying**,
4) **Analysing**,
5) **Evaluating**, and
6) **Creating**.

Each level builds on the previous one, moving from basic recall of information to higher-order thinking skills that involve critical analysis and the creation of new ideas or solutions. For the 6 levels, there is a set of verbs that can be used to describe LO (*see Figure 1*).

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Remember	Understand	Apply	Analyze	Evaluate	Create
Choose	Classify	Apply	Analyze	Agree	Adapt
Define	Compare	Build	Assume	Appraise	Build
Find	Contrast	Choose	Categorize	Assess	Change
How	Demonstrate	Construct	Classify	Award	Choose
Label	Explain	Develop	Compare	Choose	Combine
List	Extend	Experiment	Conclusion	Compare	Compile
Match	Illustrate	with	Contrast	Conclude	Compose
Name	Infer	Identify	Discover	Criteria	Construct
Omit	Interpret	Interview	Dissect	Criticize	Create
Recall	Outline	Make use of	Distinguish	Decide	Delete
Relate	Relate	Model	Divide	Deduct	Design
Select	Rephrase	Organize	Examine	Defend	Develop
Show	Show	Plan	Function	Determine	Discuss
Spell	Summarize	Select	Inference	Disprove	Elaborate
Tell	Translate	Solve	Inspect	Estimate	Estimate
What		Utilize	List	Evaluate	Formulate
When			Motive	Explain	Happen
Where			Relationships	Importance	Imagine
Which			Simplify	Influence	Improve
Who			Survey	Interpret	Invent
Why			Take part in	Judge	Make up
			Test for	Justify	Maximize
			Theme	Mark	Minimize
				Measure	Modify
				Opinion	Original
				Perceive	Originate
				Prioritize	Plan
				Prove	Predict
				Rate	Propose
				Recommend	Solution
				Rule on	Solve
				Select	Suppose
				Support	Test
				Value	Theory

Figure 1: *Revised Bloom's Taxonomy action verbs*[1]

The content mapping of the three selected GEEK4Food modules are collected in the Annexes I, II, and III.

[1] [1] Bloom, Benjamin S., (Ed.), Taxonomy of Education Objectives: Handbook I: Cognitive Domain, N.Y., David McKay Company, Inc. 1956

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6. Modules' syllabi

The GEEK4Food modules' syllabi are designed to facilitate an effective and efficient learning process, ensuring that both learners and instructors have a clear understanding of the course' objectives, content, and expectations.
They outline the learning objectives, key topics, and expected outcomes of the training course. They help learners understand what is expected of them in terms of knowledge acquisition, skills development, and overall performance.
The syllabi include also references and additional learning materials and how the assessment will be carried out.

The syllabi of the three selected GEEK4Food modules are collected in the **Annexes I, II, and III**.

7. Training materials

For each of the three training courses ("Eco-design of food packaging," "Optimised fermentation," and "Food waste valorisation in food product design"), training materials for each of the session, has been developed by the partners HEIs as ppt presentations using a general, but project-branded, template. Each partner developed high quality presentations with the most recent contents, by the use of international references all cited in the slides. In the case of the case studies, partners developed presentations with more general or more specific examples to be either used as such or as reference for the preparation of alternative case studies.
Suggestions for tutors on how to guide the discussion in the case study sessions are also included.

8. Assessment

For each course, the methodologies to assess and evaluate the knowledge and skills acquired during the training have been selected. To complement the discussions during the Q&A session just after the presentations and the case studies, for each course a series of questions have been prepared to be used either for online assessment test or files to be filled in and uploaded in dedicated training platforms.

---------------------------------- END OF THE D4.2. DELIVERABLE ---------------------------------

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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? Expert's lecture	AU Food	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	1. European Food Safety Authority (EFSA)/ Principles that could be applicable to the safetyassessment 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	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	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, sustanability 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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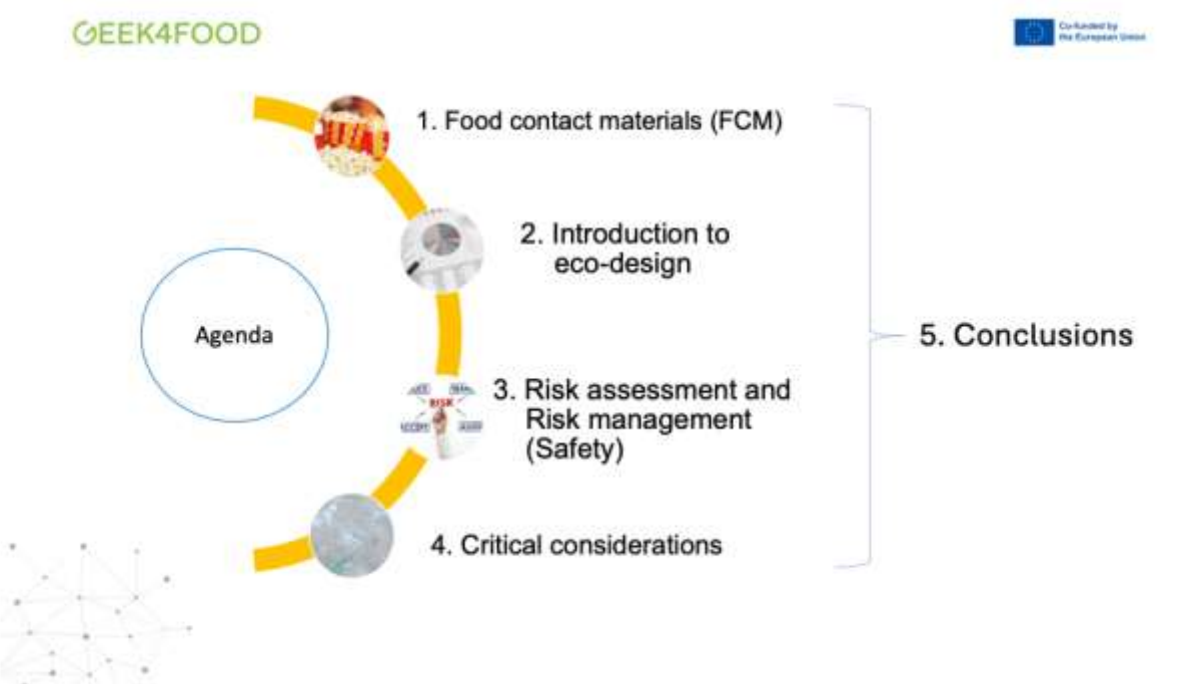

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1. Food contact materials (FCM)

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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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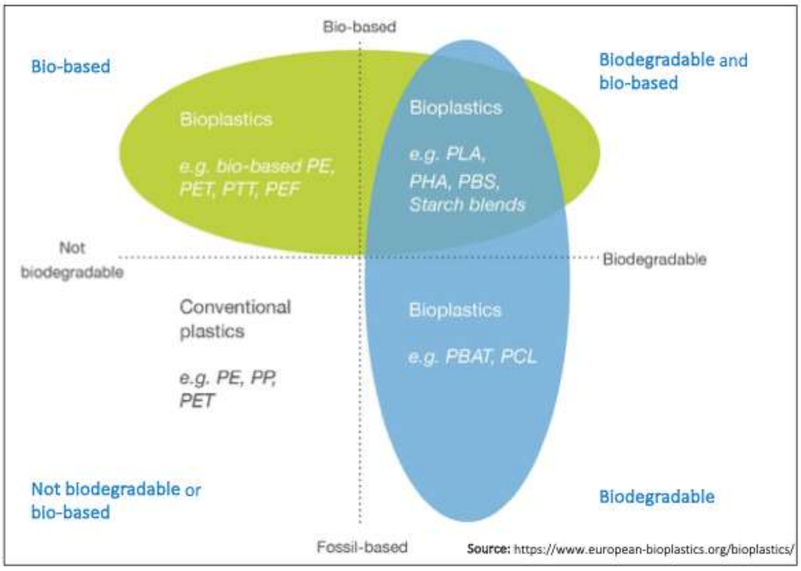
B. Types of FCM



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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

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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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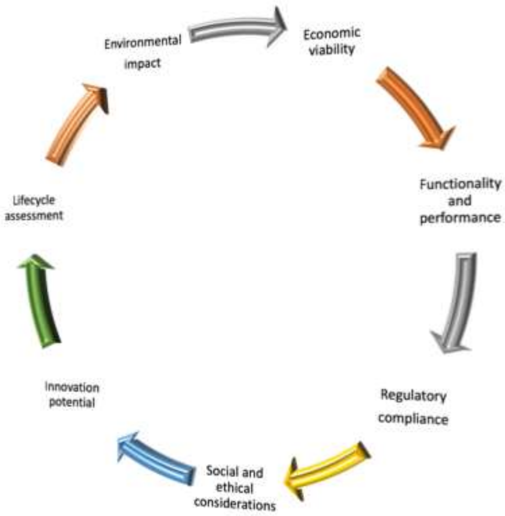

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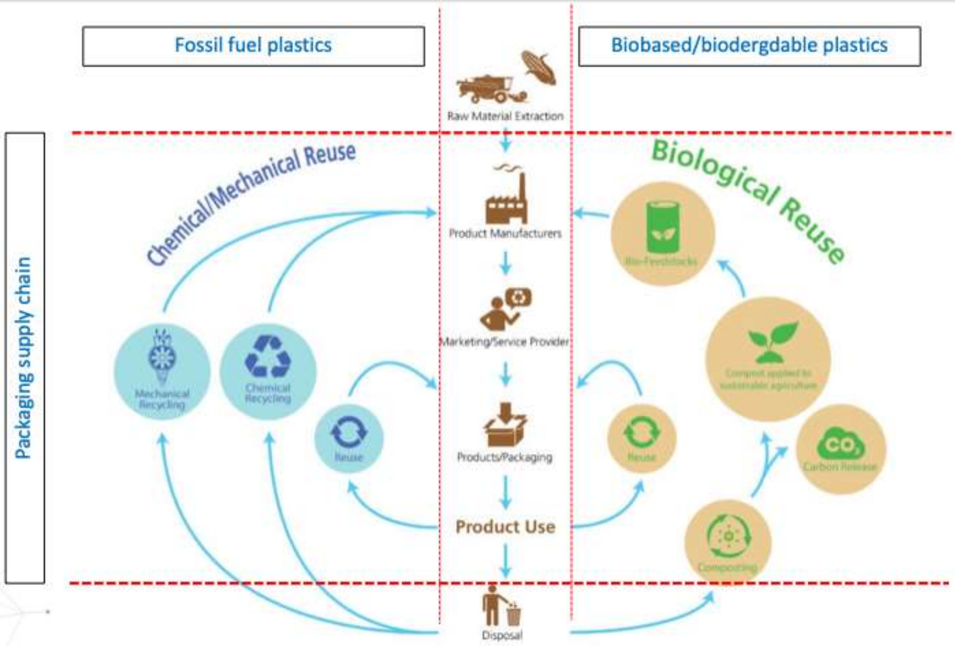
B. Circular and eco-designed packaging



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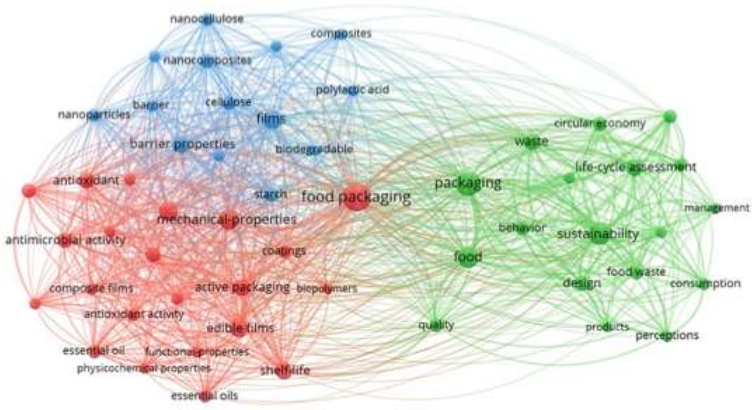
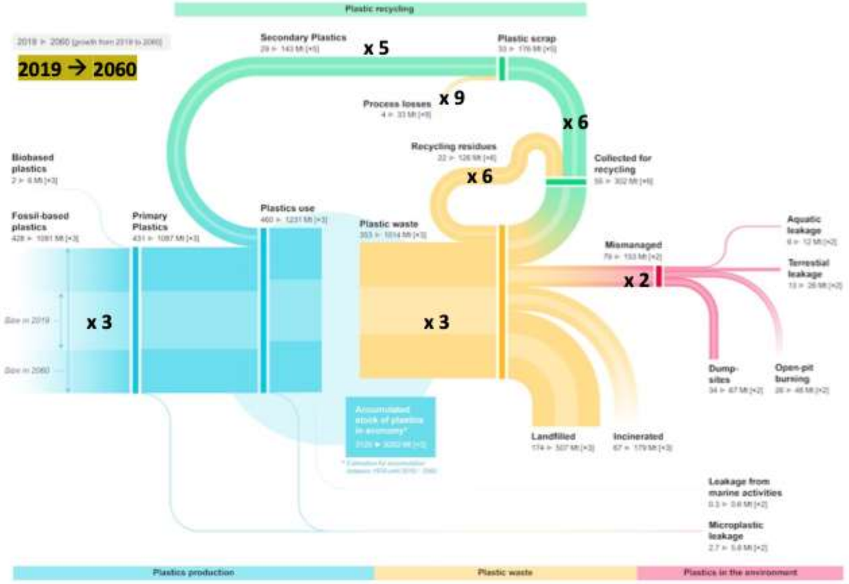
C. Eco-design and sustainable packaging

- Definition: *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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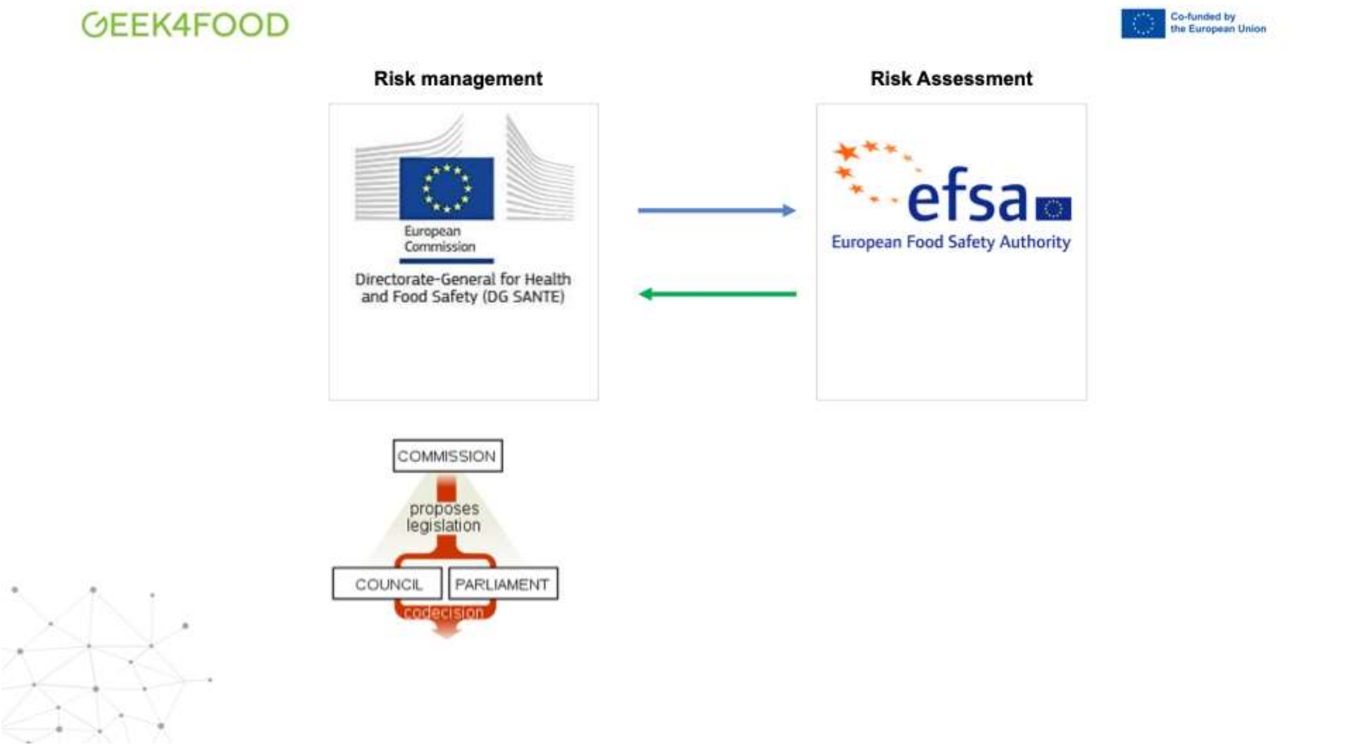
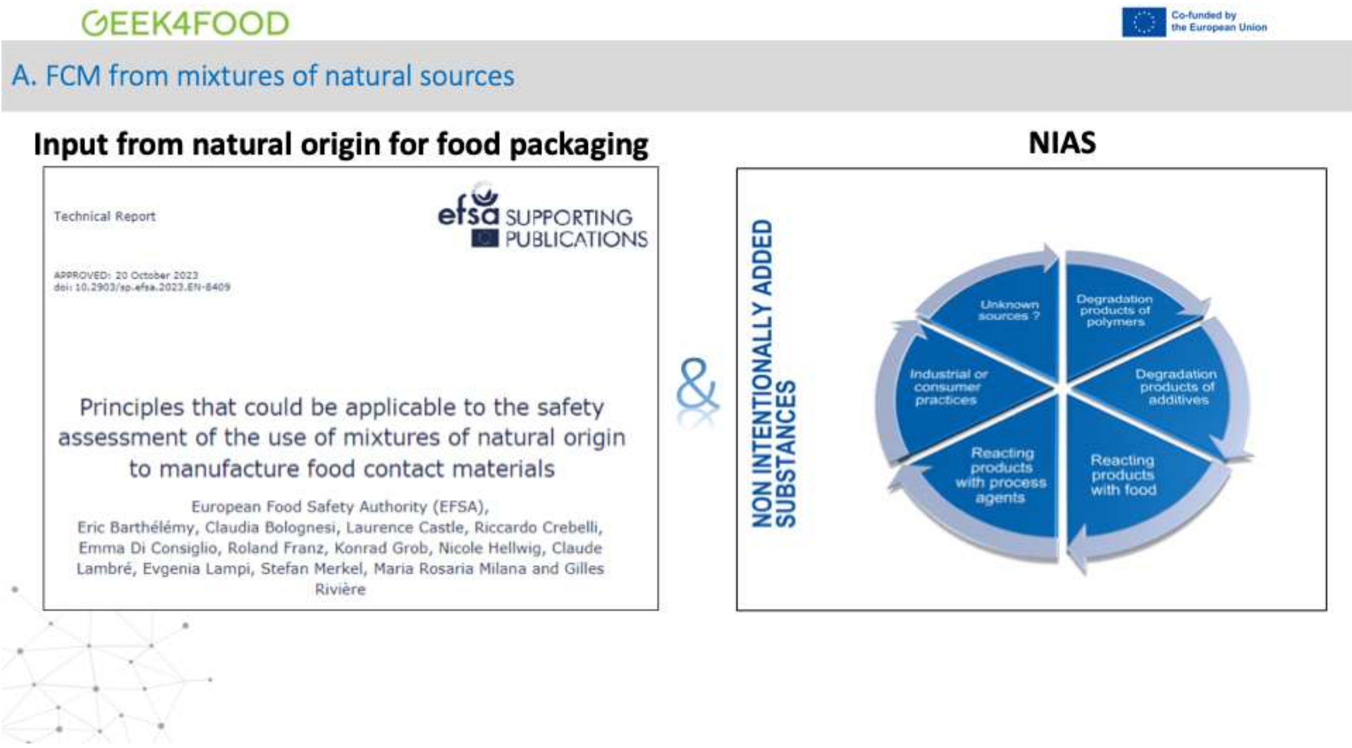
3. Risk assessment and Risk management (Safety)

Project n.: 101087203





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B. IAS and NIAS

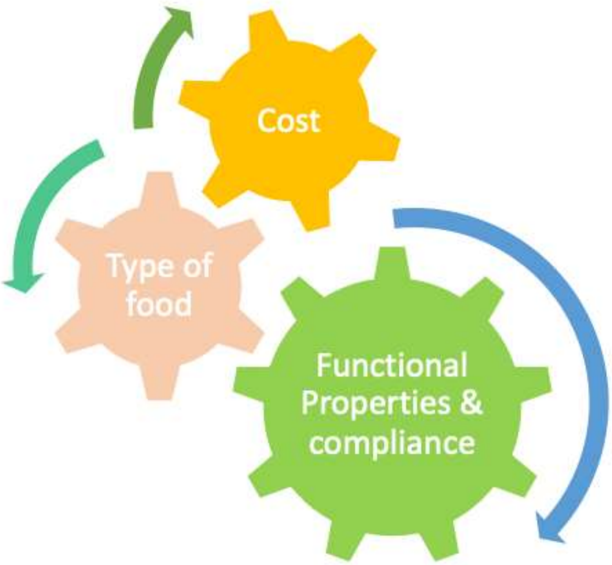
- **IAS - "Intentionally Added Substances"**
- *Regulated chemical substances (monomers, additives, stablizer agents, platicisers, etc) that are risk assessed!*

- **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)

4. Critical considerations



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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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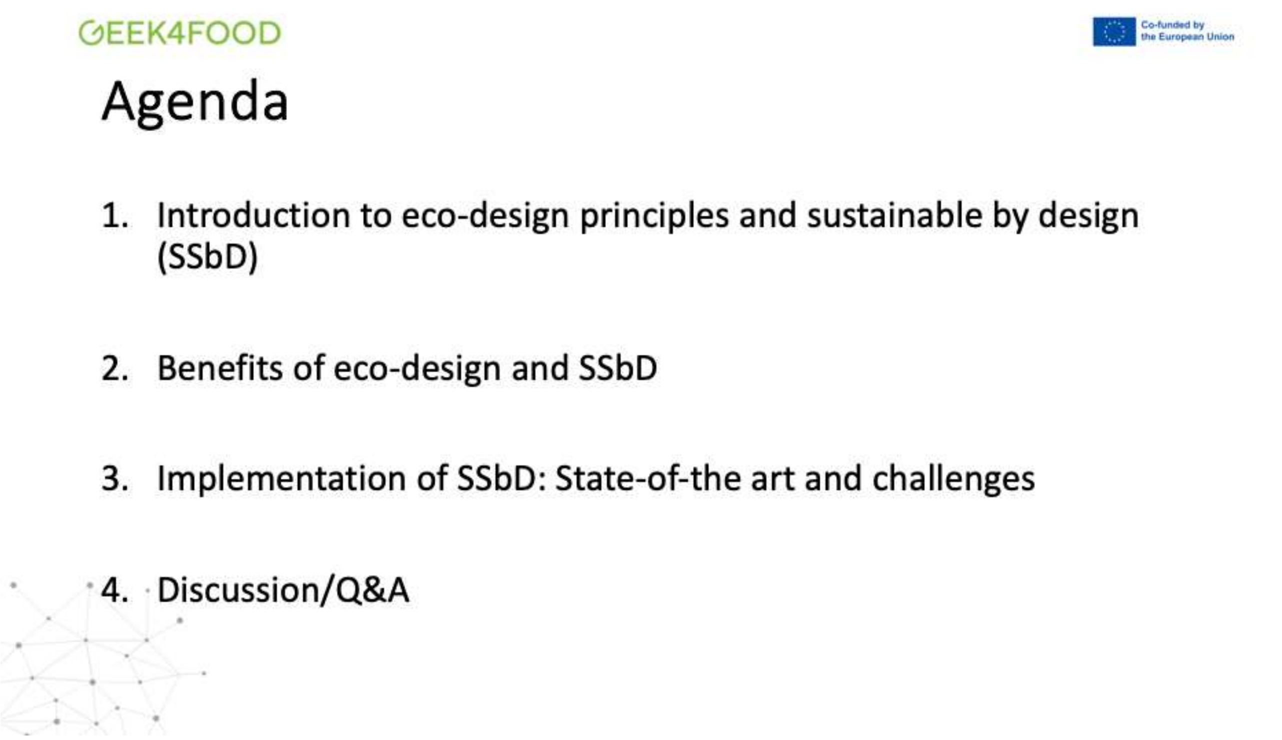

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1. Introduction to eco-design principles and sustainable by design (SSbD)

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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 ?

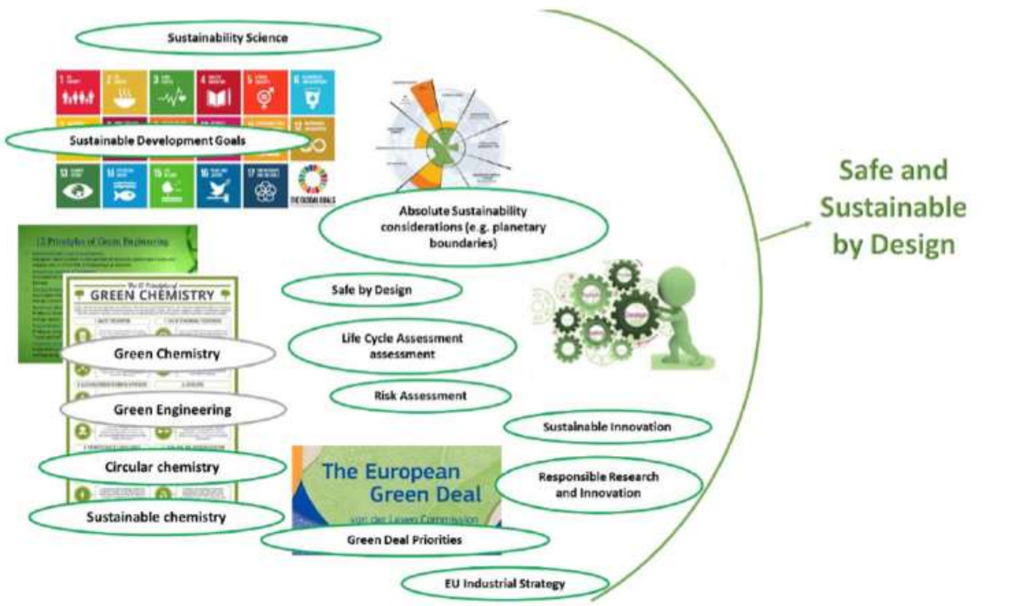
"A framework ensuring that products are safe for human health and the environment while being sustainable."

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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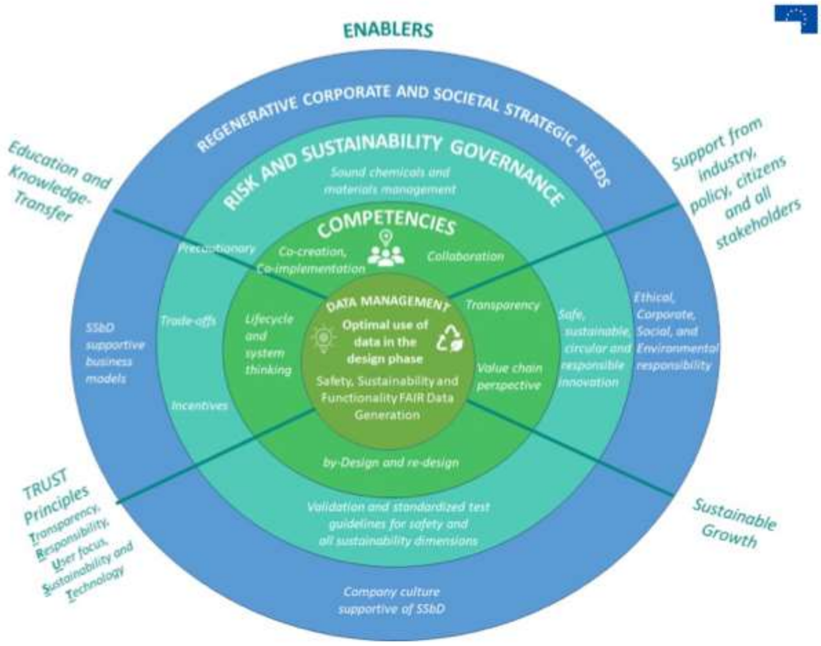

Source: Lya G. Soeteman-Hernández et al. 2024, Envir. Sustain. https://doi.org/10.1007/s42398-024-00324-w

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2. Benefits of eco-design and SSbD

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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**

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

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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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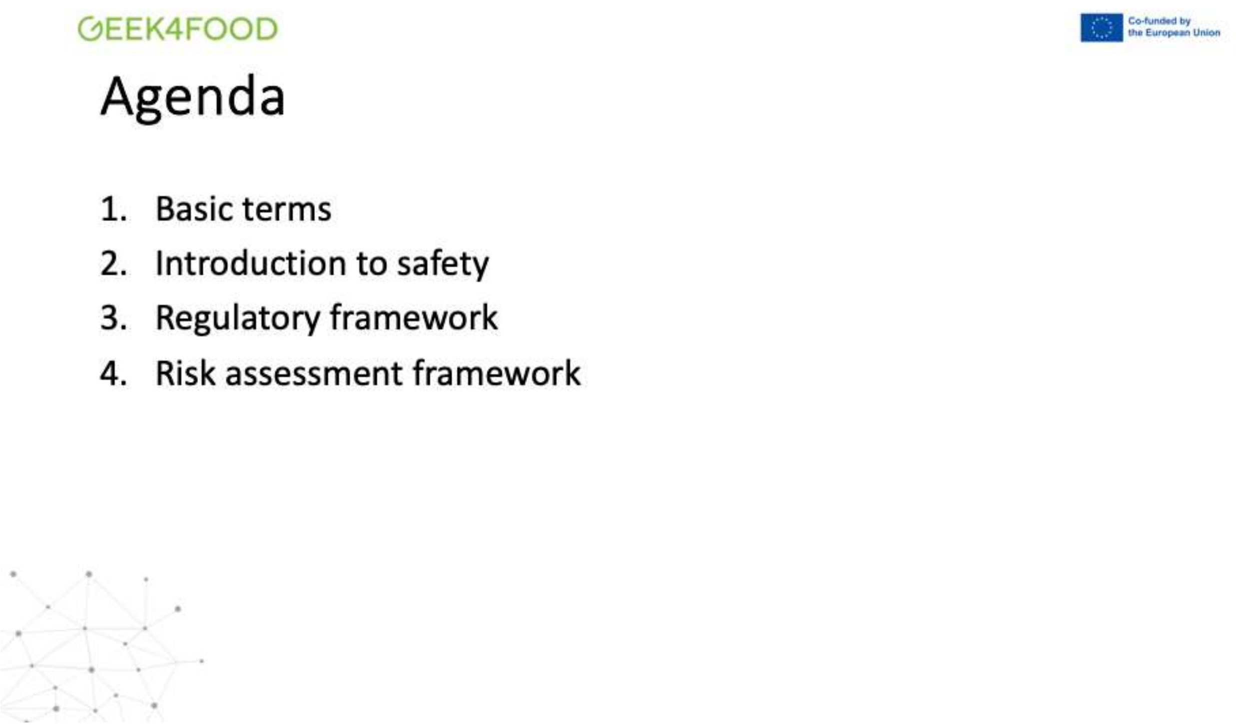
"How can businesses overcome barriers to adopting SSbD?"



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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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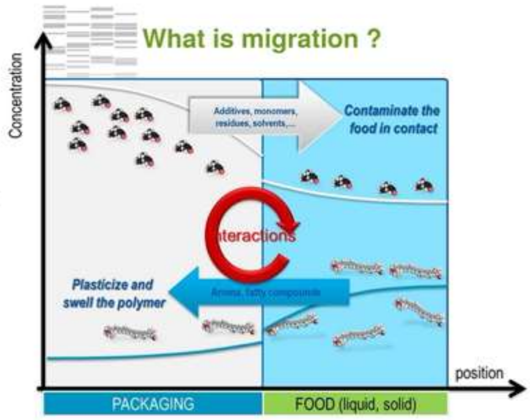
1. Migration

- 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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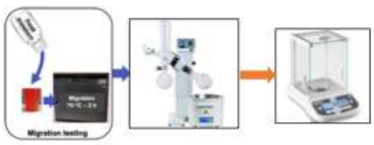
2. Types of migration

A. Overall migration(OM- limit 60 mg/kg of food or 60 mg/dm² 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.

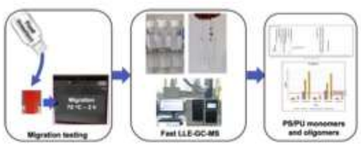
Gravimetric method



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



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3. Compliance testing/exposure

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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2. Type of polymers

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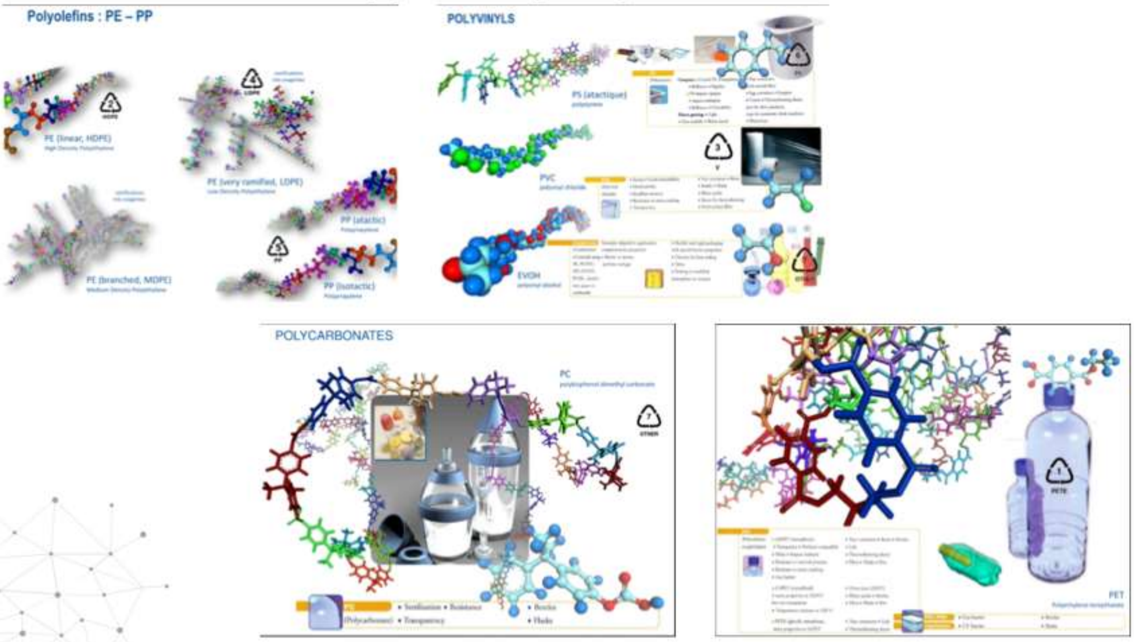

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3. Type of polymeric materials

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4. Supply chain

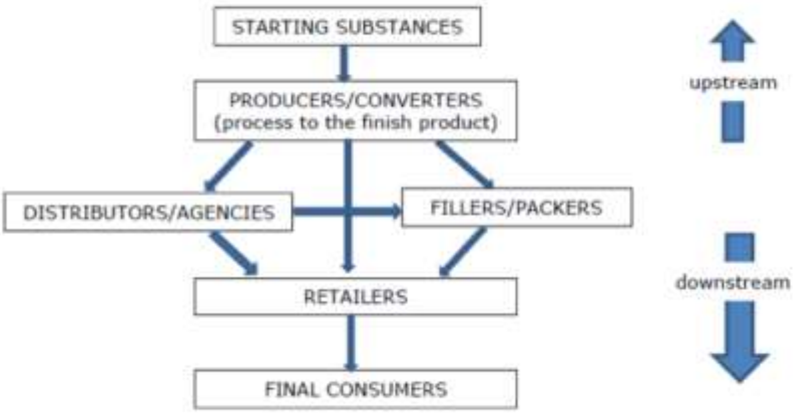

Figure 1: Simplified structure of the organisation of the FCM supply chain

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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	Contaminatio n 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

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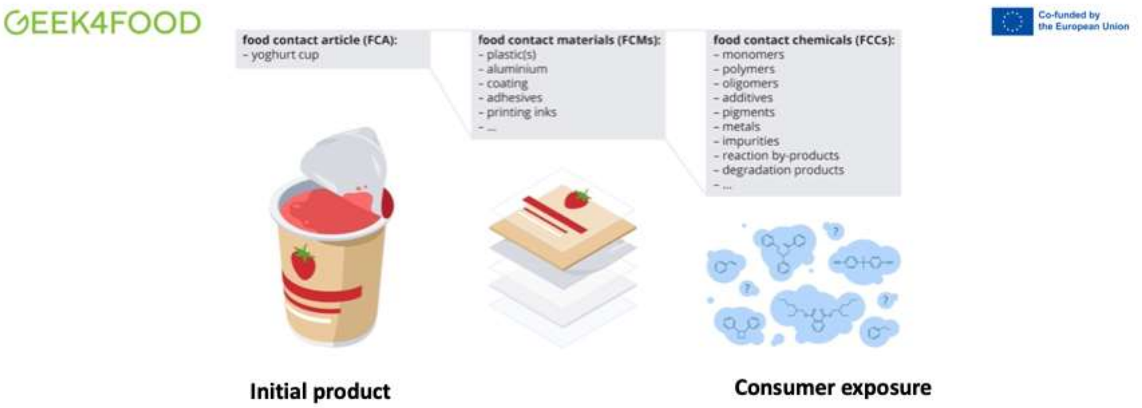

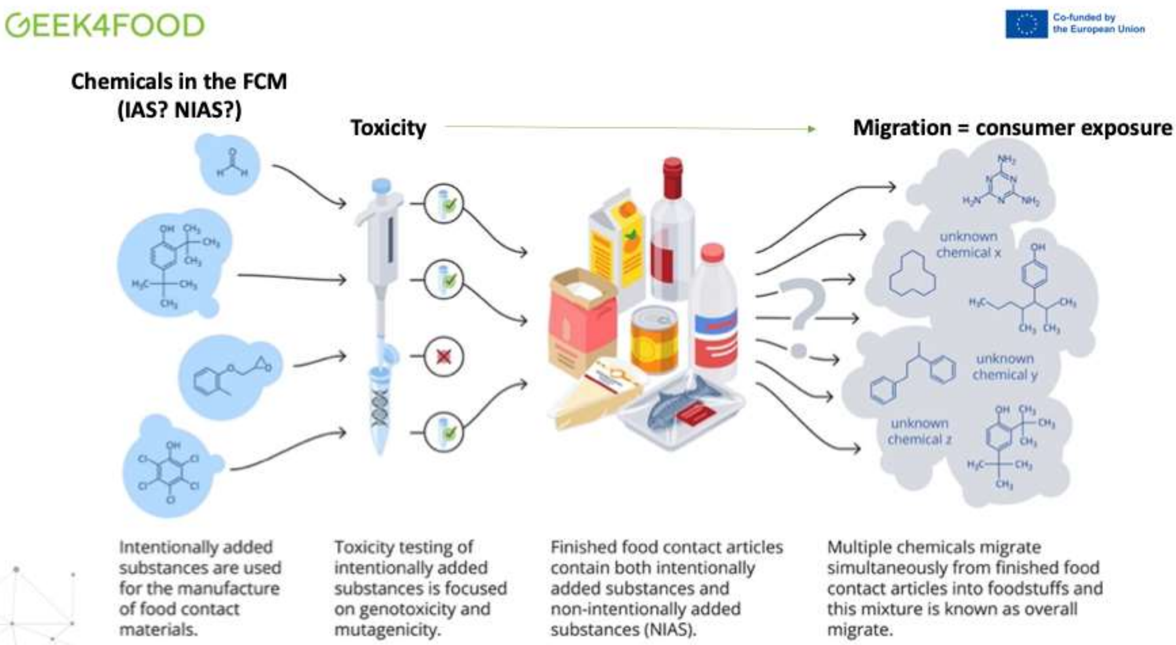

Source: Muncke et al. 2023. Envrionmental International; https://doi.org/10.1016/j.envint.2023.108161

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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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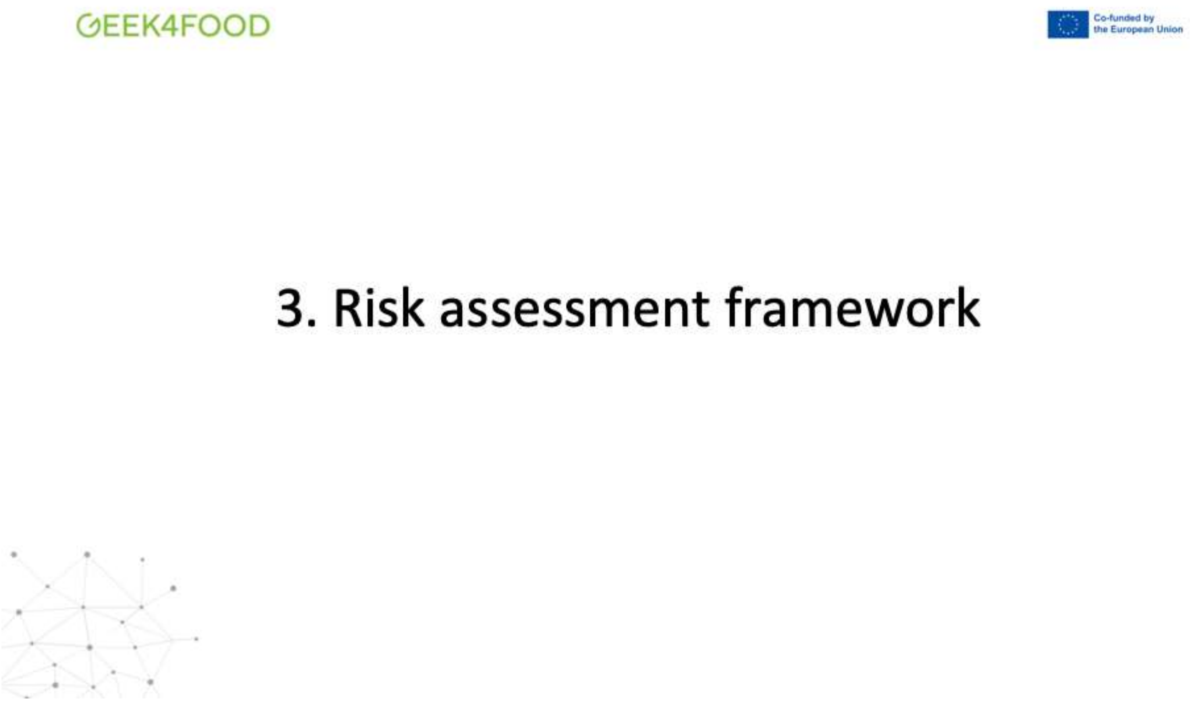
Risk and Safety assessment
efsa
EUROPEAN FOOD SAFETY AUTHORITY
• Guidance
• Criteria for safaety
• Risk assessment
• Scientific opinions
efsa SUPPORTING PUBLICATIONS
Principles that could be applicable to the safety assessment of the use of mixtures of natural origin to manufacture food contact materials
Risk management
European Commission
Directorate-General for Health and Food Safety (DG SANTE)
• Regulations;
• Official controls
• Complaince rules
• Authorisations
• Official controls
DG SANTE
EURLs
NRLs
OLs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3. Risk assessment framework

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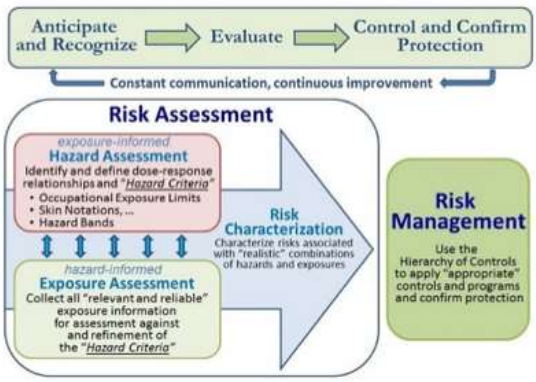
1. Risk, hazard and exposure

HAZARD VS RISK

RISK = HAZARD x EXPOSURE



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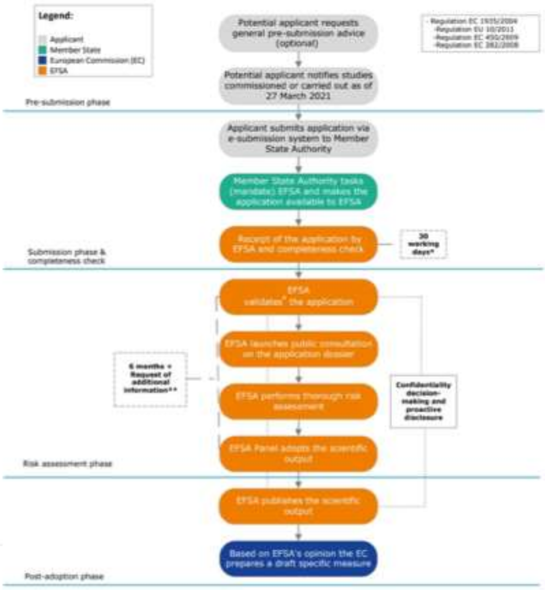
2. Risk assessment of FCM (including eco-designed)



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3. Toxicity (Hazard)

Εκτίμηση τοξικότητας

- Γενοτοξικότητα, μεταλλαξιγένεση, καρκινογένεση
  - In vivo
  - In Silico (QSAR alerts)
- Άλλα είδη τοξικότητας
  - In vivo
  - In Silico (κατηγοριοποίηση/κλάσεις Cramer (I, II, III)

QSAR – Quantitative structure-activity relationship


EFSA JOURNAL

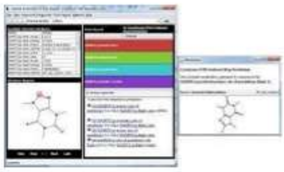
Guidance Document | Open Access

Guidance on the use of the Threshold of Toxicological Concern approach in food safety assessment

EFSA Scientific Committee, Simon J More, Vasileios Bampidis, Diane Benford, Claude Bragard, Thorhallur I Halldorsson, Antonio F Hernández-Jerez, Susanne Hougaard Bennekou ... See all authors

First published: 06 June 2019 | https://doi.org/10.2903/j.efsa.2019.5708 | Citations: 14

Υπολογισμένο με μέσο όρο βάρους 60 kg /άτομο.



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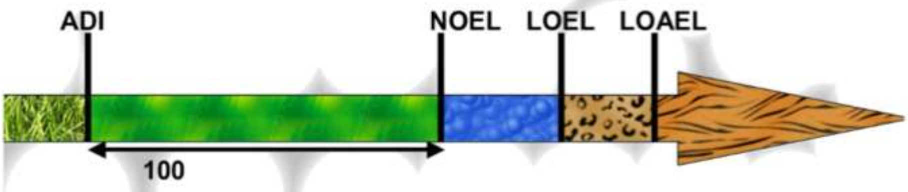
4. Setting of safety levels (hazard characterisation)

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 = 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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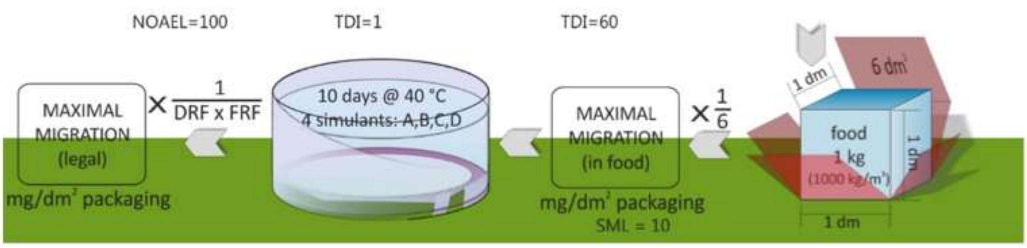
4. Setting of safety levels (hazard characterisation)



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5. Exposure (migration testing)

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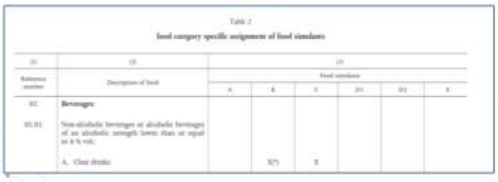
Accelerated conditions → **Worst-case scenario**

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



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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
SkyHive
MILCOOP
DUBLIN
ICC
EFFoST


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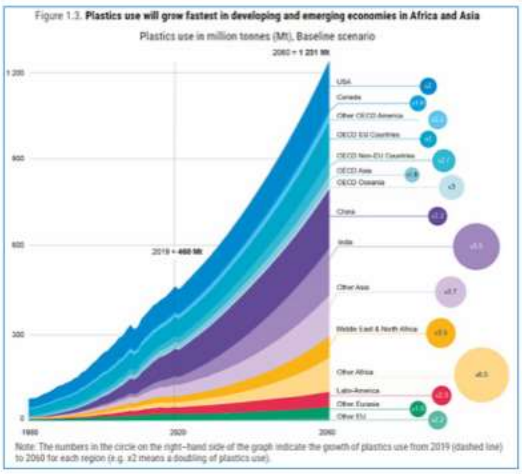
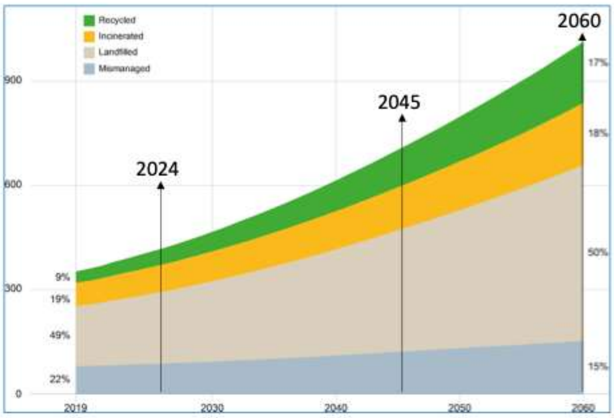
Agenda
1. Introduction
2. Existing eco-designed food packaging materials
3. Pros and cons
4. Conclusions

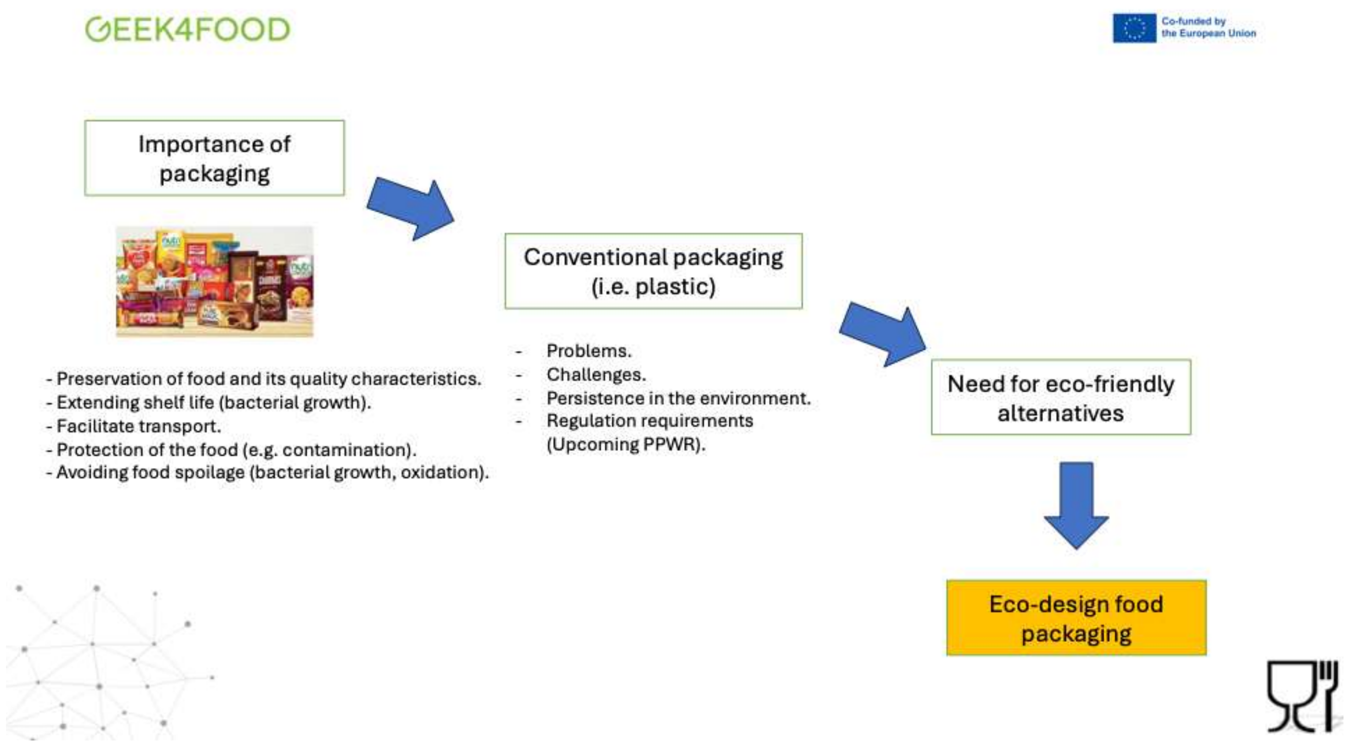
1. Introduction



Source: OECD ENV-Linkages model.



Source: OECD ENV-Linkages model.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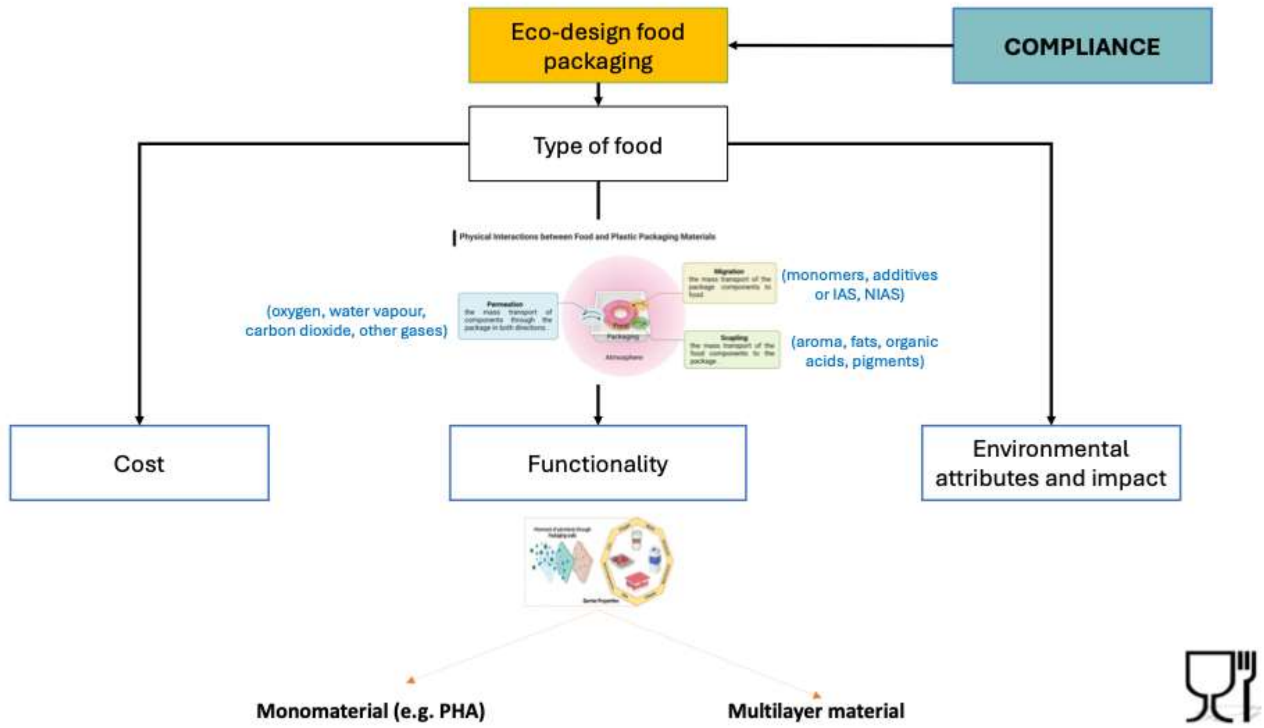
Importance of packaging
- Preservation of food and its quality characteristics.
- Extending shelf life (bacterial growth).
- Facilitate transport.
- Protection of the food (e.g. contamination).
- Avoiding food spoilage (bacterial growth, oxidation).
Conventional packaging (i.e. plastic)
- Problems.
- 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
(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

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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

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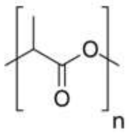
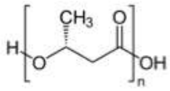
1. Biodegradable materials

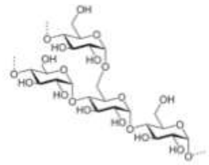
- Polylactic Acid (PLA)
- Polyhroxyalkanoates (PHA)
- Polybutylene succinate (PBS)
- Starch-based plastics
- Chitosan-based materials
- Polycaprolactone (PCL)
- Polyglygolic acid (PGA)



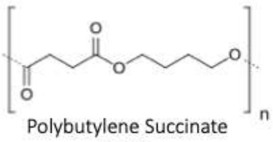
Polylactic Acid (PLA)



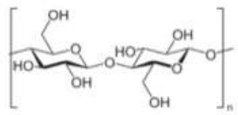
Polyhydroxyalkanoates (PHA)



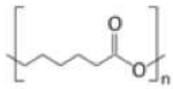
Starch-based plastics



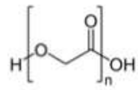
Polybutylene Succinate (PBS)



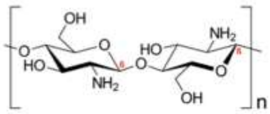
Cellulose-based Plastics (including bacterial cellulose)



Polycaprolactone (PCL)



Polyglycolic acid (PGA)



Chitosan-based materials

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

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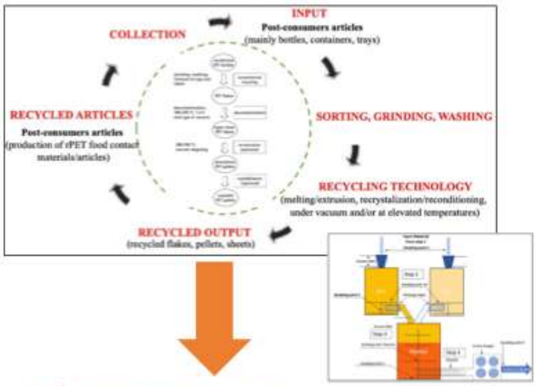
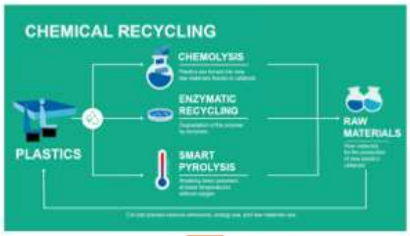
Advacnced recycling technologies for FCM uses

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)

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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

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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.

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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.

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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

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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. 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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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?"*

Thank you

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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

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

1. Content mapping file

Type of content	Session's Title	Content's core duration	Indicative resources
Challenge based lecture/discussion	How can we explore optimised fermentation processess to produce sustainable, nutritious, and affordable food ingredients while addressing potential challenges in resource efficiency, consumer acceptance, regulatory compliance, and environmental impact?" *Expert keynote*	30 min	
Content part 1	Fundamental principles of traditional and optimised fermentation, and safe & sustainable production practices	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	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	30 min	Identificate alternative microbial-derived protein sources (biomass fermentation) to conventional ones. e.g mycoproteins/single-cell proteins to vegetal/animal origin proteins.
Content part 3	Existing eco-designed food packaging materials. Pros and cons	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	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, sustanability and cost)	30 min	

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

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3. Module's content

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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

International Dairy Journal

The diversity and evolution of microbiota in traditional Turkish Divle Cave cheese during ripening

S. Ozturkoglu Budak, Marian J. Figge, Jos Houbraken, Ronald P. de Vries

Fermentation in action

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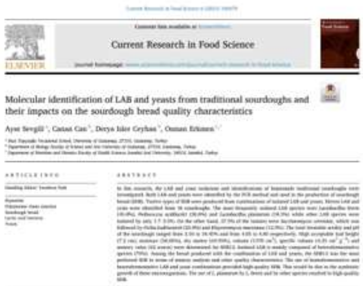
Fermentation – Bread

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/S2665927123000473#sec3

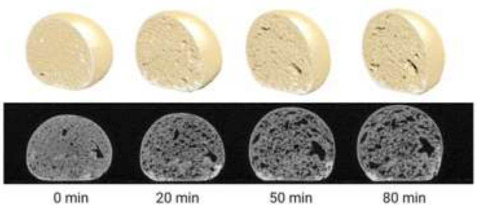


Current Research in Food Science

Molecular identification of LAB and yeasts from traditional sourdoughs and their impacts on the sourdough bread quality characteristics

Ayse Sevgili, Canan Can, Derya Isler Ceyhan, Osman Erkmen

Fermentation in action



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Question

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

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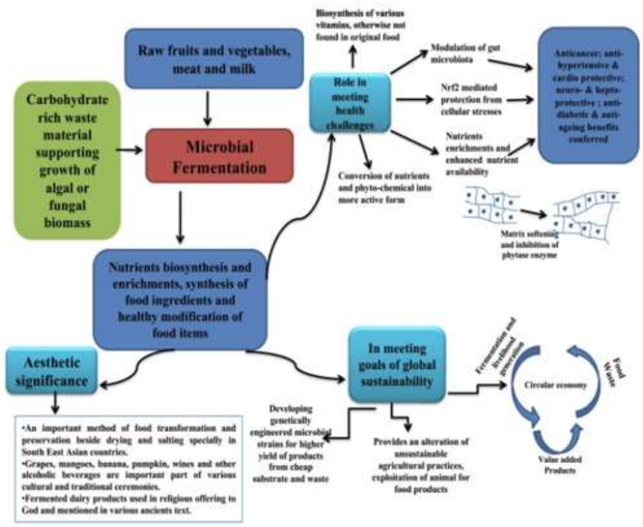
Discuss this diagram and consider the potential of fermentation.

Consider

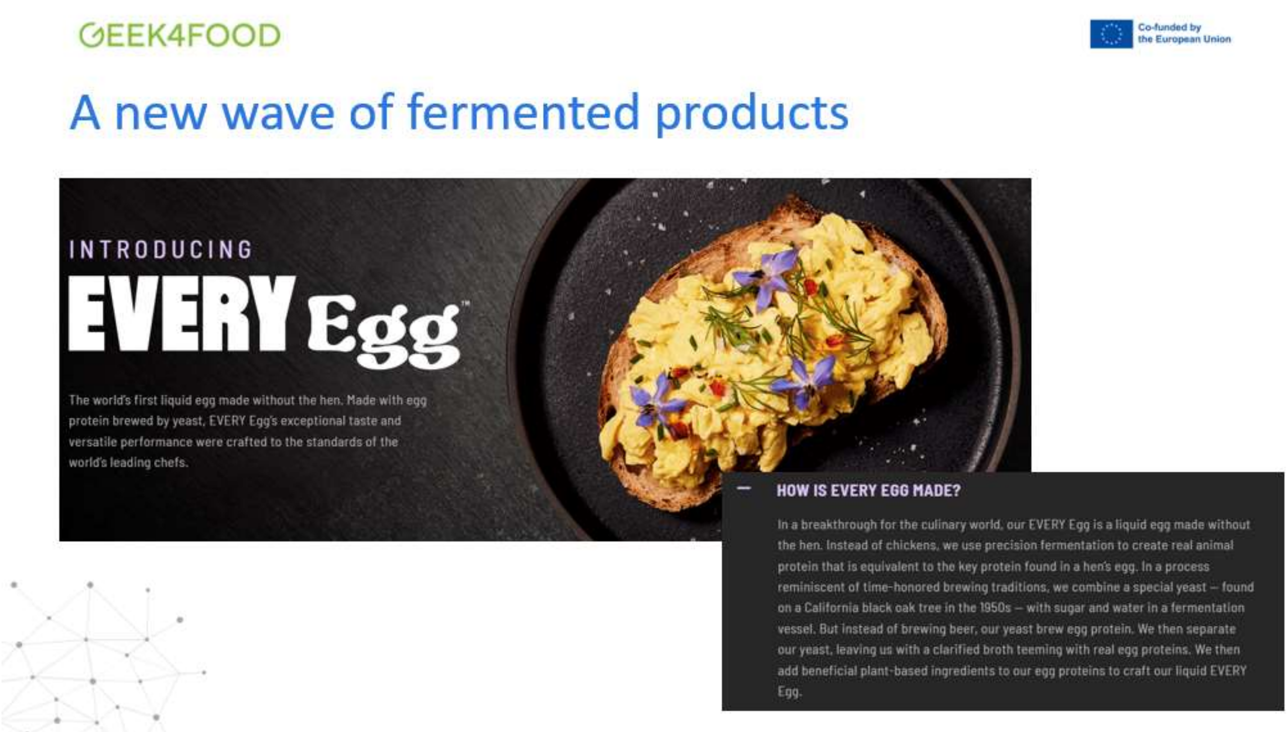
- Fermented foods and health
- Fermented foods and the microbiome.
- Fermentation as a tool in valorization.



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.



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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

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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.

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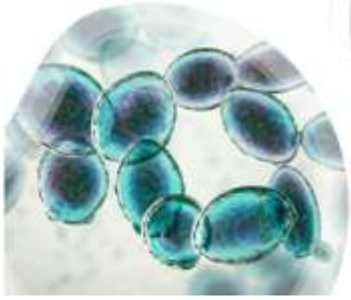
Fermentation

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 vary 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

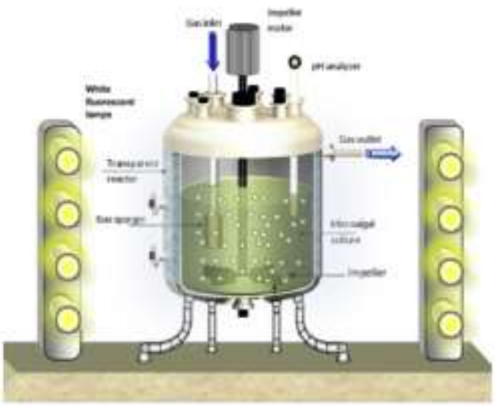
- Cultures have an optimized pH range for metabolism. Outside of this range is potentially detrimental to the culture and can therefore significantly slow or halt fermentation. Bioreactors often have pH probes built in.

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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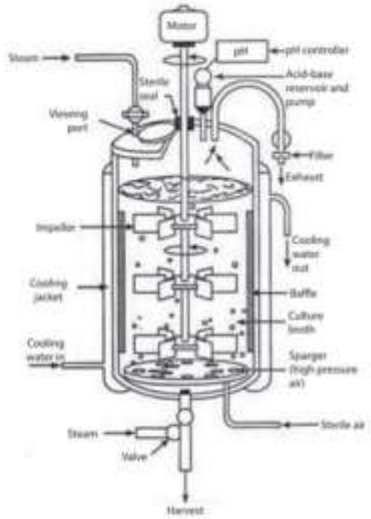
Bioreactors



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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

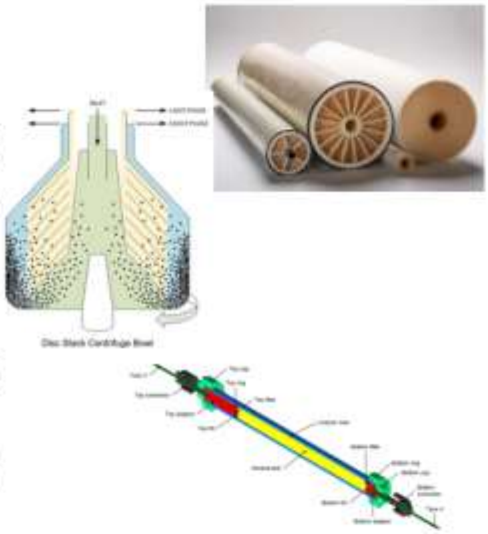
- Can separate different products from fermentation based on their densities. It can remove solid particles for clarification, isolation of lipid fractions.

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.

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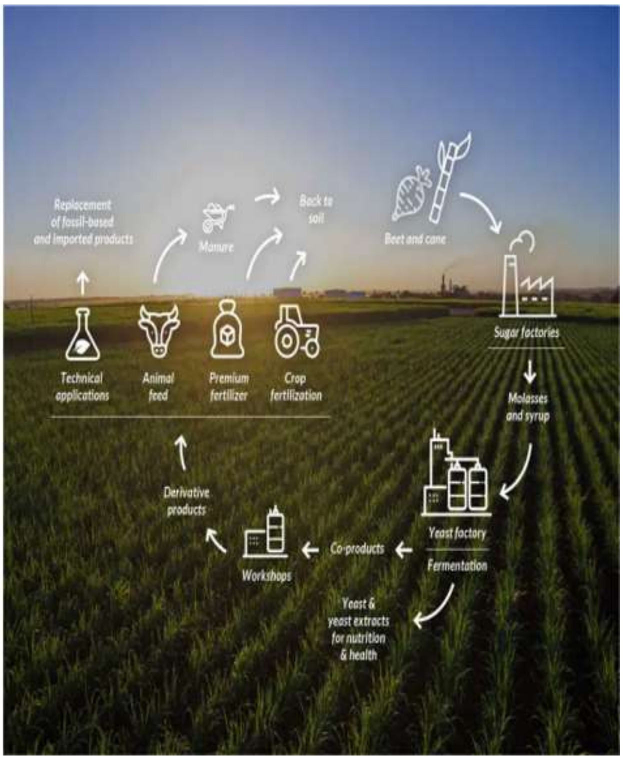
Sustainability in fermentation

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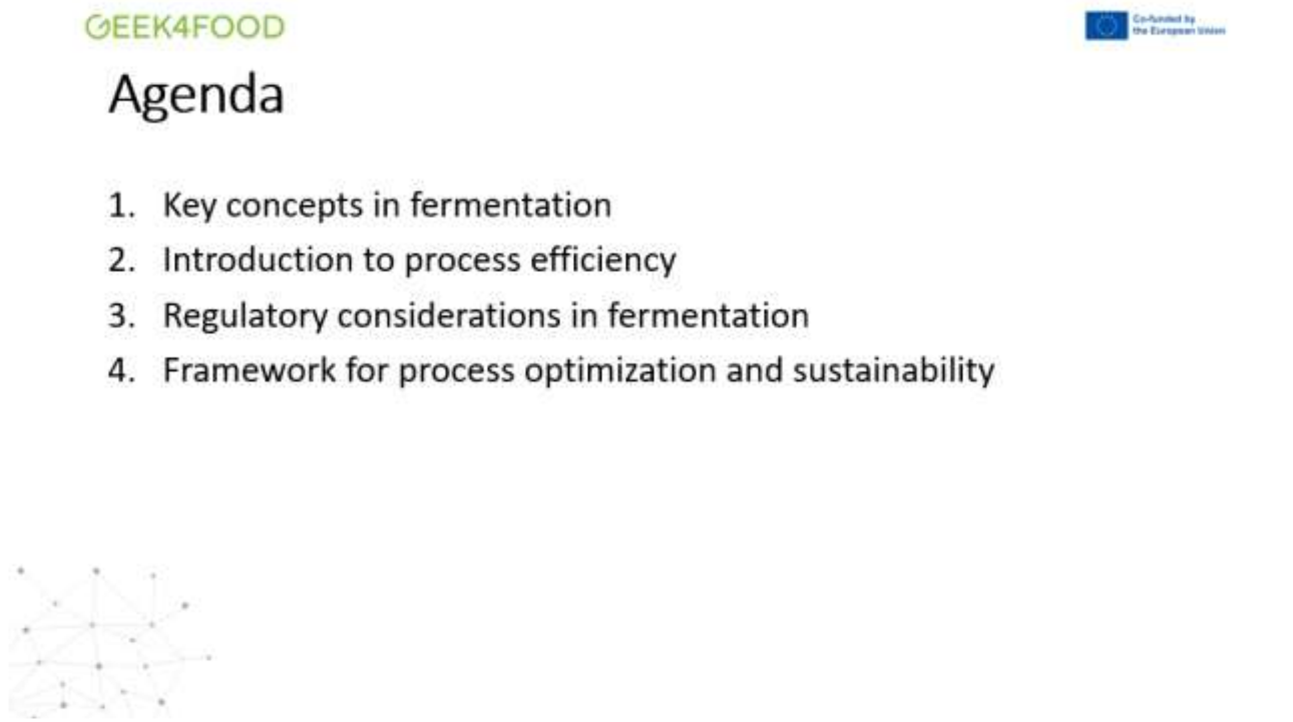
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Agenda
1. Key concepts in fermentation
2. Introduction to process efficiency
3. Regulatory considerations in fermentation
4. Framework for process optimization and sustainability

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.

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

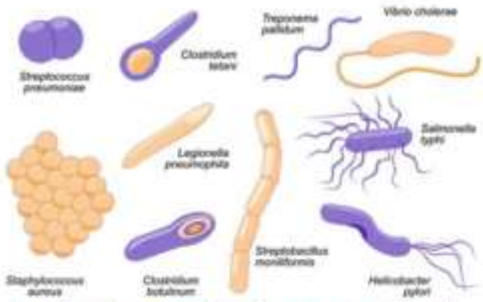
Microbial Strains
Microbial strains are specific types of microorganisms used in fermentation, influencing the quality and characteristics of the final product.

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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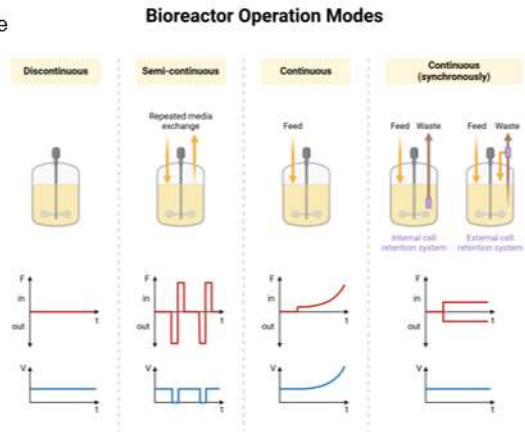
3. Types of fermentation processes

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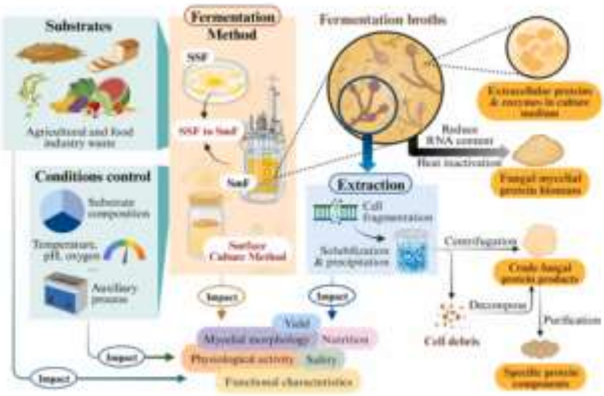
Process efficiency refers to the ability to maximize the desired output while minimizing the use of resources (e.g., energy, raw materials, water) and reducing waste during the fermentation process.

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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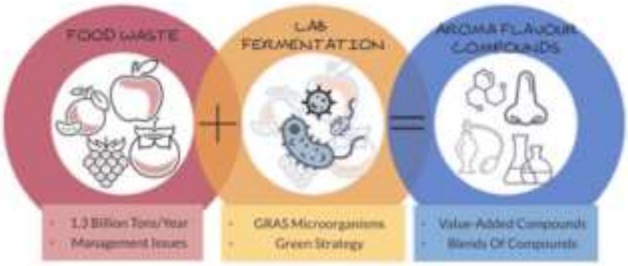
Key aspects of process efficiency – Waste minimization

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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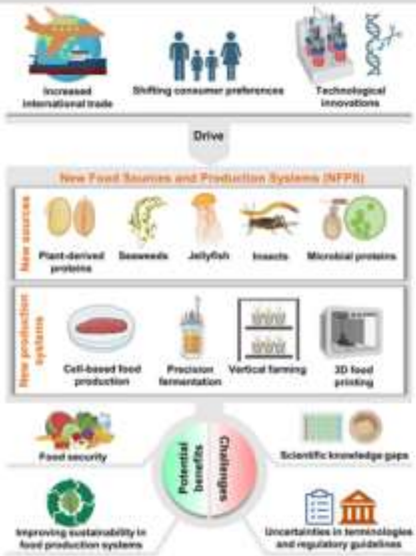
EU Regulatory Framework

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.

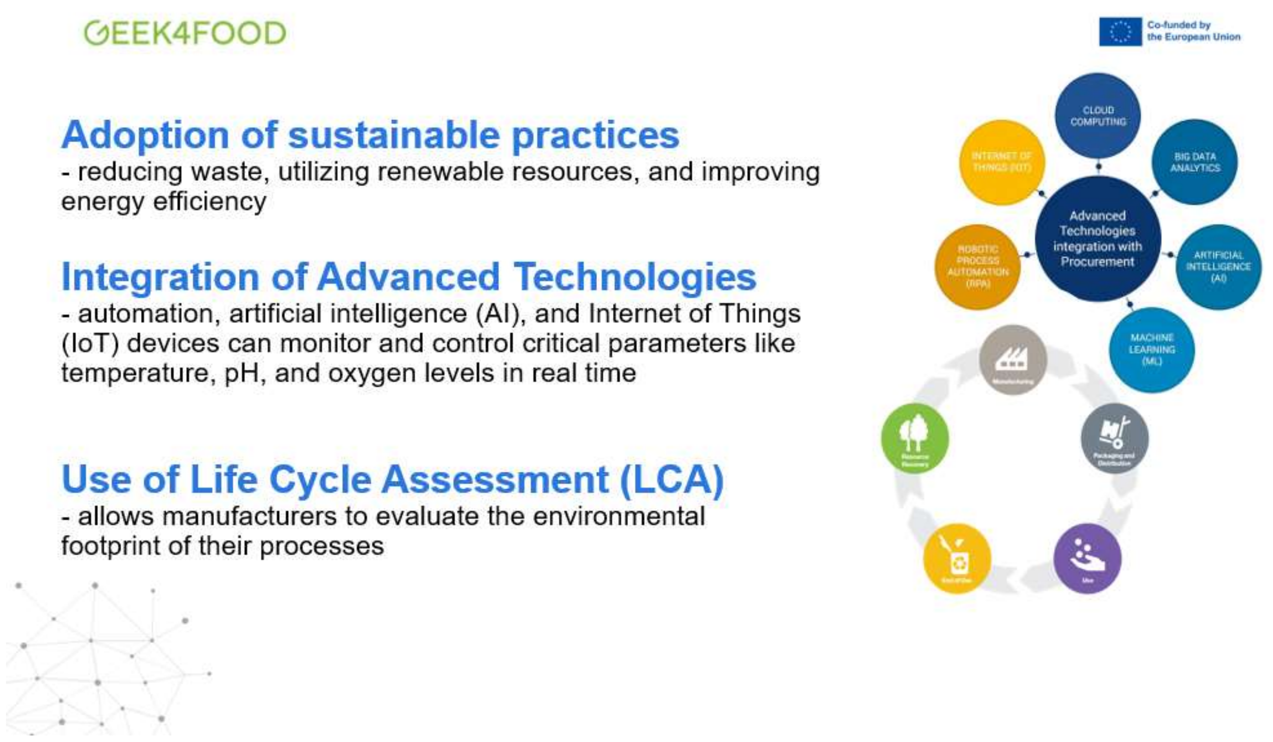
Use of Additives in Fermentation – *Regulation (EC No 1333/2008)* on food additives.

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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Improvement of microbial strain performance

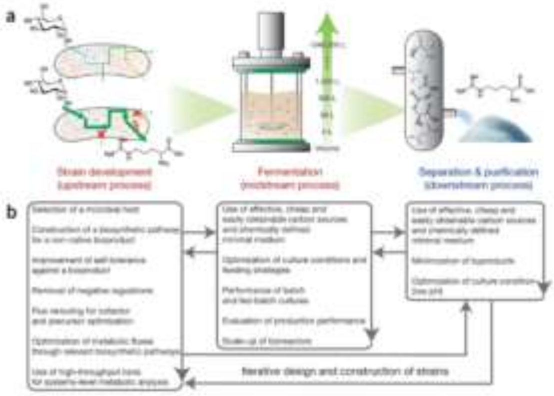
- strain optimization through genetic engineering or adaptive evolution can further enhance productivity and sustainability

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

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Valorization of by-products

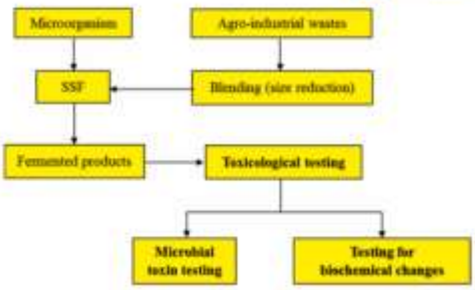
- upcycled into valuable products like animal feed, biofuels, or bioactive compounds

Regulatory compliance and certifications

- compliance with local and international sustainability standards and certifications

Continuous improvement through data-driven insights

- continuous improvement methodologies such as Lean or Six Sigma can then be applied to streamline operations while maintaining product quality



Source: https://doi.org/10.1016/j.heliyon.2023.e14814

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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.

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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

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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

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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™, 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.

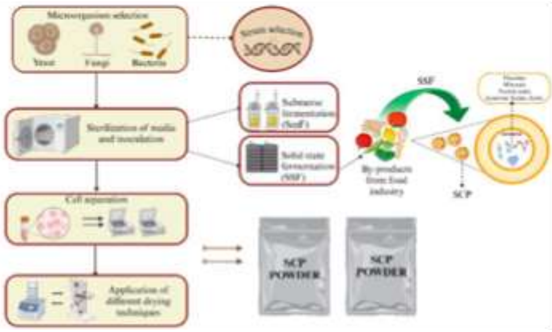

Fig 1. Schematic representation of the process for the production SCP (Source: Original)

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).

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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

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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***

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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).

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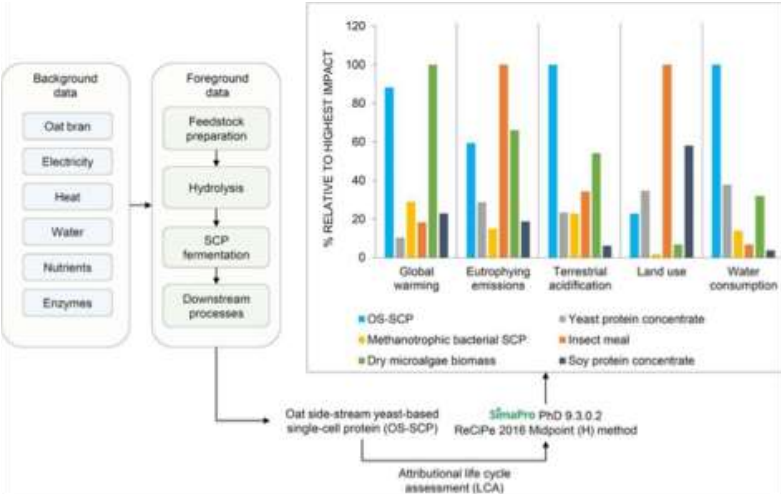

Figure 2. Comparative Environmental Footprint of OS-SCP vs. Other Novel Protein Sources

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 Järviõ 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.

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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

1. Optimized Food Fermentation Products

2. Real-World Examples of Optimized Fermentation Products

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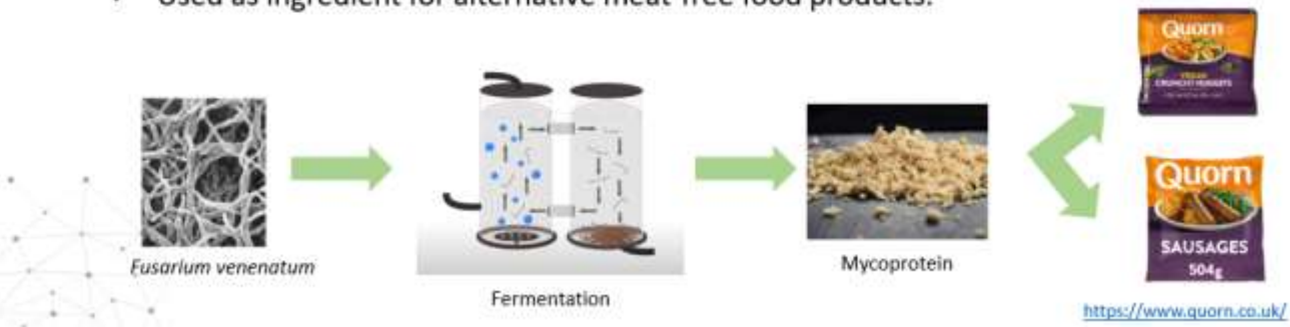
2.1. Mycoprotein-Based Products

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.



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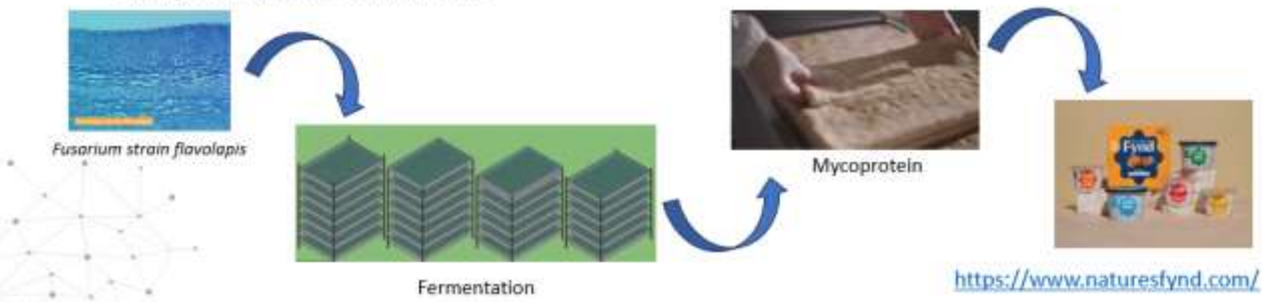
2.1. Mycoprotein-Based Products

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.



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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 Biosciences

C16 BIO

- ✓ 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?

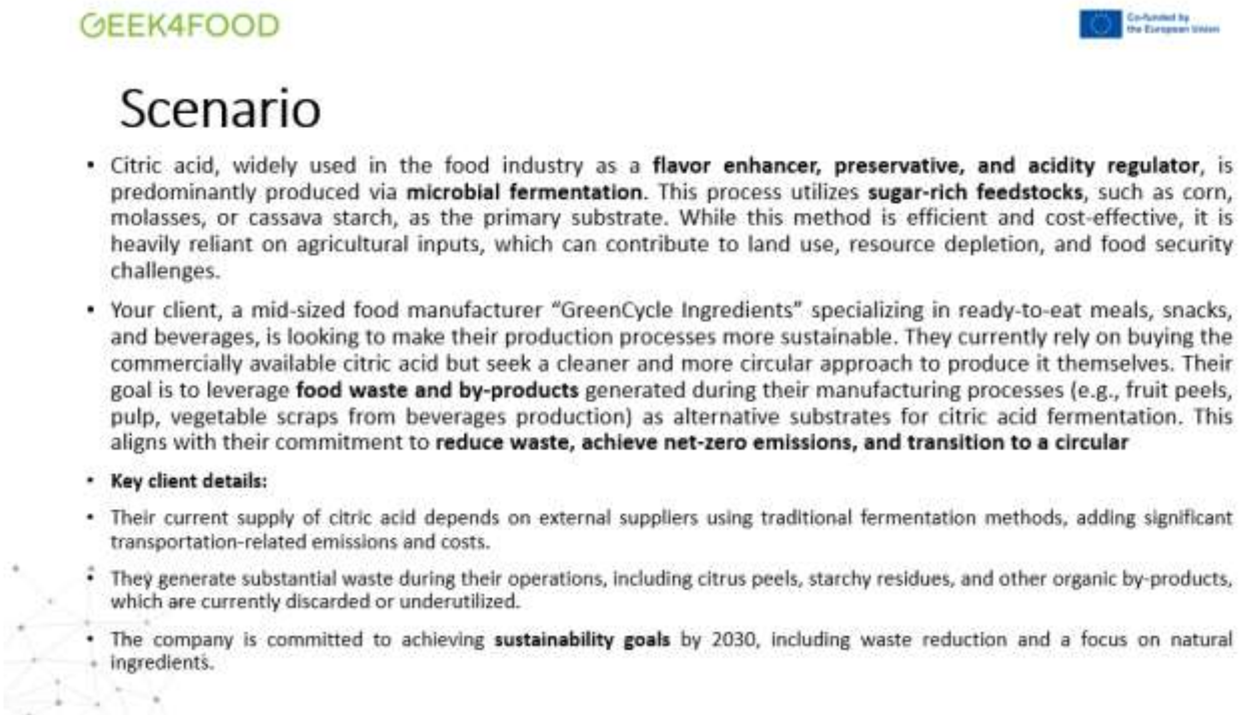
A) It always produces products that are less expensive than traditional methods

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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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**

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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.

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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

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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

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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	Content's core duration	Indicative resources
Challenge based lecture/discussion	Food waste: from what, what, what for and how: current and future sustainable strategies for valorisation *Expert keynote*	30 in	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]
Content part 1	Technological functionalities of food waste for green ingredients design	30 min	4. Review: Galanakis C. 2012. Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications [Link 4] 5. Book Chapter: Pittia & Gharsallaoui, Food waste recovery [Link 5]
Content part 2	Biorefinery approaches and innovative technologies for food ingredients	30 min	4. Review: Patel et al., 2024. Innovative biorefinery approaches for upcycling of post-consumer food waste in a circular bioeconomy context [Link 6]

Activity based content – aiming systems approach, identify the problem	Activity/Case-study 1 Identify a specific food value chain and related waste and side-streams to be valorised for innovative food ingredients and products based on their technological functionalities.	30 min	
Content part 3	Circular economy, industrial sustainability and social impact	30 min	5. Review: Fazle-Rabbi & Bin Amin, 2024. Circular economy and sustainable practices in the food industry: A comprehensive bibliometric analysis [Link 7]
Activity based content – aim to bring solutions	Activity/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.)	30 min	
Refining solution/Concluding session	Overview of the 2 case studies/Discussions	30 min	

2. Module's syllabus

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

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

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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]

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3. Module's content

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Food waste: from what and what

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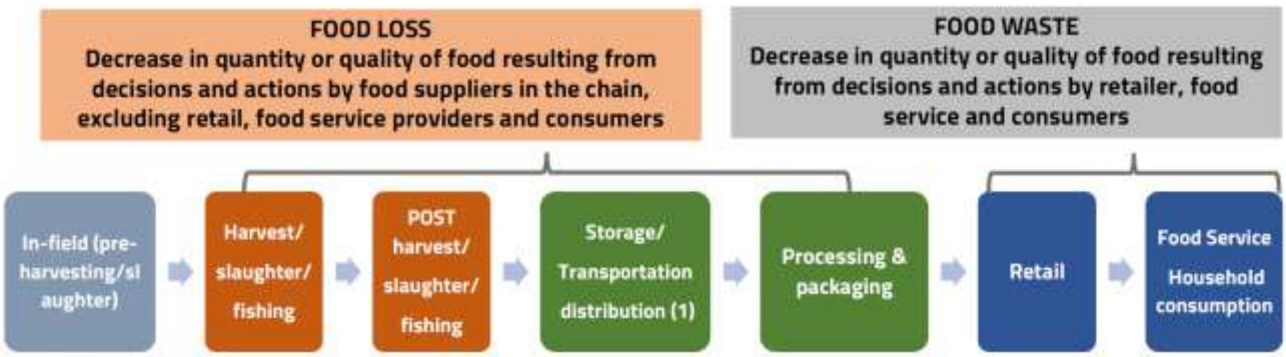
Food loss and waste (FLW)

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

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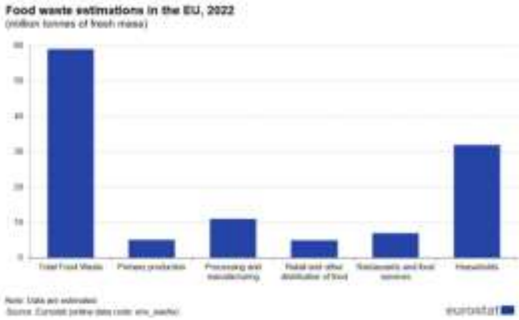
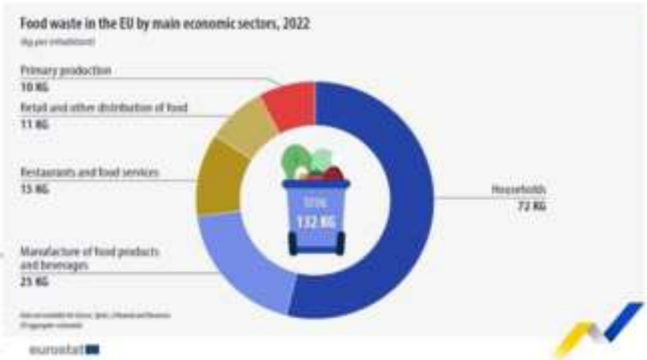
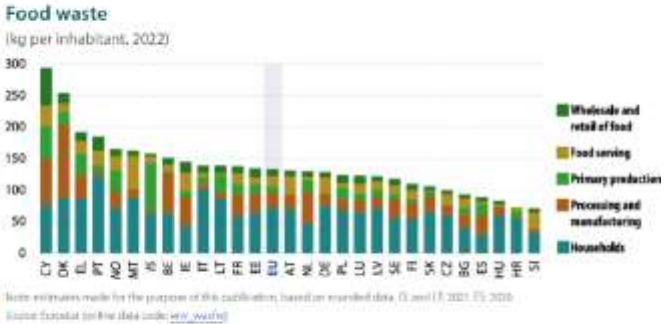
FLW statistics

Statistics



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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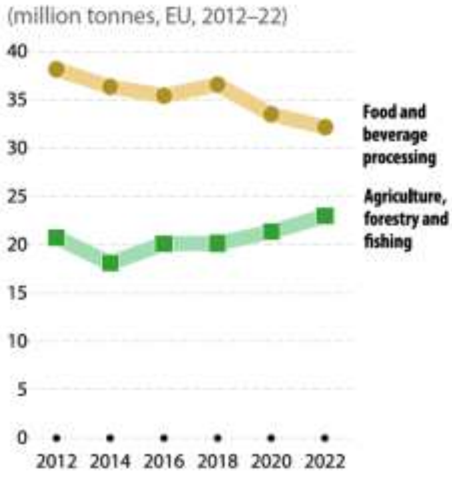
Food waste

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



Source: Eurostat (online data code: env_wasgen)

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Food waste: why?

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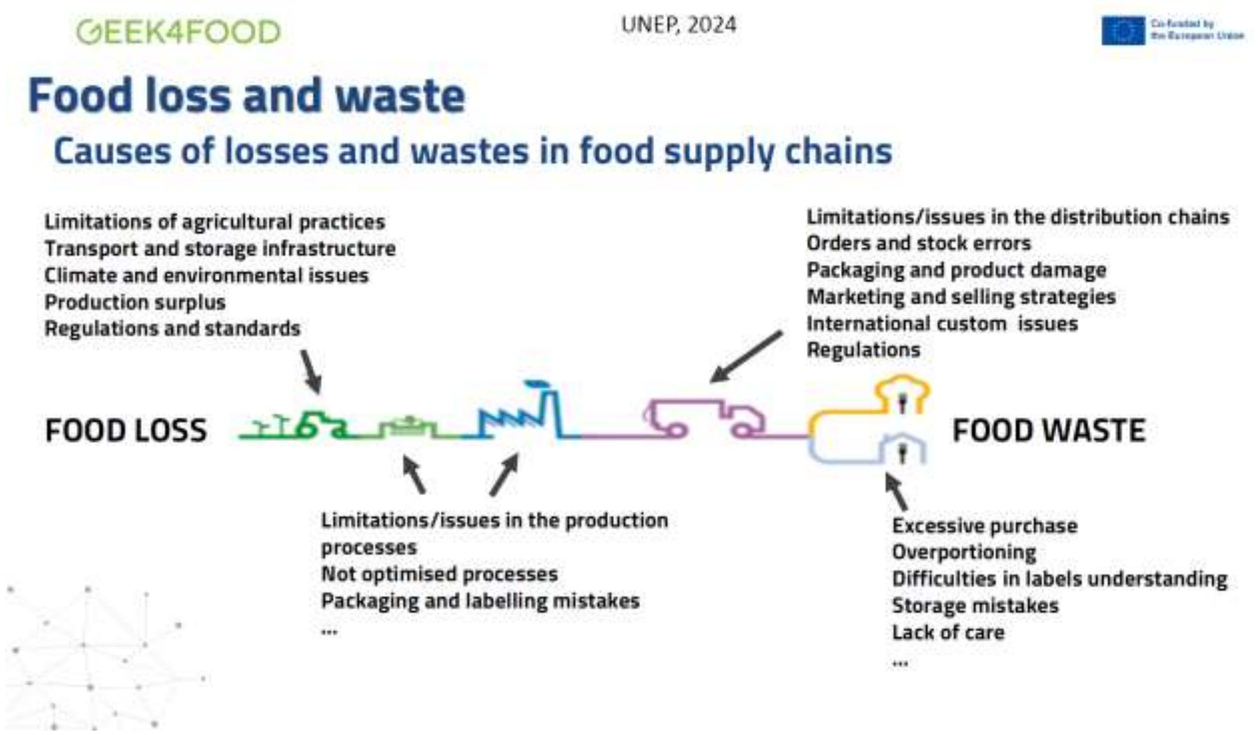

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UNEP, 2024

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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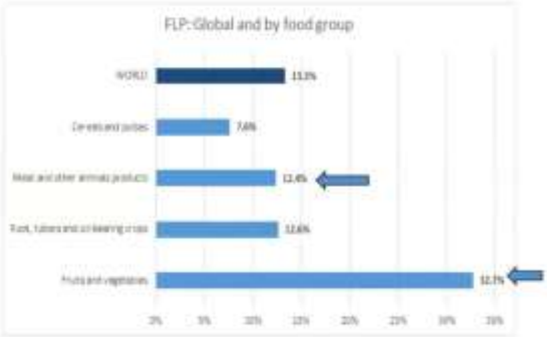
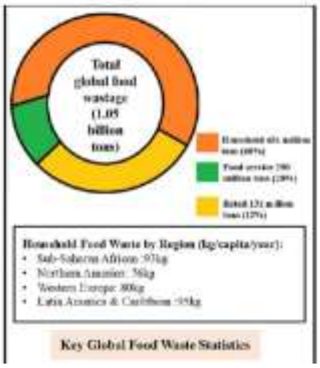
Food loss and waste

The magnitude

- An estimated **13 percent of food was lost in the supply chain, from after harvest, and prior to reaching retail shelves in 2021** (FAO, 2023).
- An estimated **19 percent of food was wasted in households, food services and in retail in 2022,** the equivalent of 132 kg per capita. (UNEP, 2024).
  - **Households account for sixty percent (60 %) of the food that is wasted globally**. Around the world, each day, over 1 billion meals are thrown away in households alone. (UNEP, 2024).



Source: FAO, 2023



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Food waste valorization: how and what for?

UNEP, 2024

Food loss and waste

Causes of losses and wastes in food supply chains

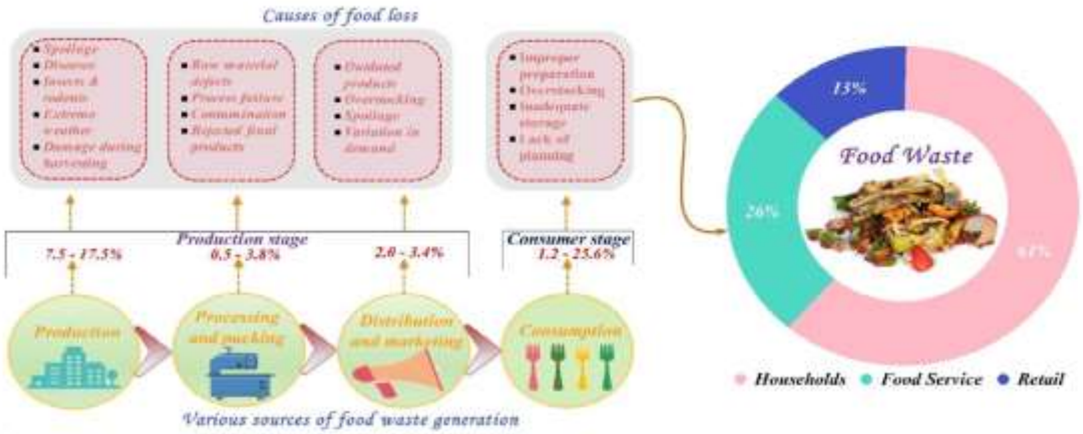

Fig. 1. Sources and generation of food waste from various sector (UNEP, 2021).
Source: Di Fraia et al., 2024

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UNEP, 2024

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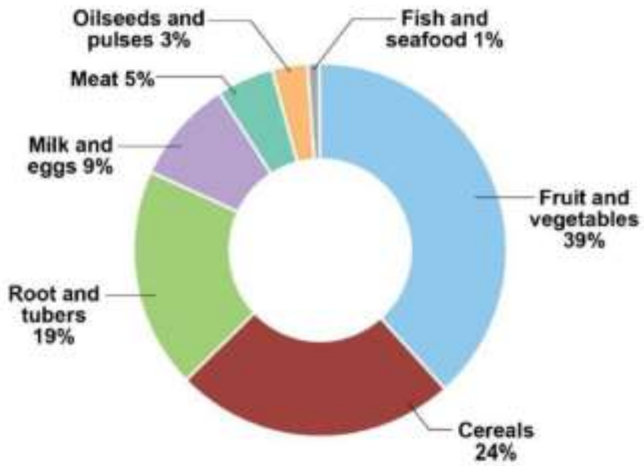
Food loss and waste

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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UNEP, 2024

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Food loss and waste

The complexity of FLW in processing (prior to retail)

Moonsami et al., 2024

- 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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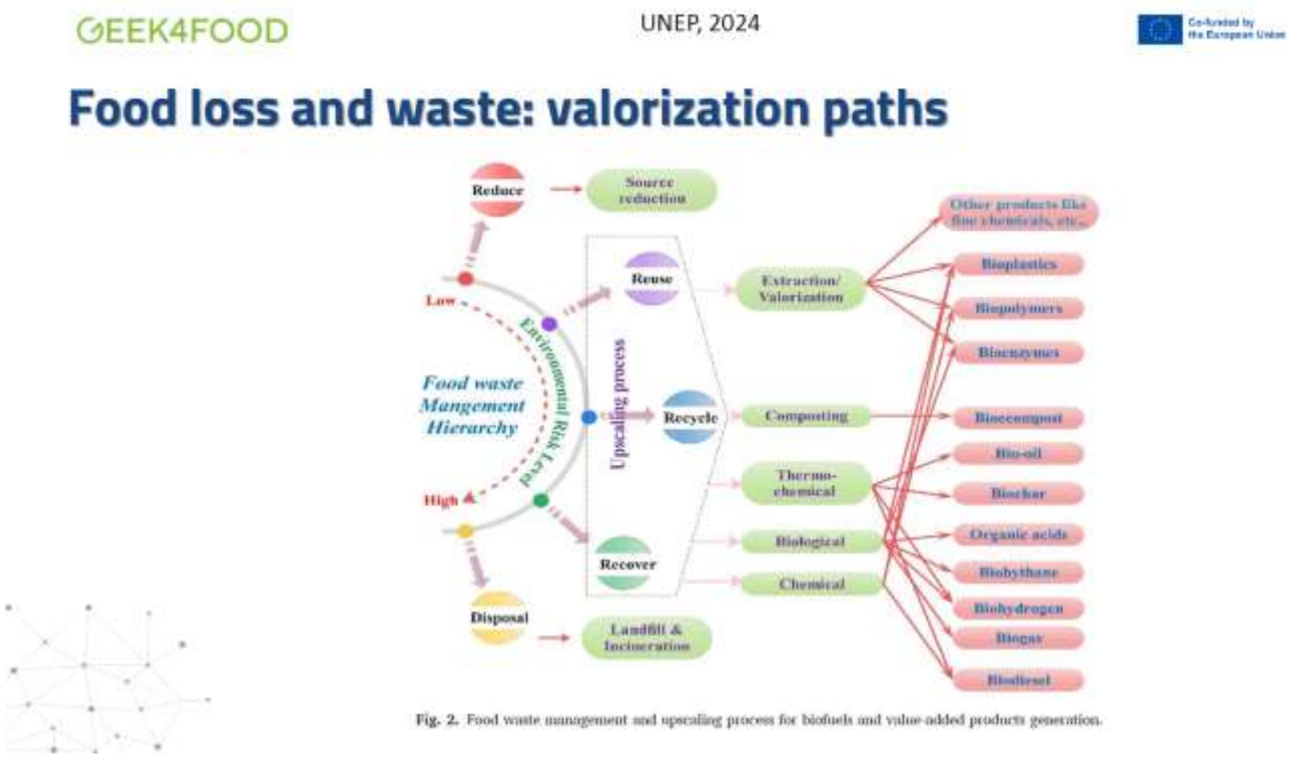

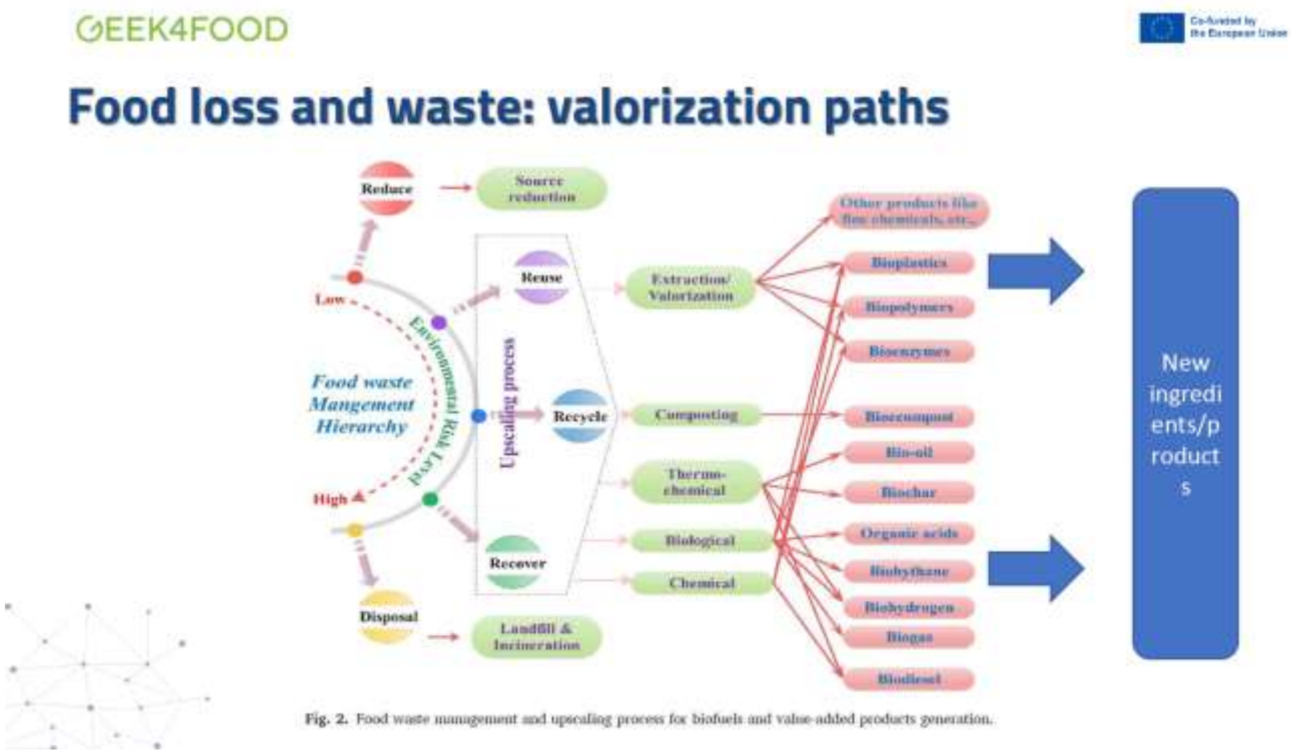

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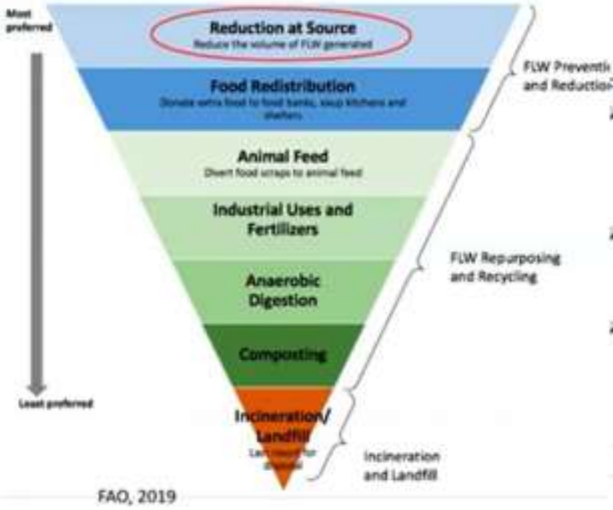
Food loss and waste: prioritization of actions



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

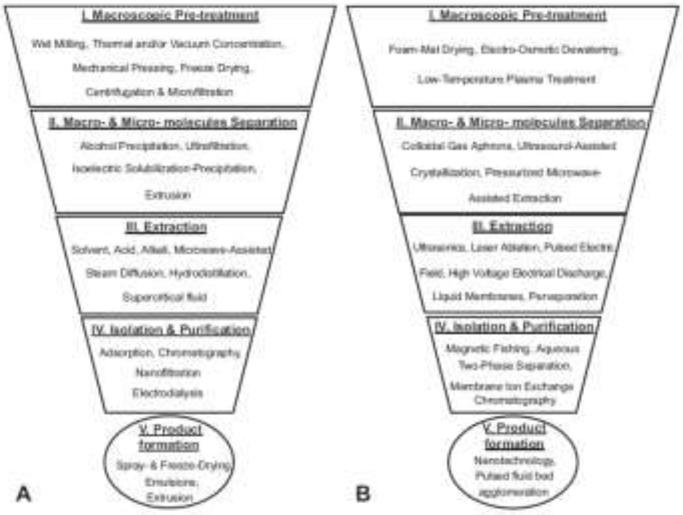

Fig. 1. Recovery stages of high-added value components from food wastes: (A) established and (B) emerging technologies.
Source: Galanakis , 2012

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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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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/

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/

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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

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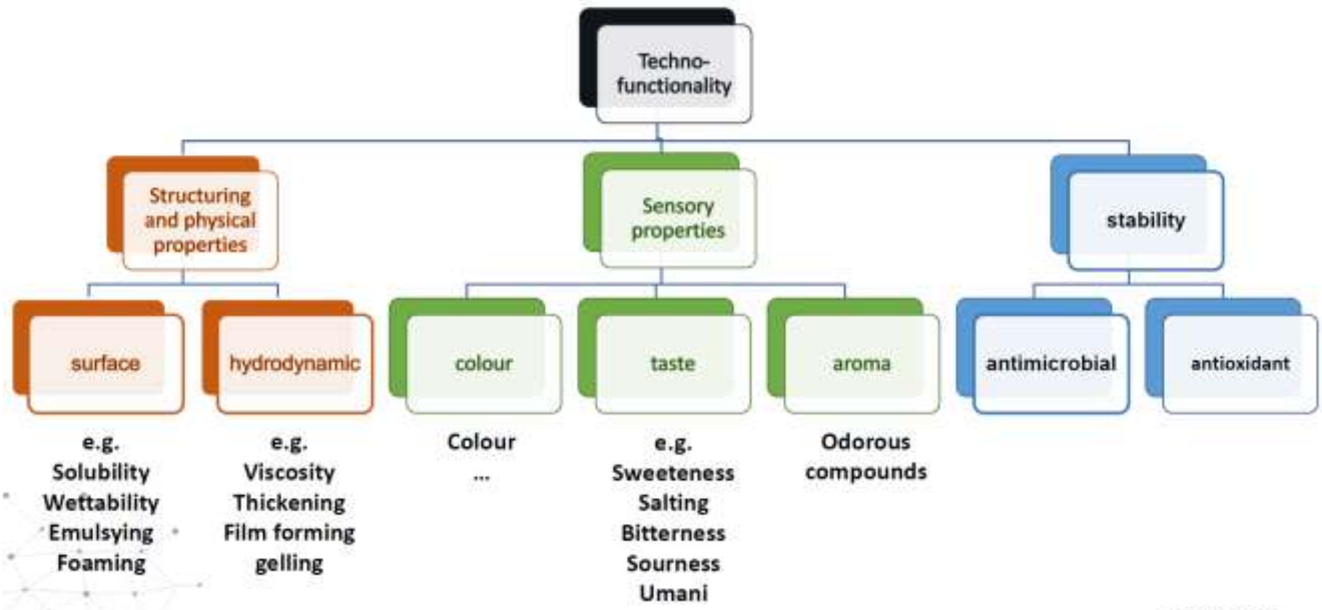

Pittia, 2025

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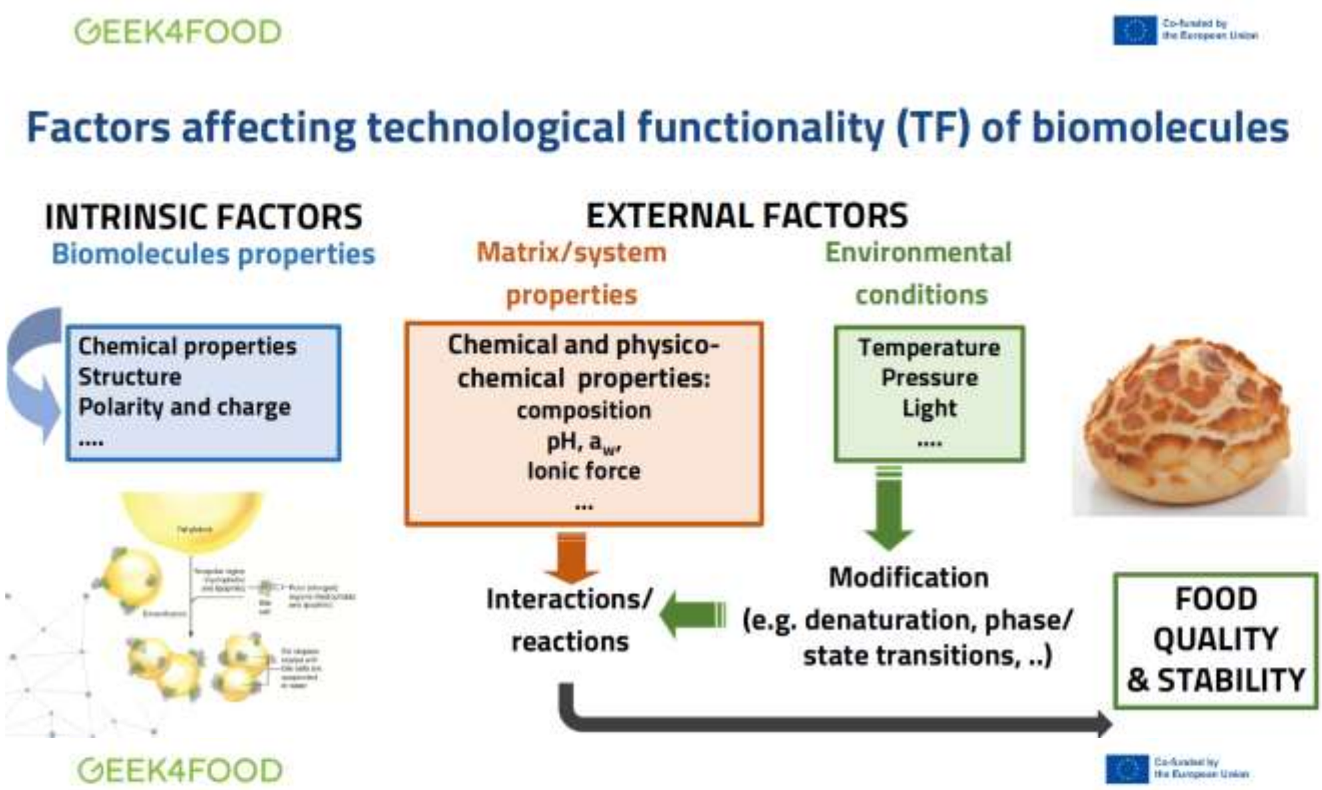

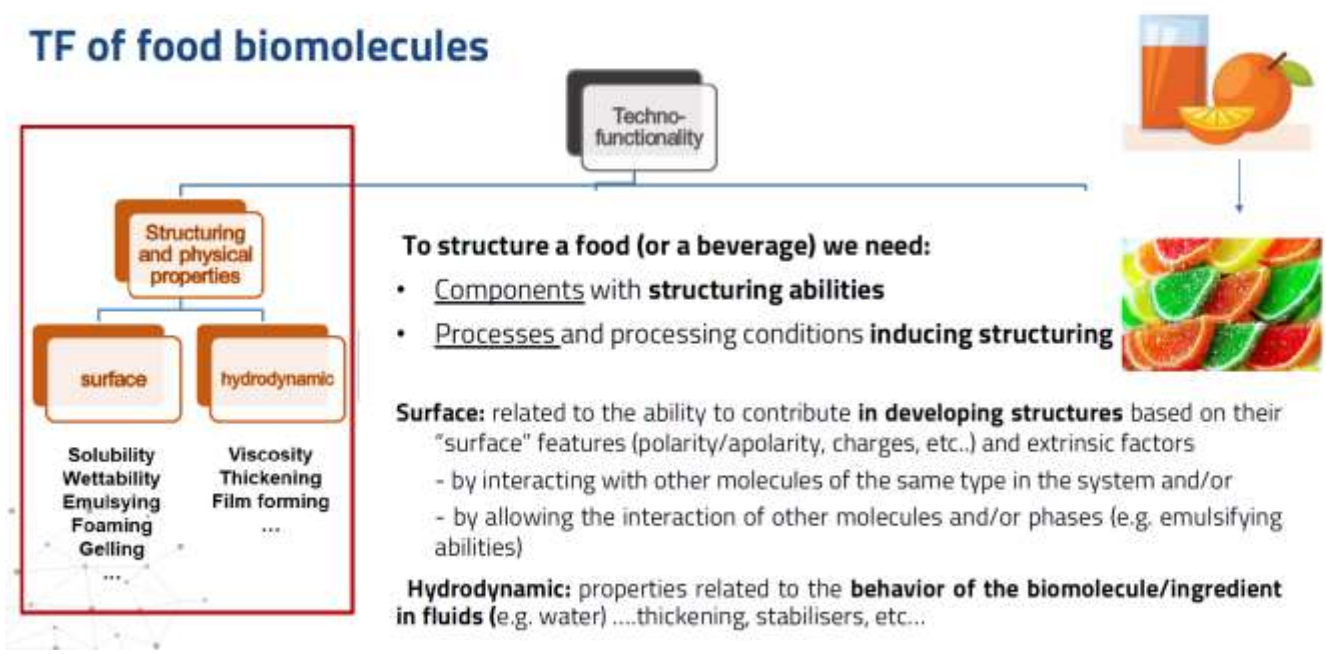

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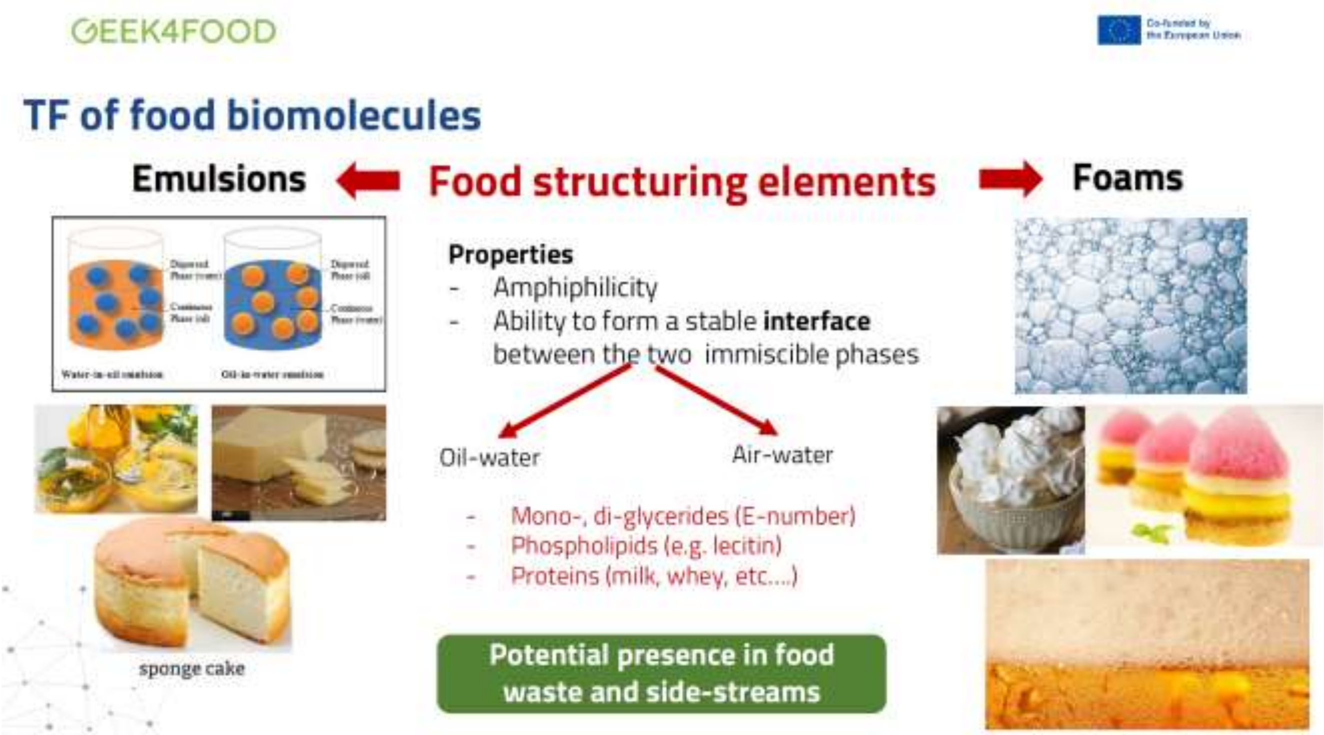

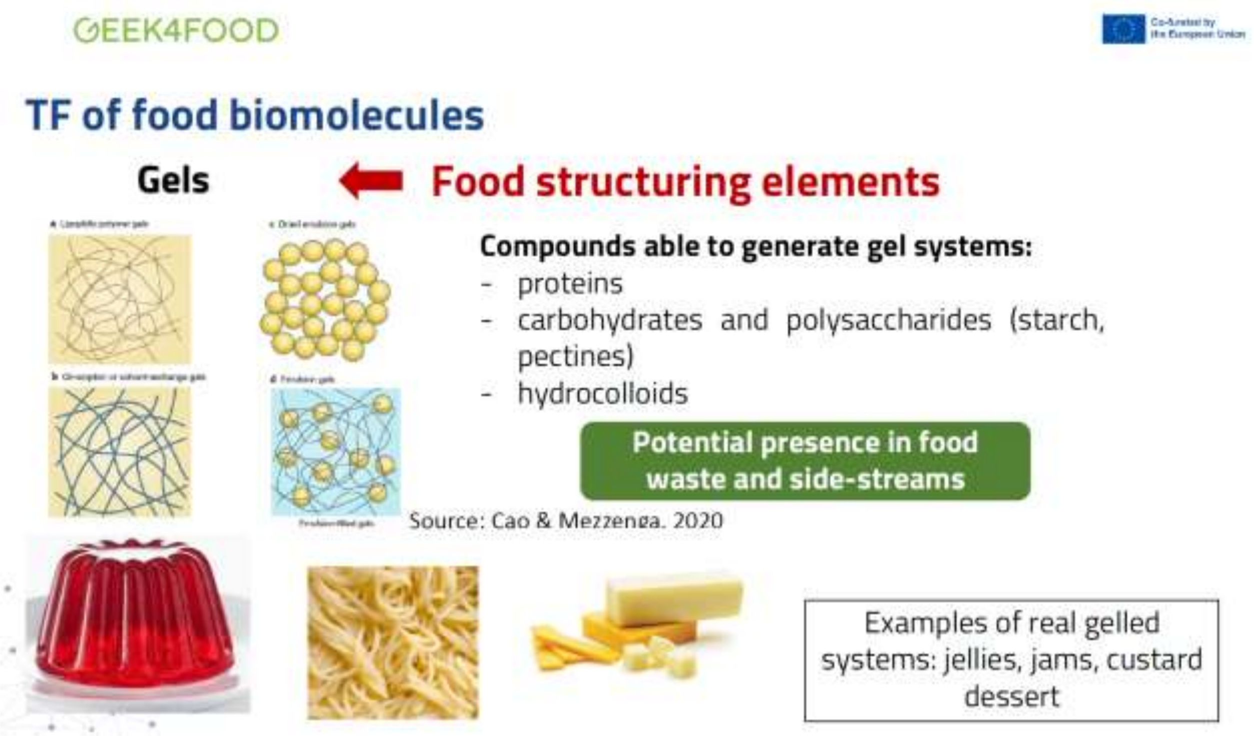

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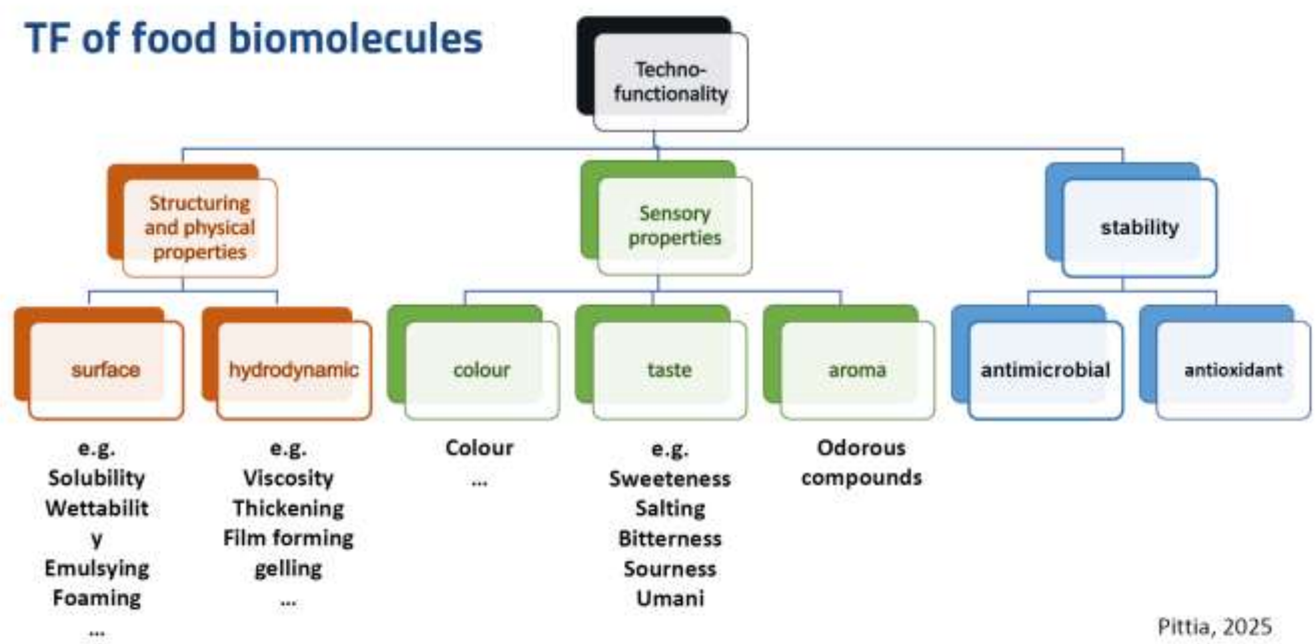

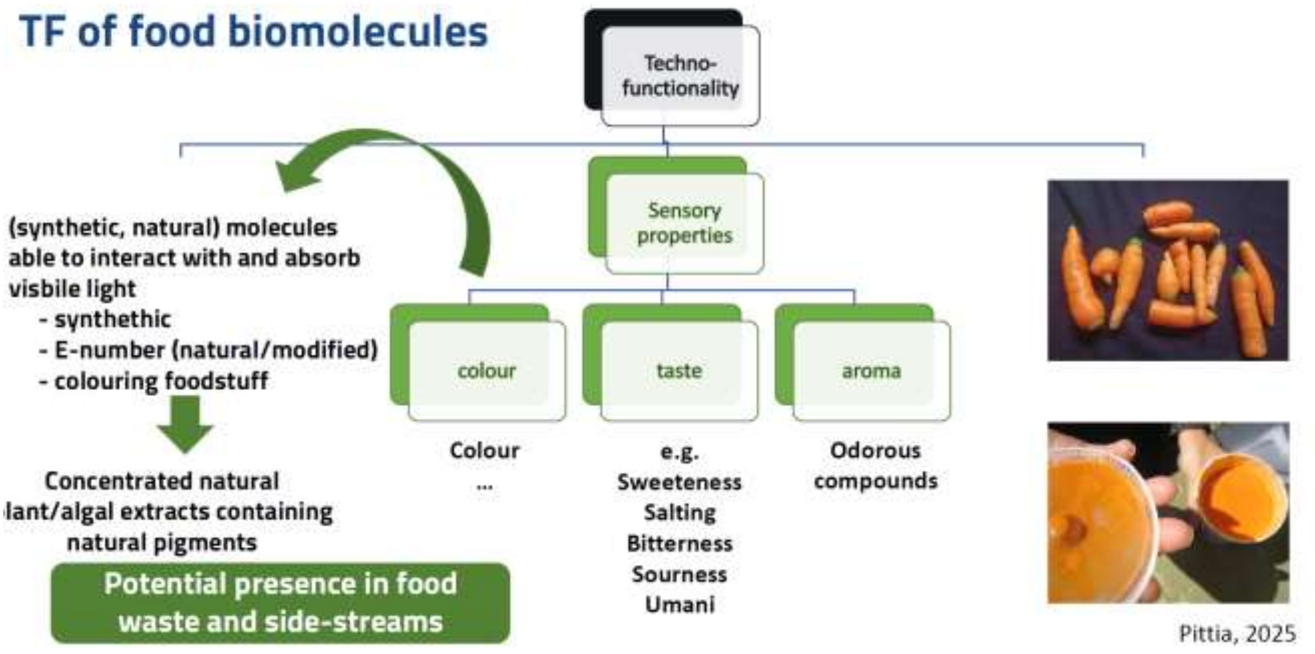

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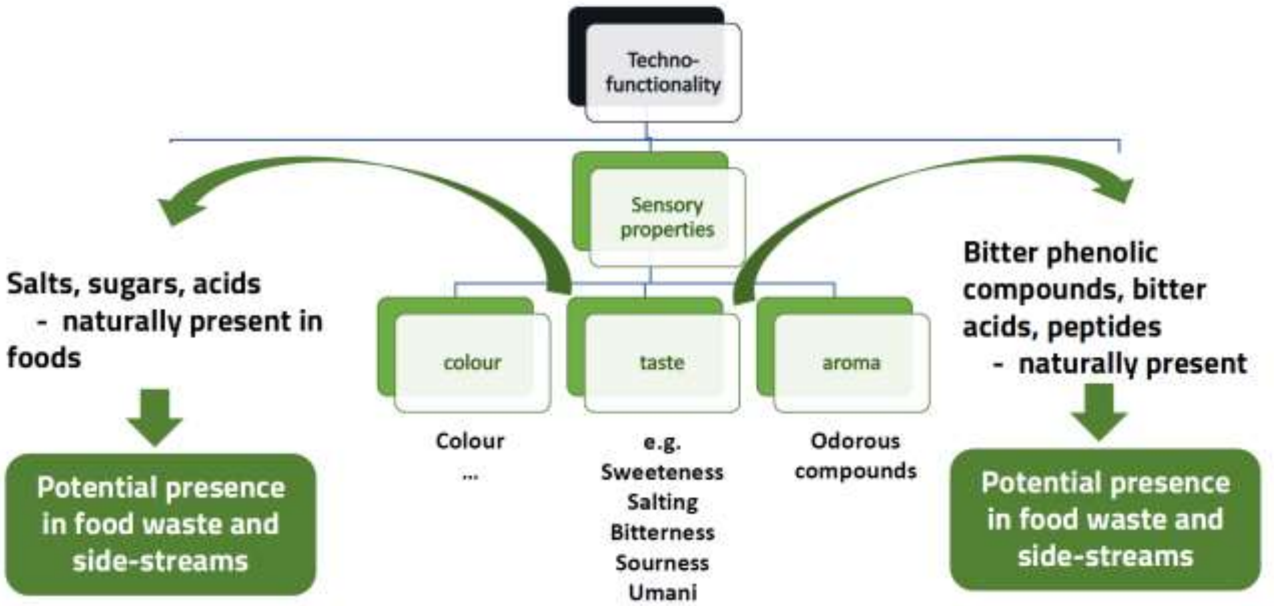
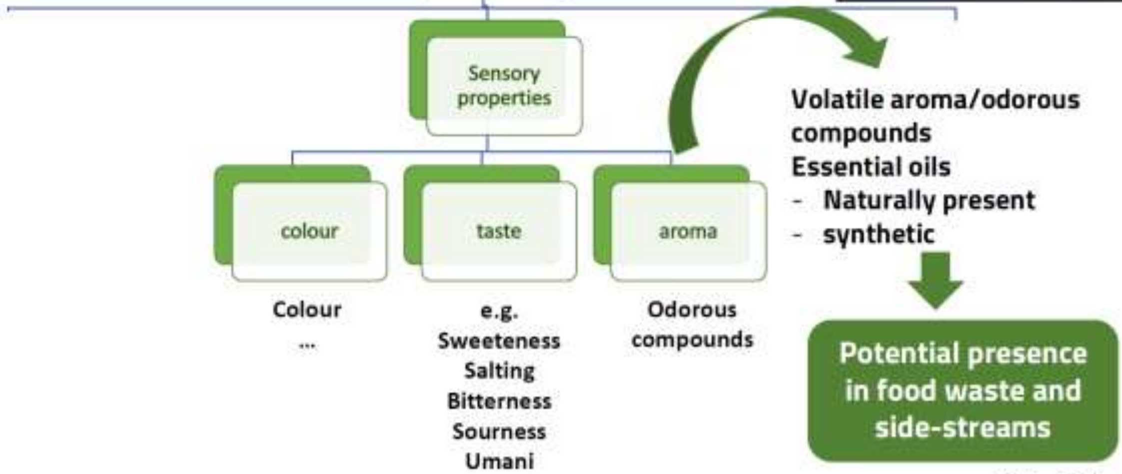


Pittia, 2025



Pittia, 2025

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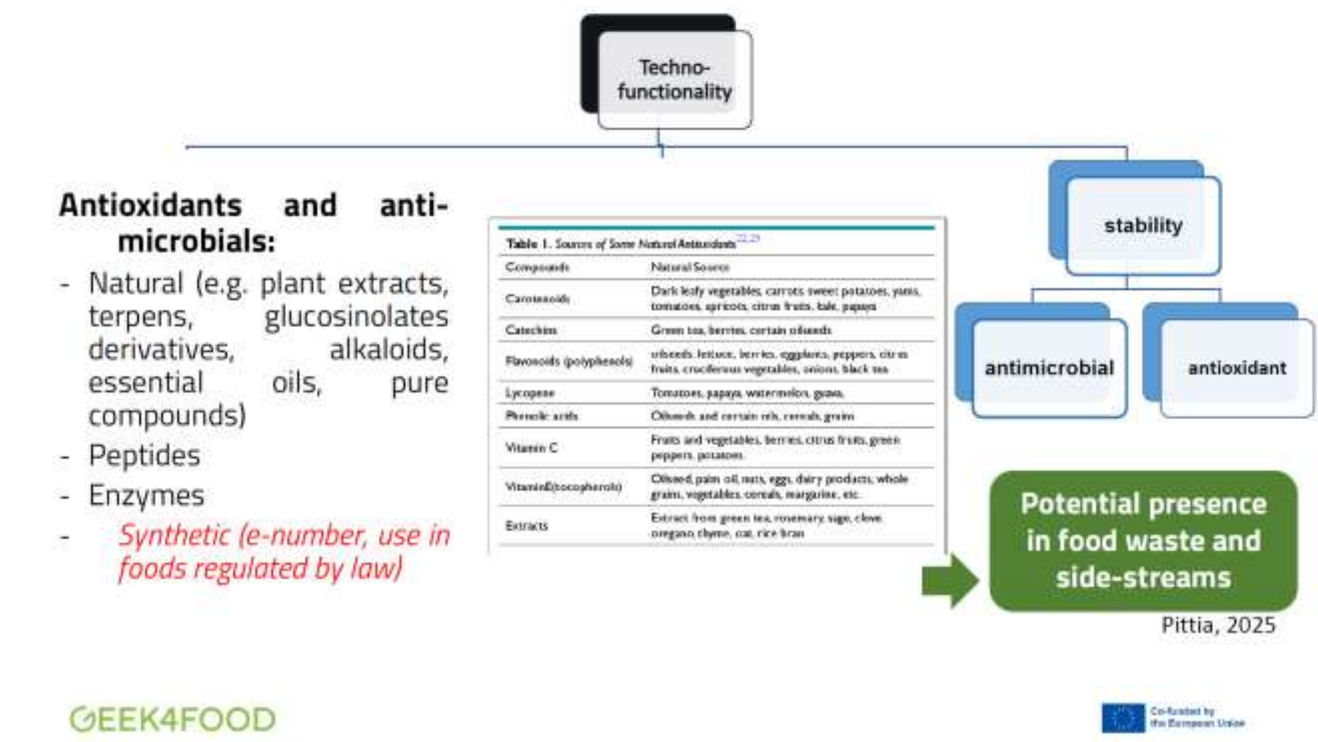

Table 1. *Sources of Some Natural Antioxidants*[22,23]

Compounds	Natural Sources
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 these raw materials, food waste and side-streams processing products become food ingredients (or additives?)

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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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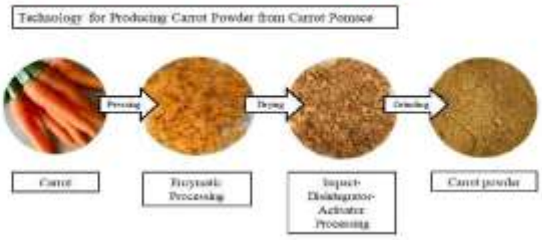
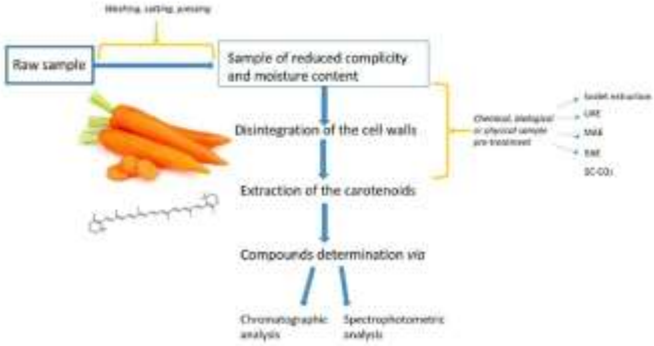
Issues and challenges



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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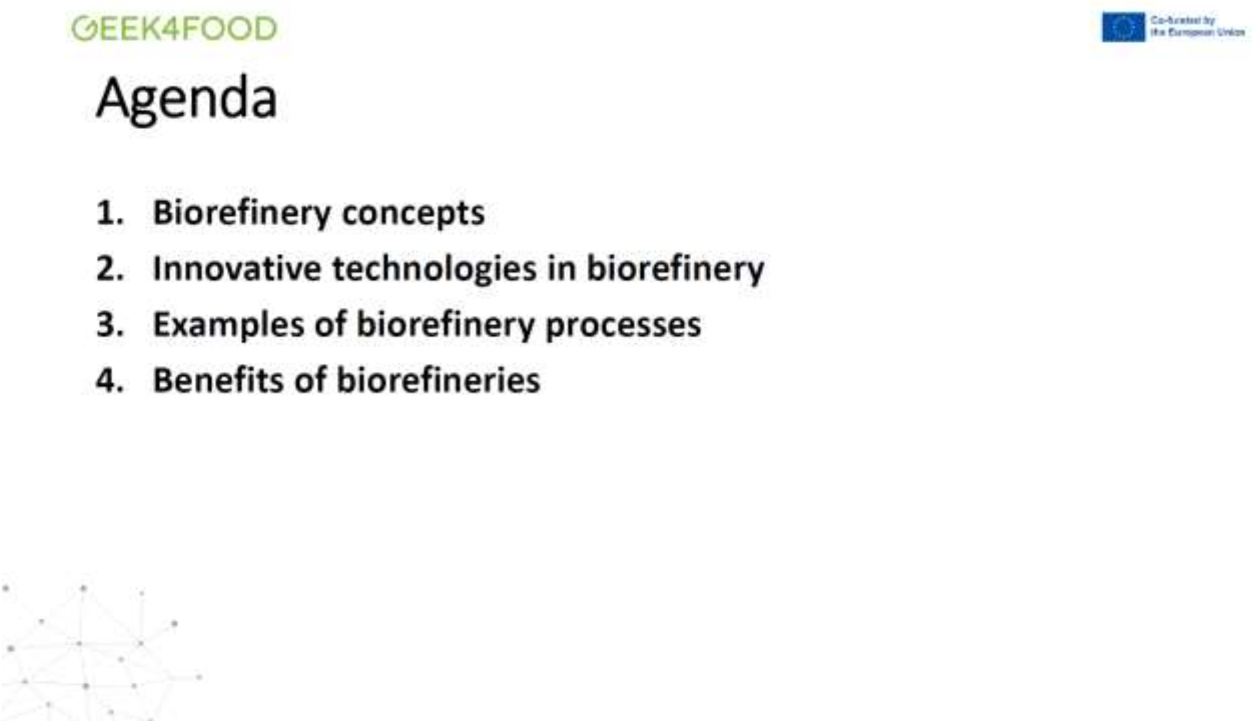
Issues and challenges

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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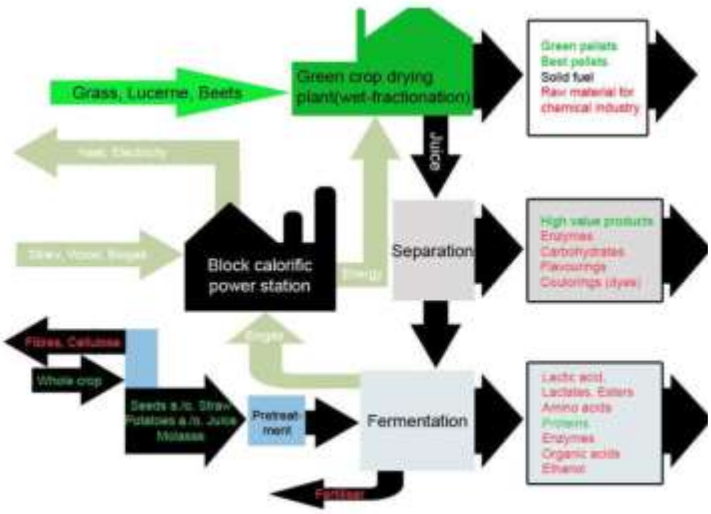
Why biorefineries

- 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.



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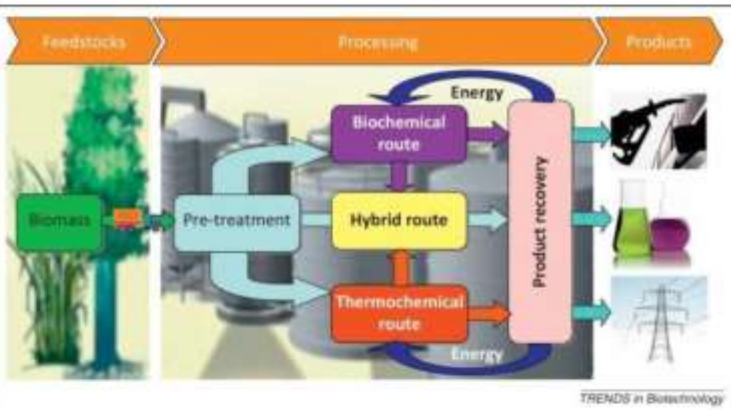
1. Biorefinery approaches associated to food systems

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

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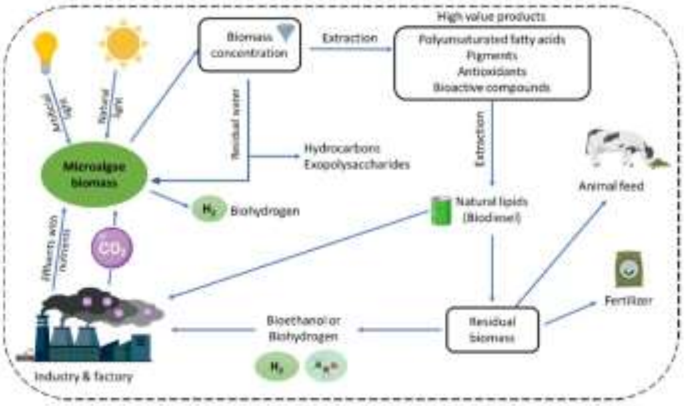
1. Biorefinery approaches associated to food systems

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:	Fermentation:	Anaerobic Digestion:	Hydrothermal Carbonization:	Advanced Extraction Techniques:
Utilize enzymes to break down complex biomass components into simpler, more usable forms, aiding in the extraction of valuable ingredients.	Employ microorganisms to ferment biomass into products like alcohols, organic acids, and biogas.	Break down organic matter in the absence of oxygen to produce biogas, a renewable energy source.	A thermochemical process that converts biomass into a carbon-rich solid (biochar) and a liquid phase containing valuable chemicals.	• Develop methods like high hydrostatic pressure, ultrasound, and microwave-assisted extraction for efficient and environmentally friendly ingredient recovery.

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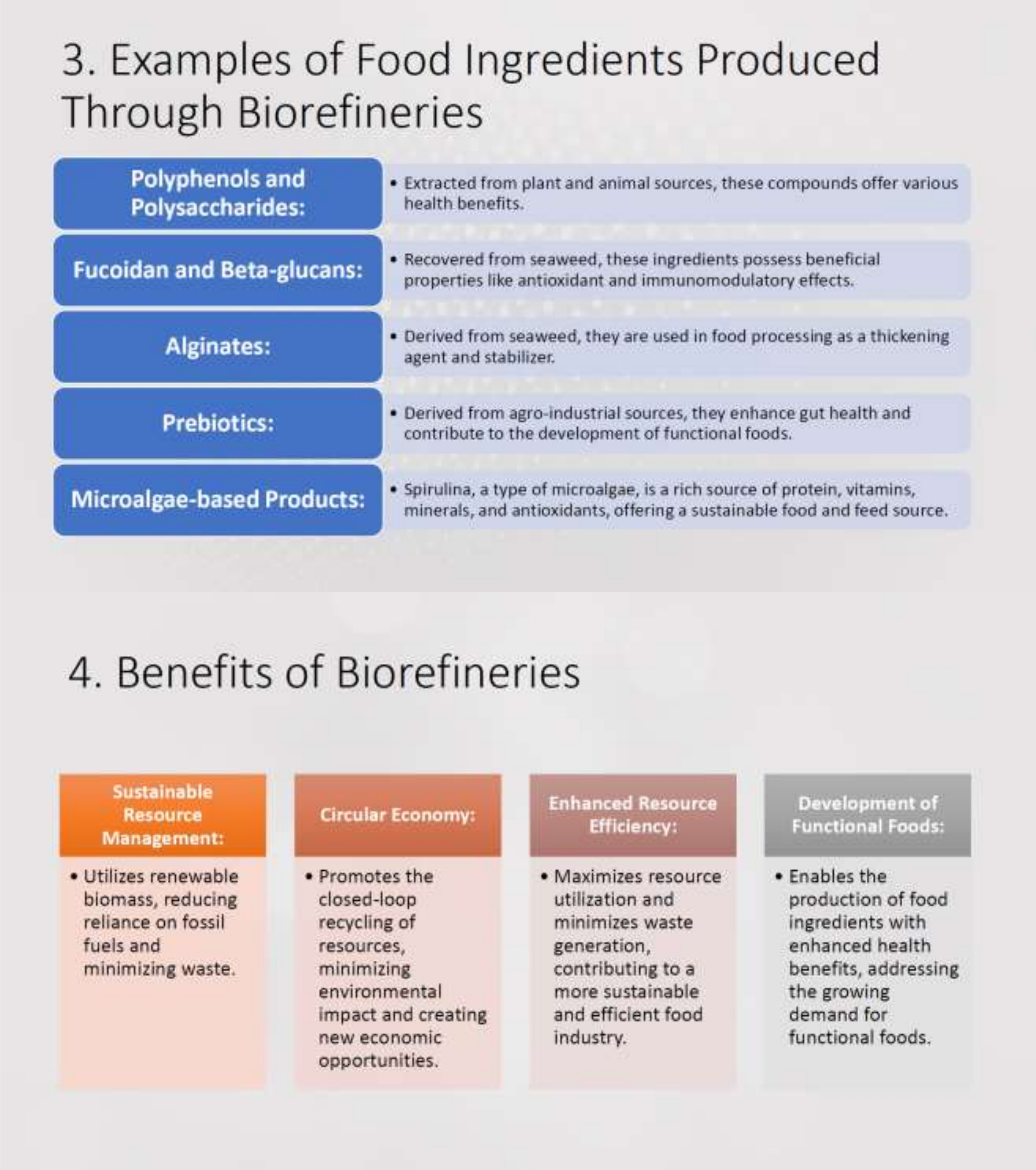

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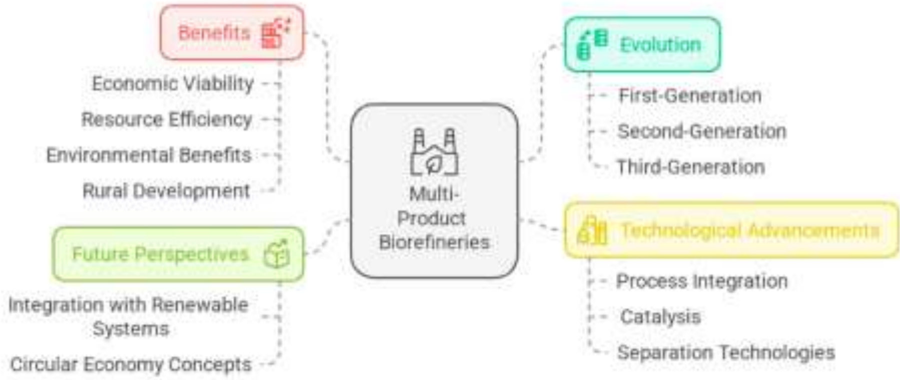
4. Multi-product biorefineries: evolution, benefits, and future



https://doi.org/10.20935/AcadEnergy7605

Thank you

www.geek4food.com

Project n.: 101087203

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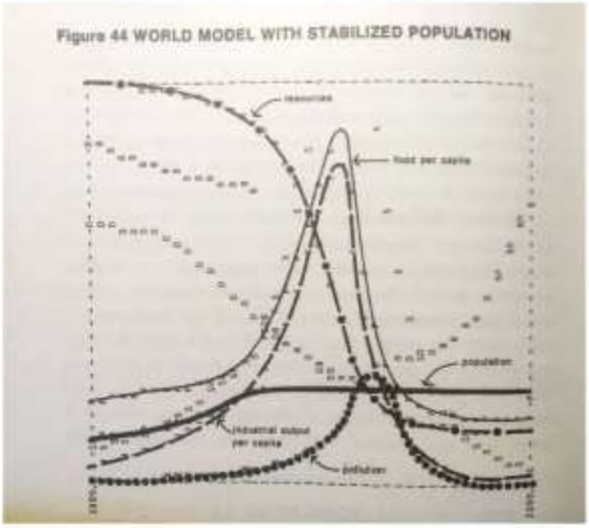
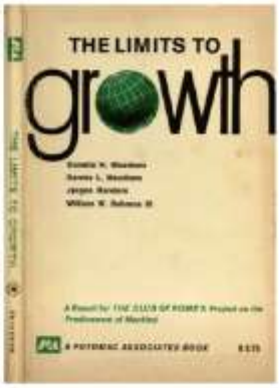
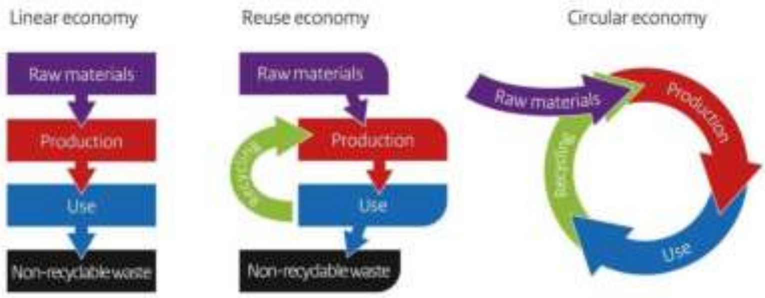
1. The Limits of growth. Club de Roma 1972.

- 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



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

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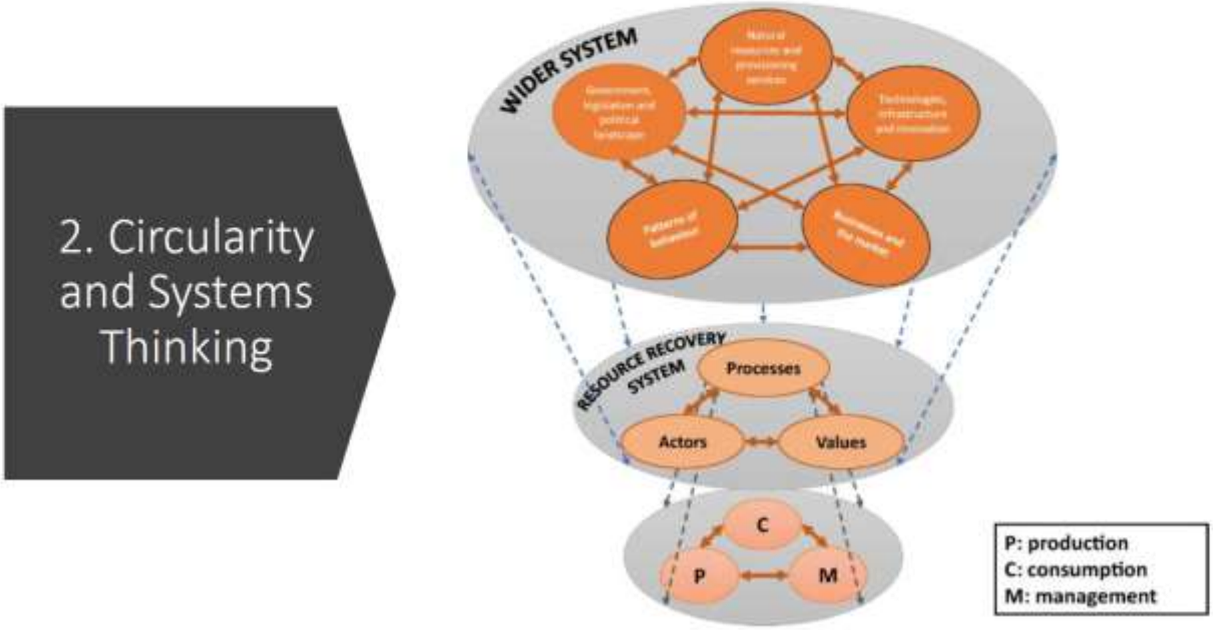
2. The Circular Economy model

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.



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

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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

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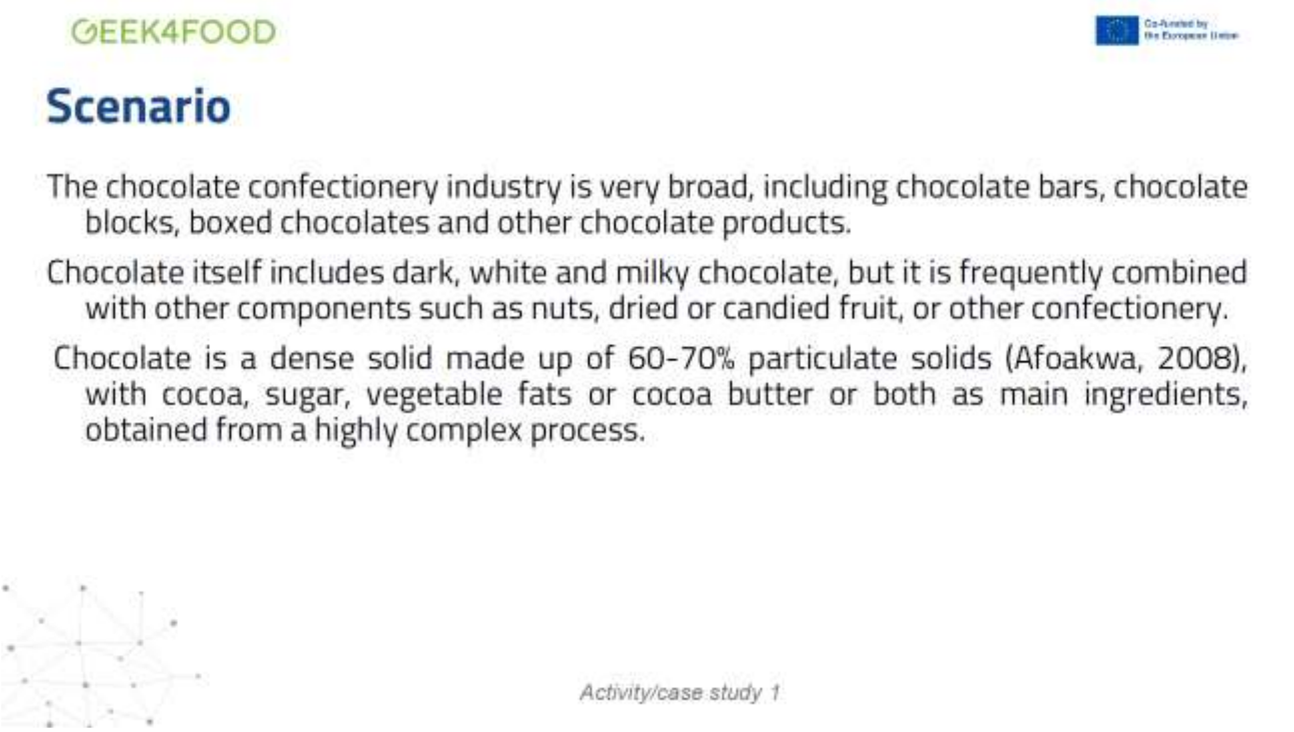

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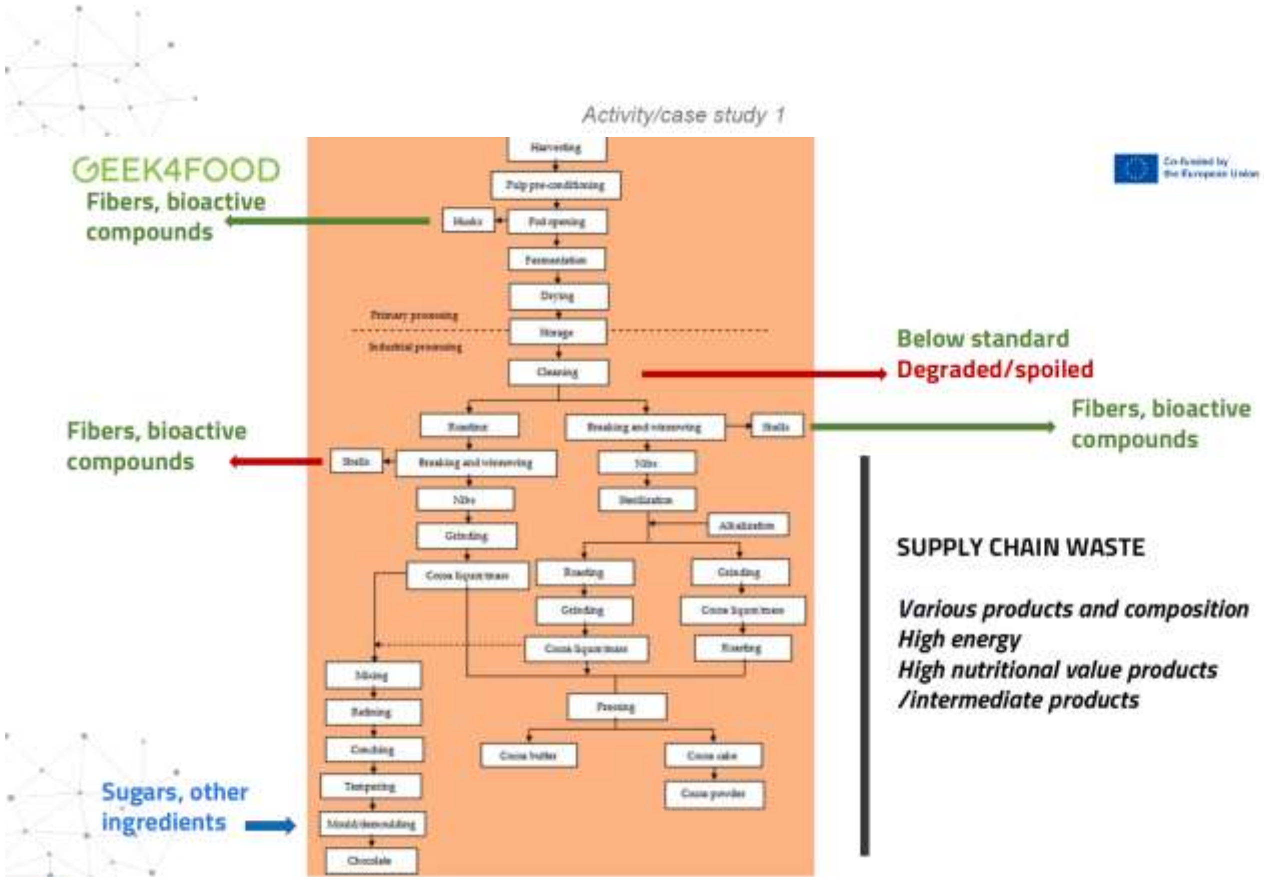
Confectionery products	Raw materials	Product chemical composition	Nutritional content
Chocolate	Sucrose, Cocoa, Vegetable fat/ Cocoa butter, Milk, Lecithin	Free fatty acids, Polyphenols, Lactose, Protein, Potassium, Magnesium, Copper, Iron	Energy 507 calories Water 1.1% Carbohydrates 57 g/100 g Protein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



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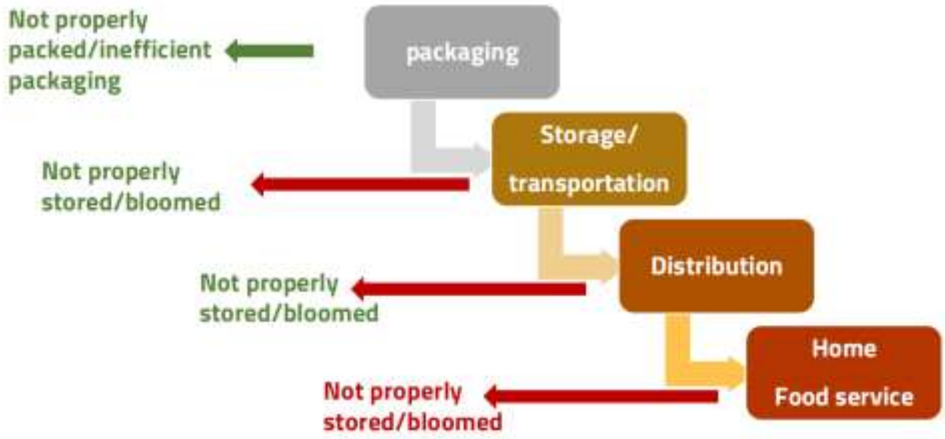
After chocolate production



Activity/case study 1

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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

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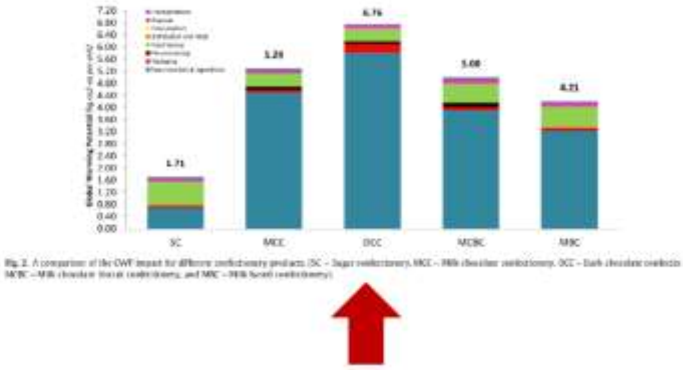

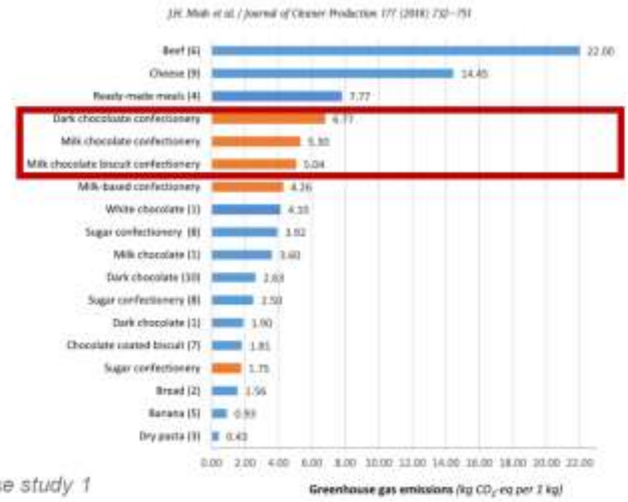

Source: Miah et al., 2018

Activity/case study 1

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Question 1

FROM THE FULL PROCESS DIAGRAM, IDENTIFY THE POTENTIAL OF

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

of the wasted products/intermediate products.

Activity/case study 1


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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

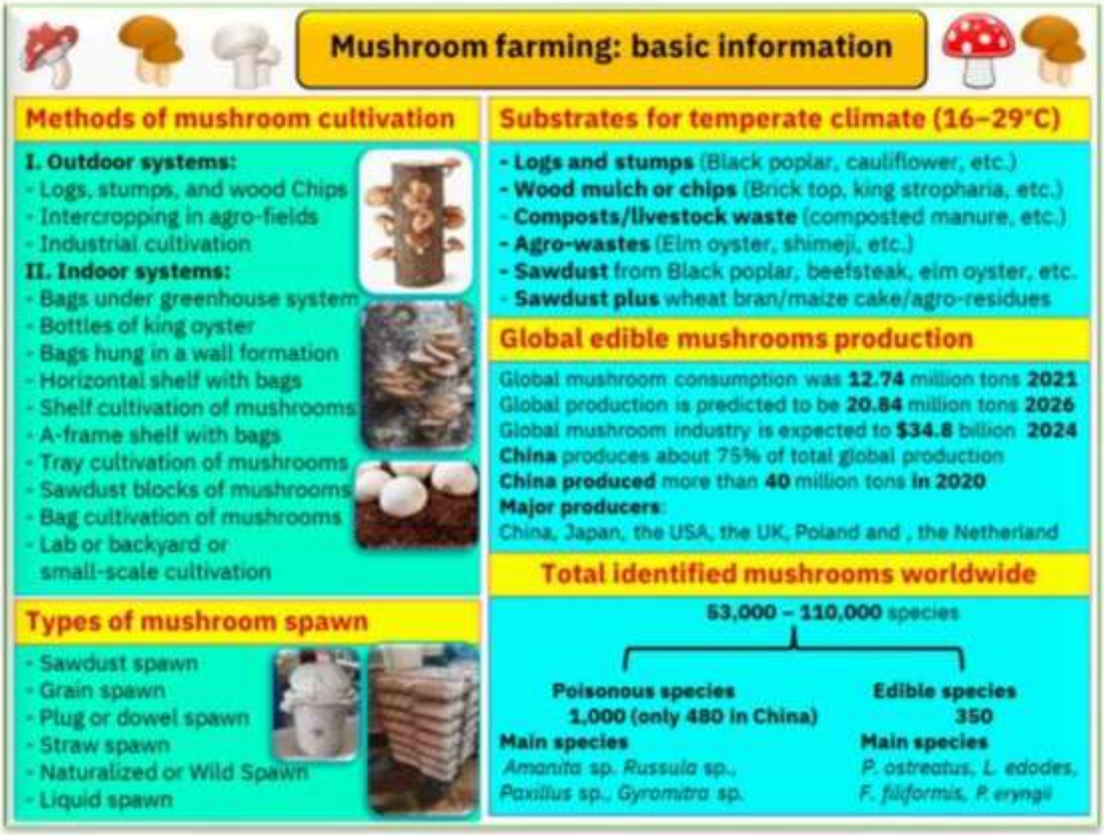
Jesus Frias, Technological University Dublin

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



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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.

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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.

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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

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4. Assessment

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GEEK4Food Assessment form on the Training "Waste valorisation in food product design"

Online training workshop – Assessment form
6th June 2025, 10:00 am – 2:00 pm (CEST/Rome/Wien/Berlin time)

Questo modulo raccoglie automaticamente gli indirizzi email di chi risponde. Modifica impostazioni

email *

Testo risposta breve

Name *

Testo risposta breve

Surname *

Testo risposta breve

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Session 1: Food lost and wasted

Descrizione (facoltativa)

1.1. Food loss is related to: *

- ◯ all food production, from primary production to consumers
- ◯ only to primary production
- ◯ from primary production to the end of production

1.2. Select the challenges in the food supply chain to be faced for food lost and wasted: *

- ◯ costs
- ◯ safety
- ◯ technologies
- ◯ staff competences
- ◯ all the above

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Session 2: Biorefinery approaches and innovative technologies for food ingredients

Descrizione (facoltativa)

2.1. Describe an example of a biorefinery related to your area of expertise: *

Testo risposta breve

2.2. Discuss innovative processing in the context of the biorefinery in question 2.1.: *

Testo risposta breve

Session 3: Technological functionality

Descrizione (facoltativa)

3.1. Technological functionality of a food product, ingredient or biomolecule includes also the nutritional aspects? *

- Yes
- No

3.2. Technological functionalities are a series of attributes that an ingredient or food biomolecule could have in a more complex system. Based on the presentations of today, your background and experience, which of the technological functionality could be valorised from food wasted products? *

Testo risposta breve

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Session 4: Circular economy, industrial sustainability and social impact

Descrizione (facoltativa)

5.1. What are the principles of circularity? *

Testo risposta breve

5.2. How can circularity change industrial processes (think of your own food production)? *

Testo risposta breve

5.3. What is the impact that circular economy changes may have in society? *

Testo risposta breve

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