Coordinator and partners:

eAfoBy

Enhancement of Agro Food Chain Byproducts through Innovative and Sustainable Methods

Project Reference: 2024-1-RO01-KA220-HED-000246776

Co-funded by the European Union

Project code: 2024-1-RO01-KA220-HED-000246776

Table of contents

Co-funded by
the European Union

GUIDE DESCRIPTION

Name of project: „Enhancement of Agro Food Chain Byproducts through Innovative and Sustainable Methods`` Project Acronym eAfoBy

Project Reference: 2024-1-RO01-KA220-HED-000246776

Guide addressed to experts and specialists in agriculture, food technologies, food safety, food control and nutritionists, economic agents.

- **Professors responsible with theoretical parts:**
- **Coordinator (USAMVCN):** Maria Simona Chiș, Adriana Păucean, Anca Fărcaș, Anamaria Pop, Man Simona, Oros Simona
- **Partner 1 (UPV):** Purificación García Segovia, Marta Igual, Javier Martinez Monzó, Carolina Contreras Monzón
- **Partner 2 (UPORTO):** M. Beatriz Oliveira, Helena Sousa, Anabela Costa, Rita Alves
- **Partner 3 (ULST):** Alexa Ersilia, Negrea Monica, Cocan Ileana, Jianu Calin
- **Partner 4 (ROMPAN):** Voica Daniela, Avram Dana, Marin Daniela.

- *Funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the ANPCDEFP. Neither the European Union nor the ANPCDEFP can be held responsible for them.*

Project code: 2024-1-RO01-KA220-HED-000246776

Chapter 1: Introduction to Agro-Food Chain Byproducts

Co-funded by the European Union

Project code: 2024-1-RO01-KA220-HED-000246776

INDEX:

1. Basic concepts
2. European legislation

Co-funded by
the European Union

Concept of circular food system, zero-waste, and by-product.

Circular food system: it means producing food in a less harmful, more regenerative way. It also extends to food companies, chefs and domestic, integrating food scraps into their food/dishes, food sharing apps or the way food is packaged to use less plastic and more biodegradable materials.

Zero-waste: aims at rethinking the way we produce and consume in order to preserve the value and energy embedded in our planet's resources whilst enabling civilization to flourish and prosper. While waste management aims at turning waste into resources, zero waste is about keeping resources from becoming waste.

By-product: is a secondary product derived from a production process, manufacturing process or chemical reaction; it is not the primary product or service being produced.

Concept of sustainability and circular economy

sustainability - is etymologically derived from the French verb *soutenir*, meaning “to uphold” or “to support,” reflecting its foundational emphasis on maintaining and sustaining systems over time.

sustainability - as a systemic and balanced integration of economic, social, and environmental performance, explicitly accounting for equity and impacts within and between generations.

circular economy - A regenerative system in which resource inputs, waste generation, emissions, and energy losses are minimized through the slowing, closing, and narrowing of material and energy flows, achieved by means of durable product design and strategies such as maintenance, repair, reuse, remanufacturing, refurbishment, and recycling.

Concept of Agro by-products or agro residues

Agro by-products or agro residues - are mainly obtained from agricultural production, harvesting, and processing in farm areas and from food processing industries such as oilseed extraction, brewery, malt production, cereal grain milling, fruit and vegetable processing.

- by-products from fruit and vegetable processing industry, crop waste and residue, by-products from sugar, starch and confectionary industry, by-products from distilleries and breweries, by-products from grain and legume milling industry, and oil industry

Concept of in vivo, in vitro, and in silico digestion

In vivo digestion is performed on living organisms. It is highly complex from a biological perspective, but costly and with strong ethical implications.

In vitro digestion involves laboratory simulation. It is a reproducible, ethical, and cheaper method.

In silico digestion is a computer simulation. It is useful for theoretical prediction, but it is model-dependent.

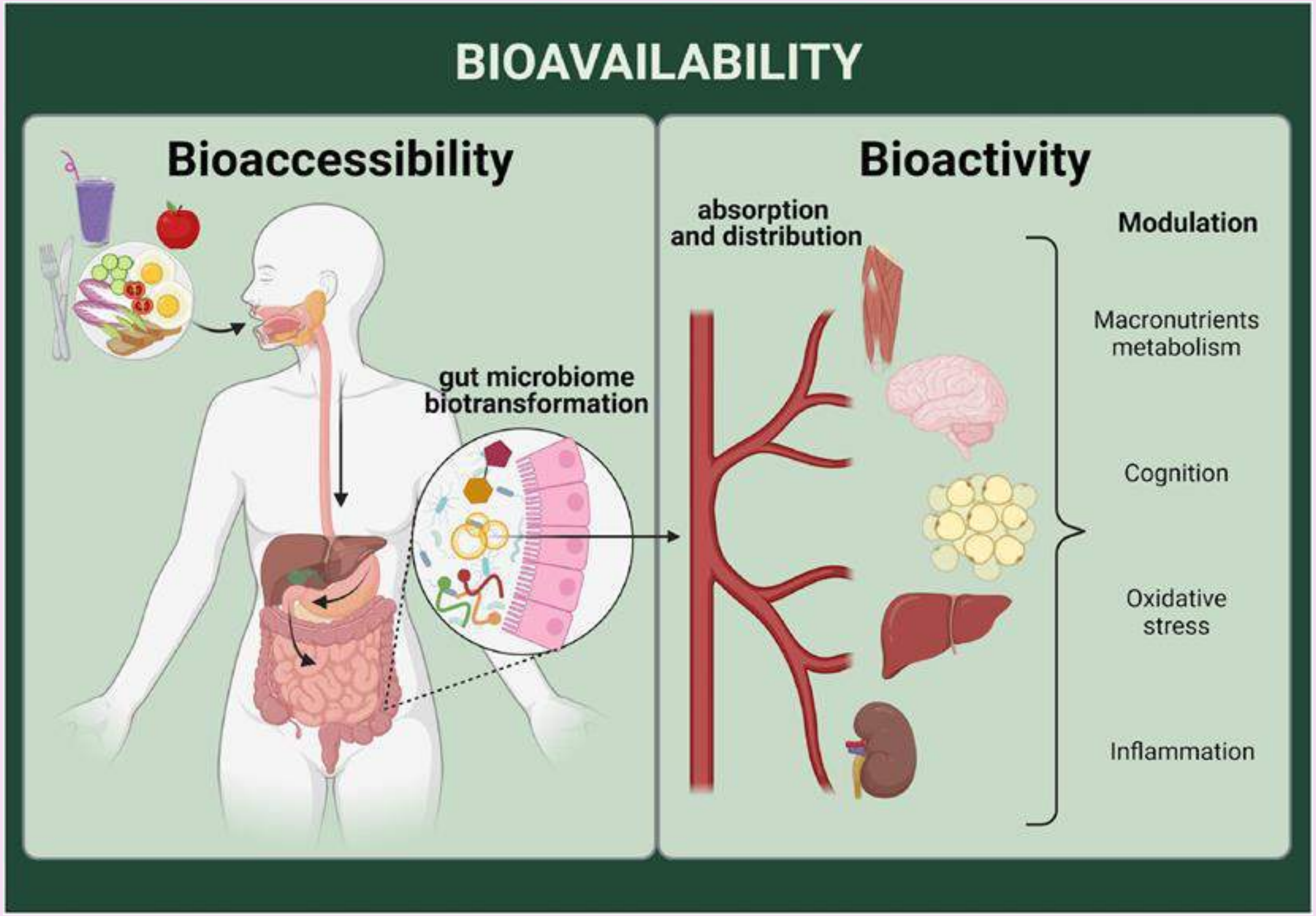
Bioaccesibility, Bioavailability and Bioactivity

Bioavailability: The fraction absorbed and available for physiological functions or storage.

Bioaccessibility: The fraction of a compound that is released from the food matrix and is available for absorption.

Bioactivity: The ability of a compound to generate a beneficial biological effect after being absorbed.

Relationship between this key concepts



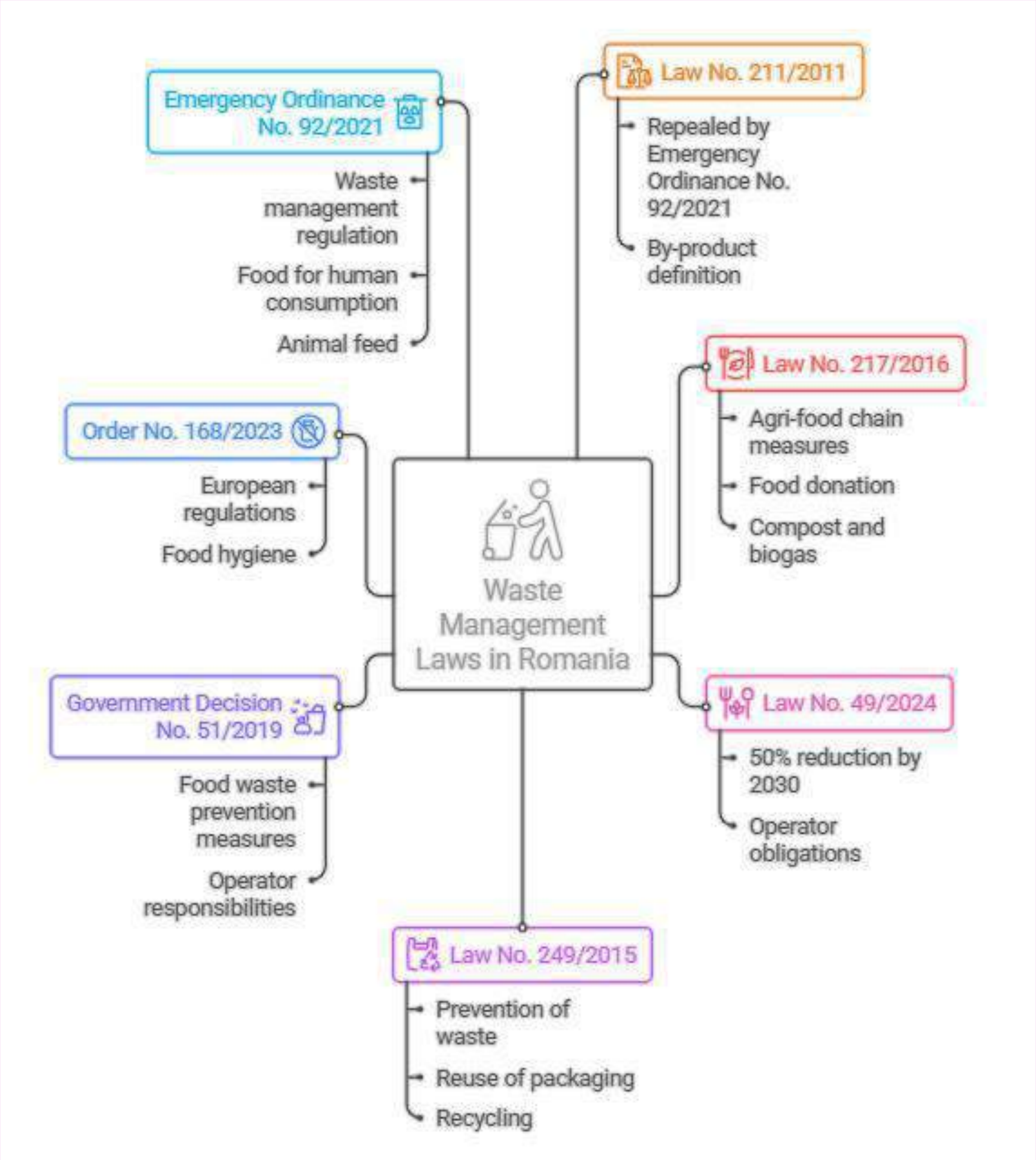
Rodrigues, D. B., et al.(2022). *[Figure 1. Background and definitions]* [Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence:

2. European legislation

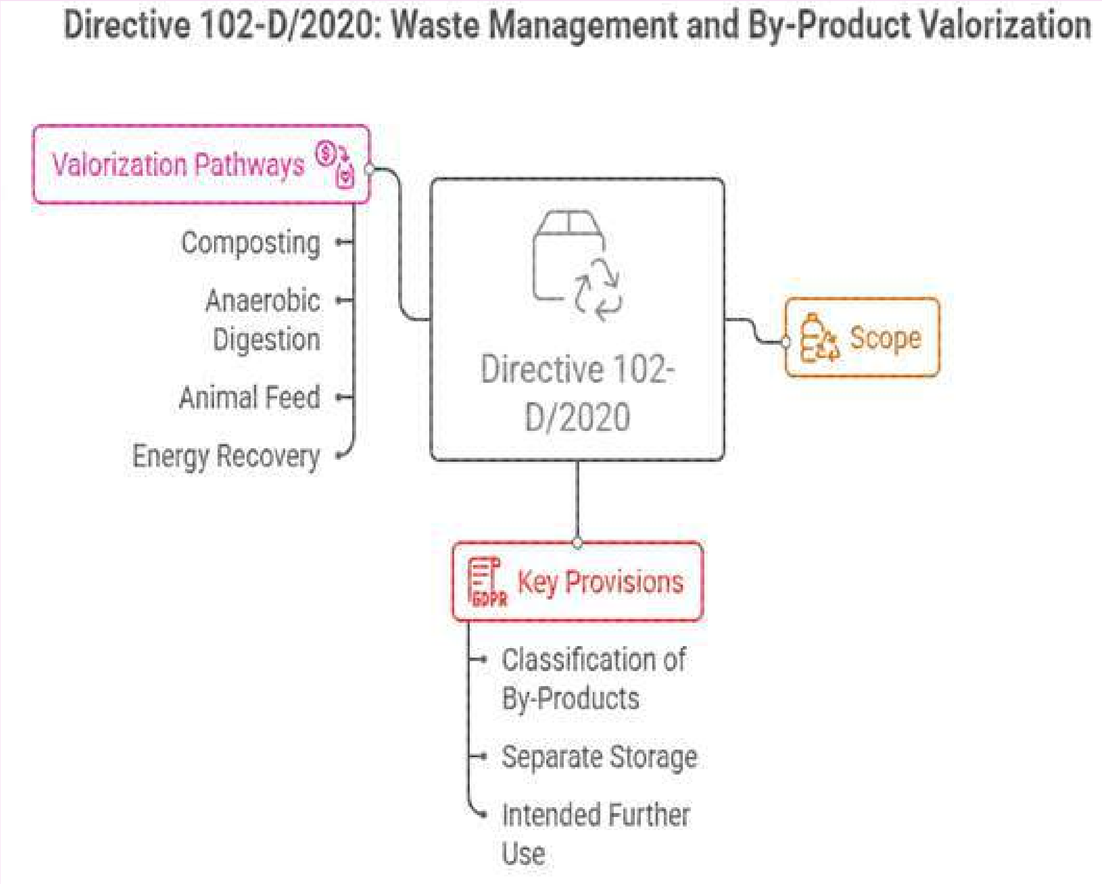
European legislation:

- **Council Directive 1999/31/EC of 26 April 1999** on landfill
- **Directive 2008/98/EC** of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives
- **Directive (EU) 2018/851** of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste
- **Directive (EU) 2018/850** of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on waste disposal
- **Commission Delegated Decision (EU) 2019/1597 of 3 May 2019** supplementing Directive 2008/98/EC of the European Parliament and of the Council with regard to the common methodology and minimum quality requirements for the uniform measurement of food waste levels.
- **Regulation (EC) no. 178/2002** - General principles and requirements of food law, establishing the European Food Safety Authority and establishing procedures in the field of food safety

2.1. National Romanian legislation on the valorization and storage of by-products from the agri-food chain



2.2. Portugal national legislation on the valorization and storage of by-products from the agri-food chain

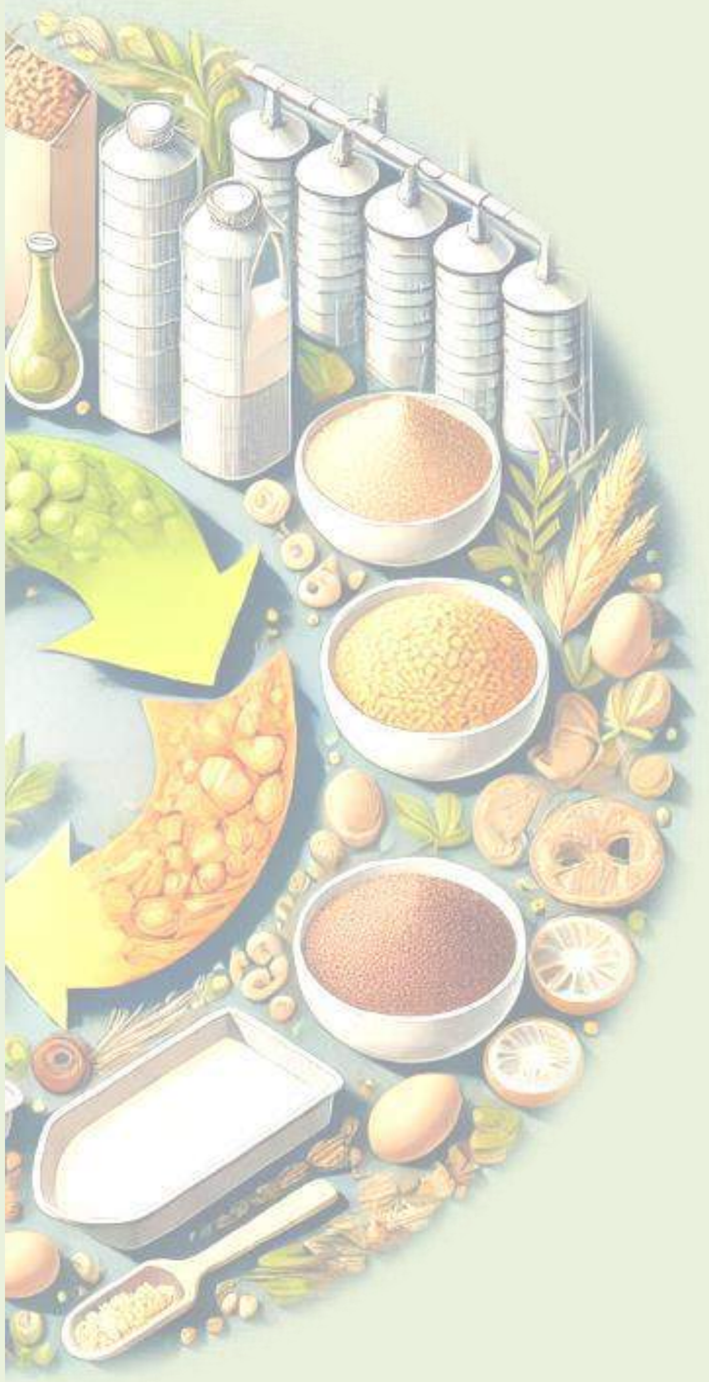


2. 3. Spanish national legislation on the valorization and storage of by-products from the agri-food chain

Project code: 2024-1-RO01-KA220-HED-000246776

Chapter 2: Byproduct Sources in Agro-Food Chains

Co-funded by the European Union



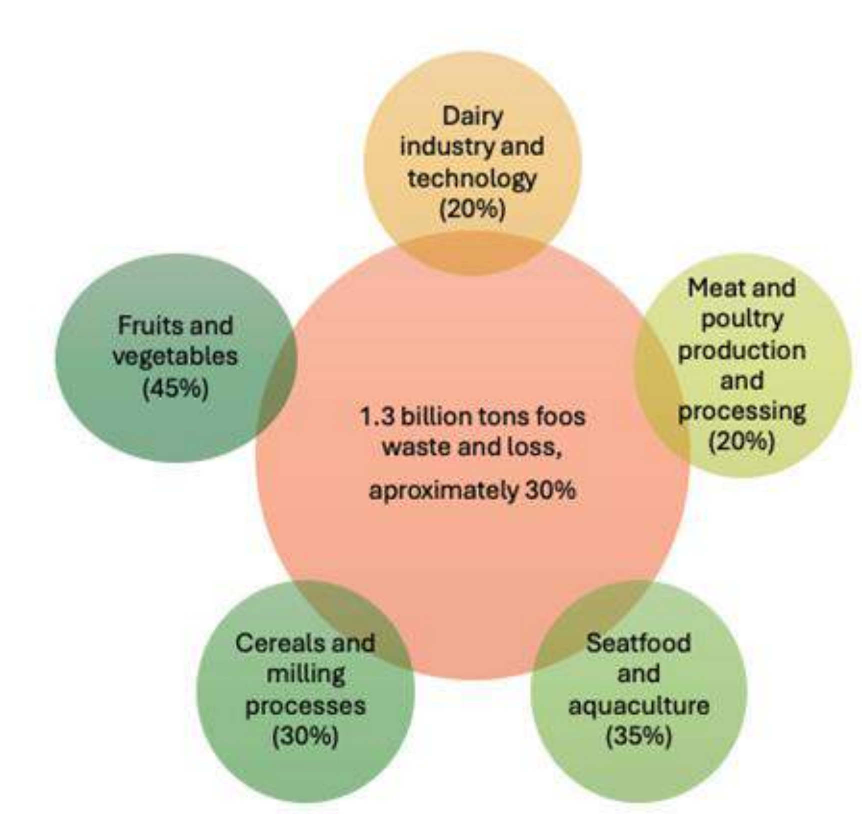
INDEX

1. Classification of agro-food chain byproducts
2. Importance of managing byproducts efficiently
3. Case studies

1. Classification

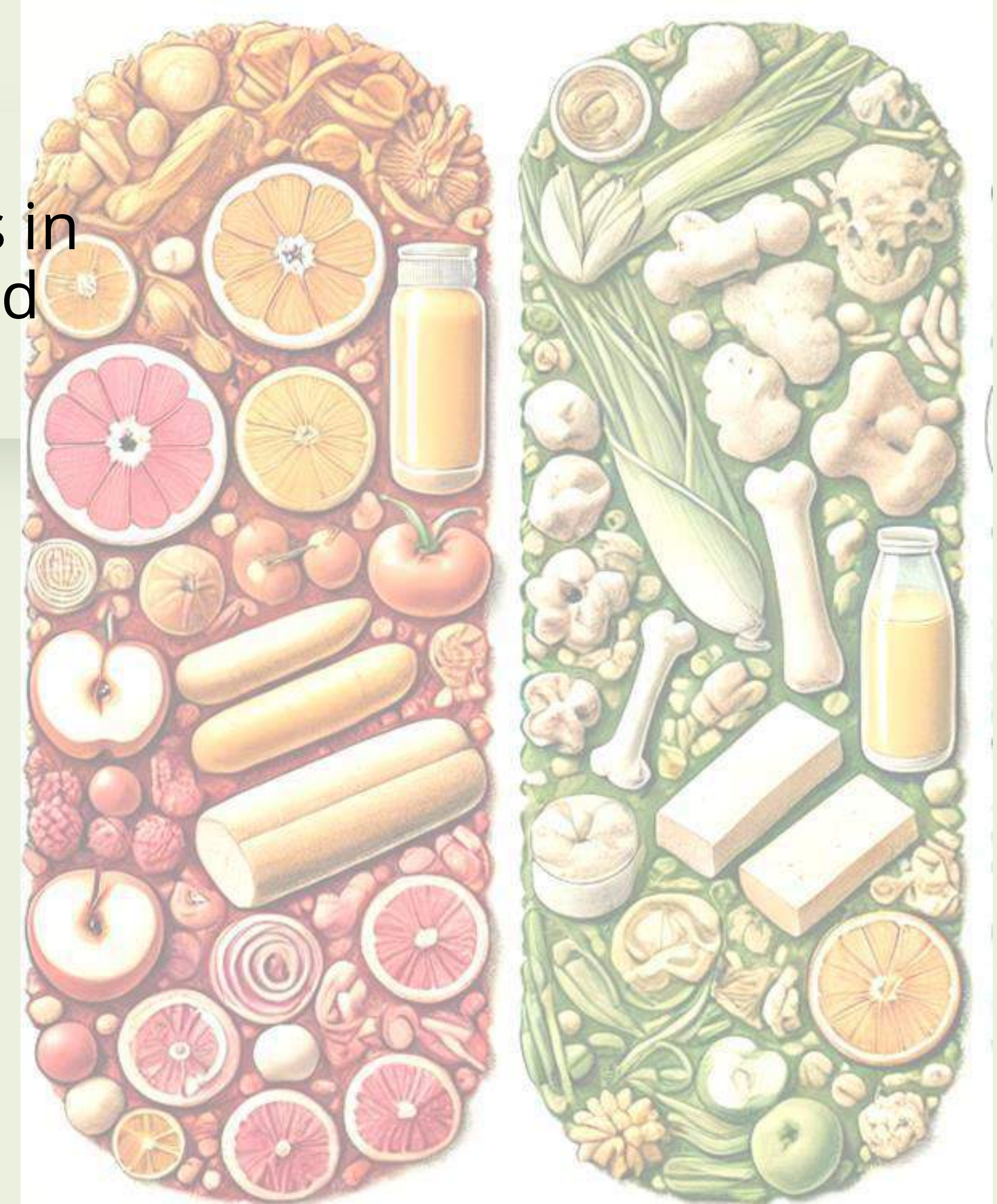
- Main categories:
  - Plant-based (fruit peels, vegetable residues, cereal bran)
  - Animal-based (bones, fat, whey)
  - Mixed (fermentation residues, byproducts from ready-to-eat meals)

Estimated Global Annual Food Loss and Waste by Primary Sector



Brennan et al., 2024

Key Byproducts in European Food Industry



Wine industry: Grape pomace, seeds, and stems

Olive oil industry: Olive pomace, wastewater

Coffee industry: Silver skin,

Cereal industry: Bran, germ, broken grains

Fruit and vegetable processing: Peels, sedes, Pulp

Beer industry: pomace

Milk processing: Whey, fermentation residues

Meat processing: Blood, bones, hides

2. Importance of Agro-Food Chain Byproducts

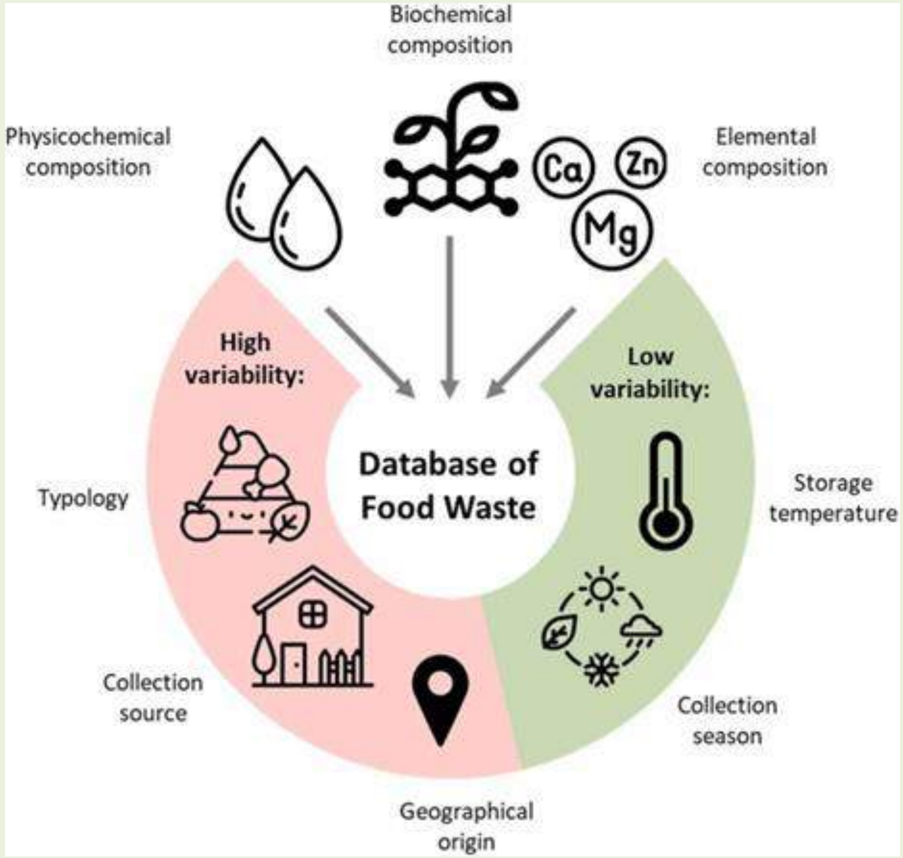
- Economic benefits: Alternative revenue sources
- Environmental impact: Reducing waste and emissions
- Circular economy: Reusing byproducts for biofuels, animal feed, bioplastics, and ingredients to new food

Valorization Strategies for Byproducts

- **Animal feed**
  - Grape pomace for cattle feed
- **Bioenergy production**
  - Biogas from organic waste
- **Nutraceuticals and food ingredients**
  - Whey proteins, antioxidants
- **Composting and soil amendments**

Challenges in Byproduct Management

- Storage issues: Risk of microbial contamination
- Transportation and logistics: High costs
- Regulatory constraints: Compliance with food safety and waste management laws



Moonsamy et al., 2024.
https://doi.org/10.1016/j.fbp.2024.08.012

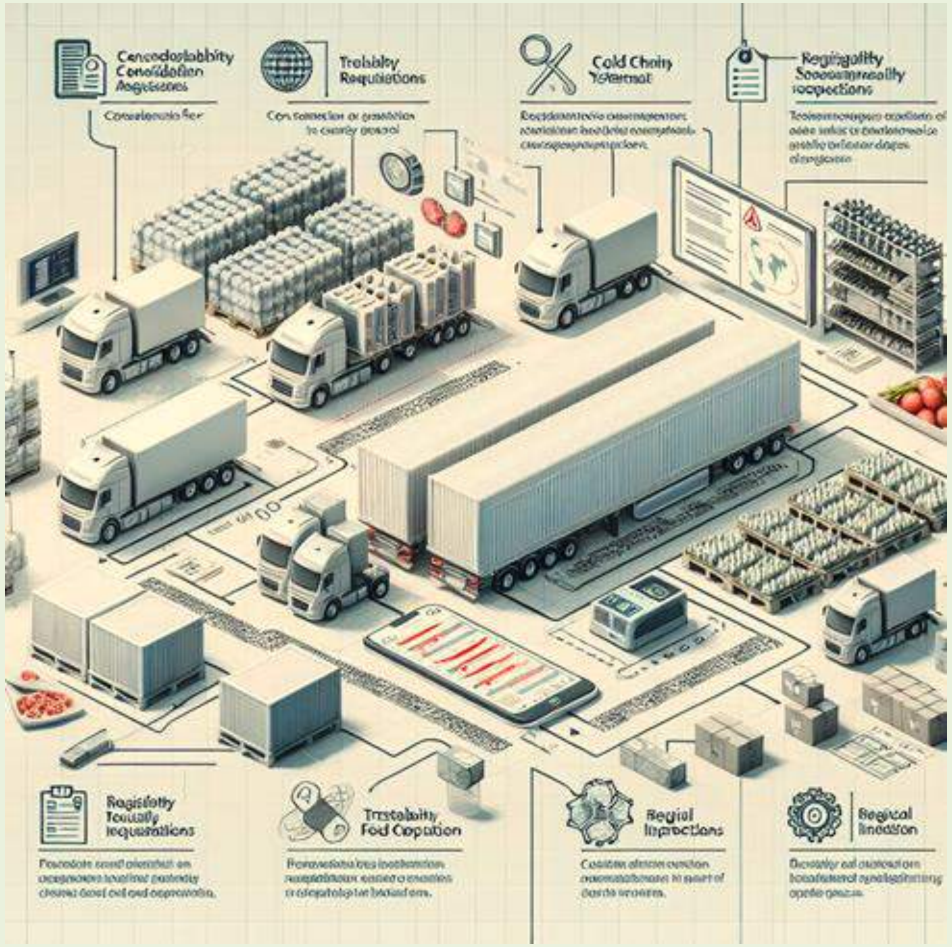
Storage Requirements for Plant-Based Byproducts

- Humidity and temperature control
- Microbial safety standards
- Packaging and labeling requirements

Storage Requirements for Animal-Based Byproducts

- Categorization under Regulation 1069/2009:
  - Category 1: High-risk (must be incinerated)
  - Category 2: Intermediate risk (fertilizers, biogas)
  - Category 3: Low-risk (animal feed, cosmetics)
- Refrigeration and containment

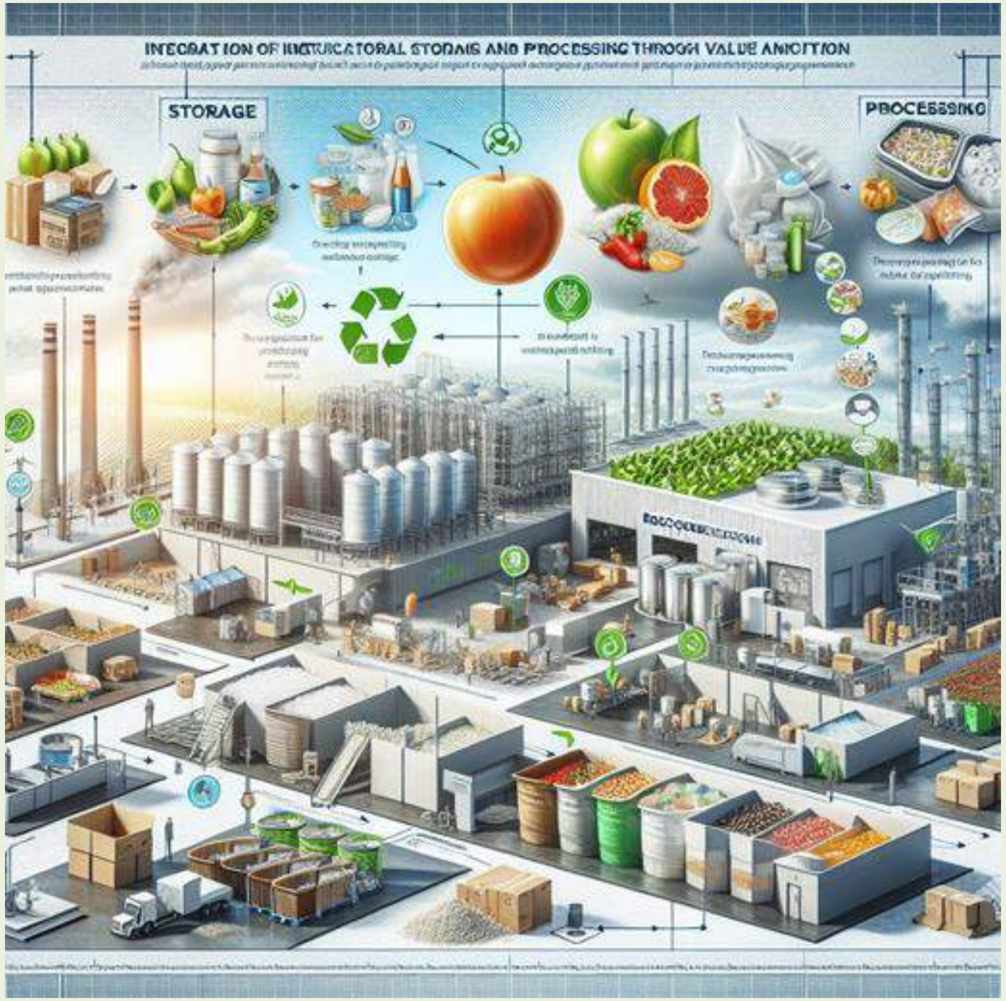
Storage and Transport of Byproducts – Logistics Considerations



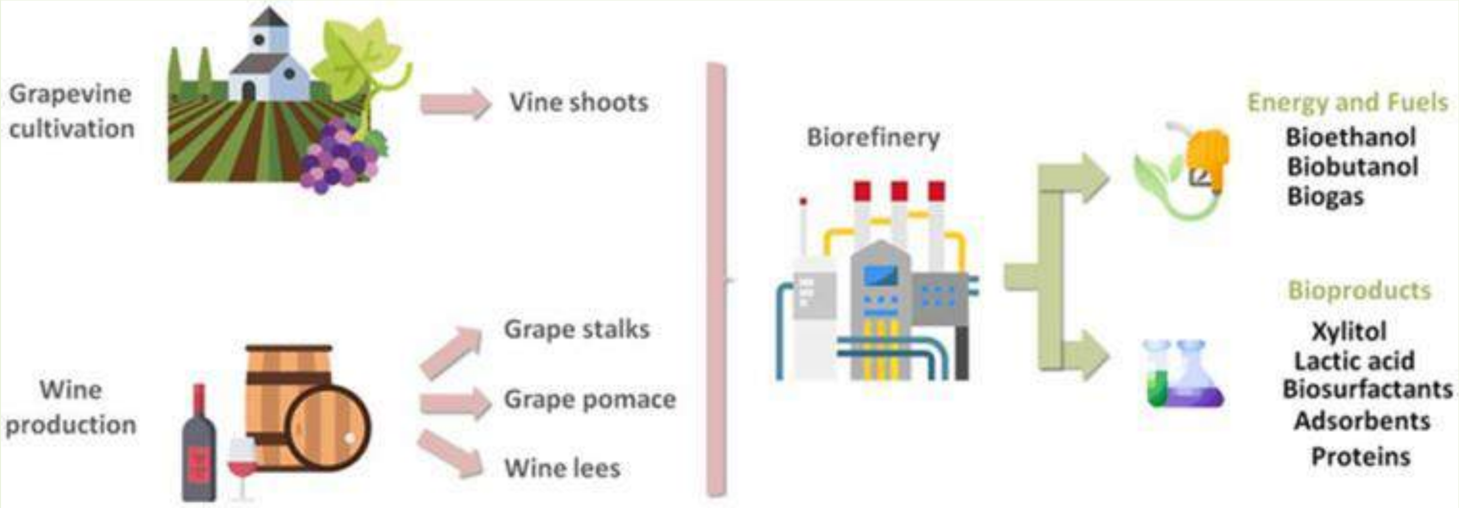
- Cold chain requirements
- Traceability systems
- Regulatory inspections

Sustainability and Circular Economy Approach

- Integration of storage and processing for value addition
- Reducing food waste through repurposing byproducts
- Sustainable packaging and waste reduction initiatives



3. CASE STUDIES

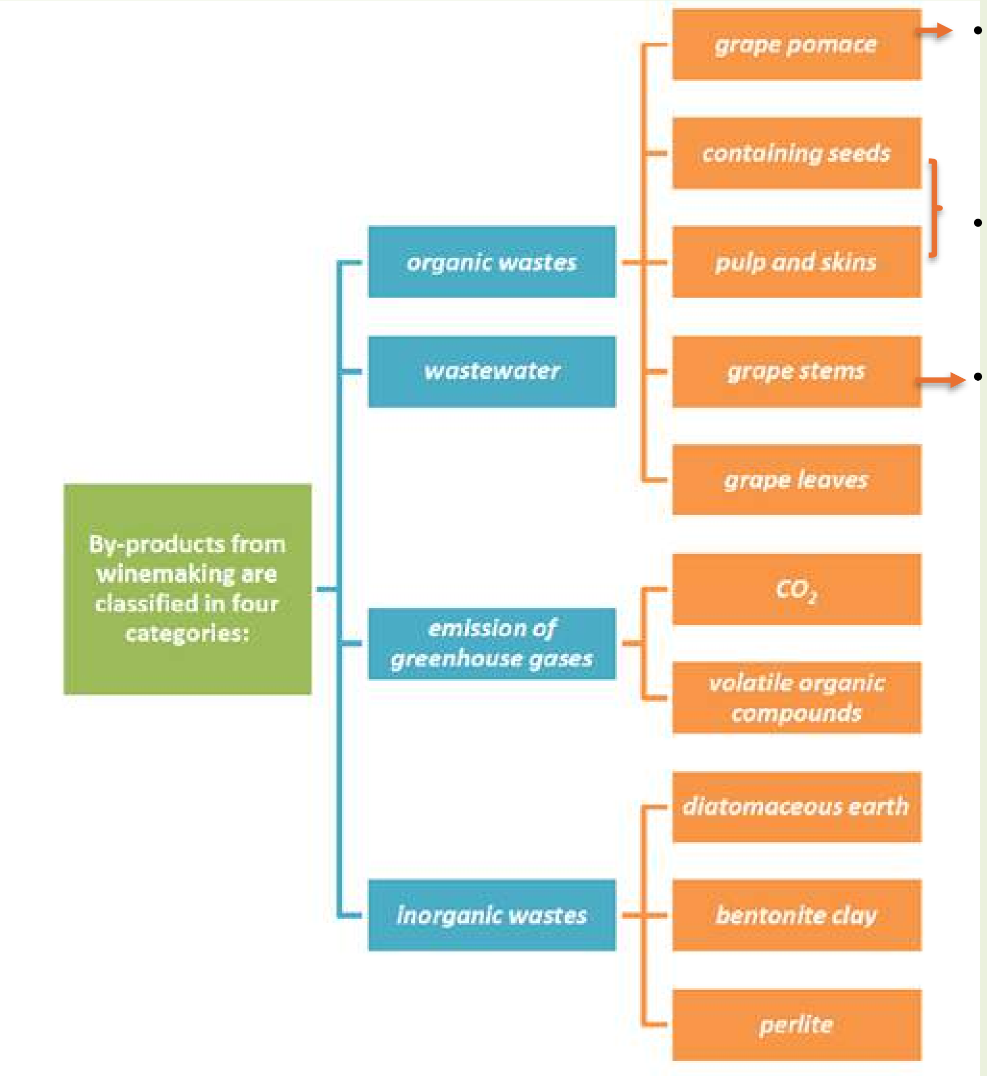


Contreras et al., 2022 https://doi.org/10.1016/j.fbp.2022.05.005

Wine Industry

- Main byproducts: Wine shoots, grape stalks, grape pomace, seeds, wine lees, tartrates
- Storage requirements: Temperature control, aeration
- Legislative aspects: EU hygiene standards, waste disposal regulations

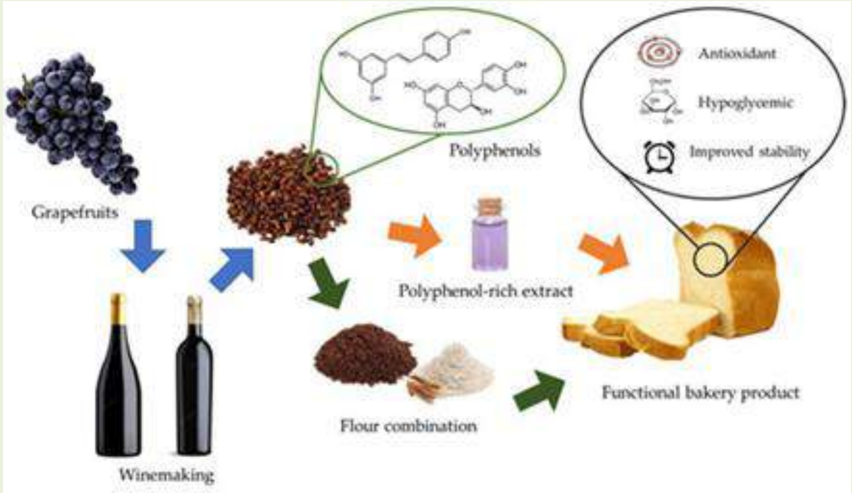
By-products from wine industry



- **Grape pomace** is considered the main by-product of wine production, accounting for 25-45% of the grape harvest, consisting mainly of skins, seeds, and pulp obtained after the pressing operation

- **Skin and seeds** account for about 13% of processed grapes and are especially a rich source of polyphenols with multiple health benefits.

- **Grape stems** are eliminated at the beginning of the process and constitute up to 25 % of total residues in the sector of winemaking. It represents the less characterized material from the point of view of their valuable content in bioactive compounds



Grape pomace

Grape pomace is the main solid by-product formed during the pressing and fermentation phases of wine production.

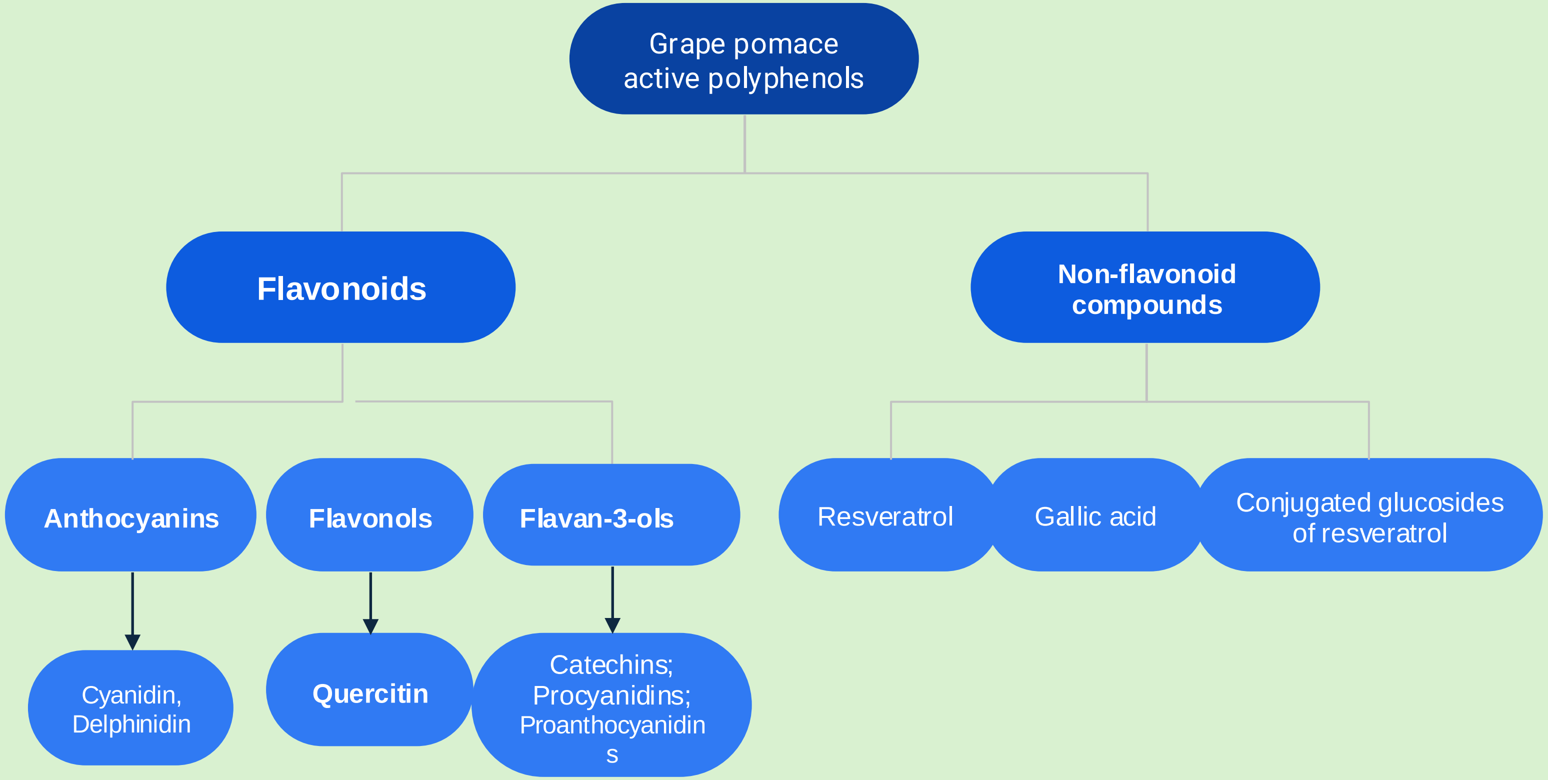
This is composed of the skins, seeds, and stems remaining after winemaking, constituting 20–30% of the weight of the processed grapes.

This percentage depends on the grape variety, viticultural practices, environmental factors, and winemaking techniques.

Grape pomace

Wine making

Grape pomace



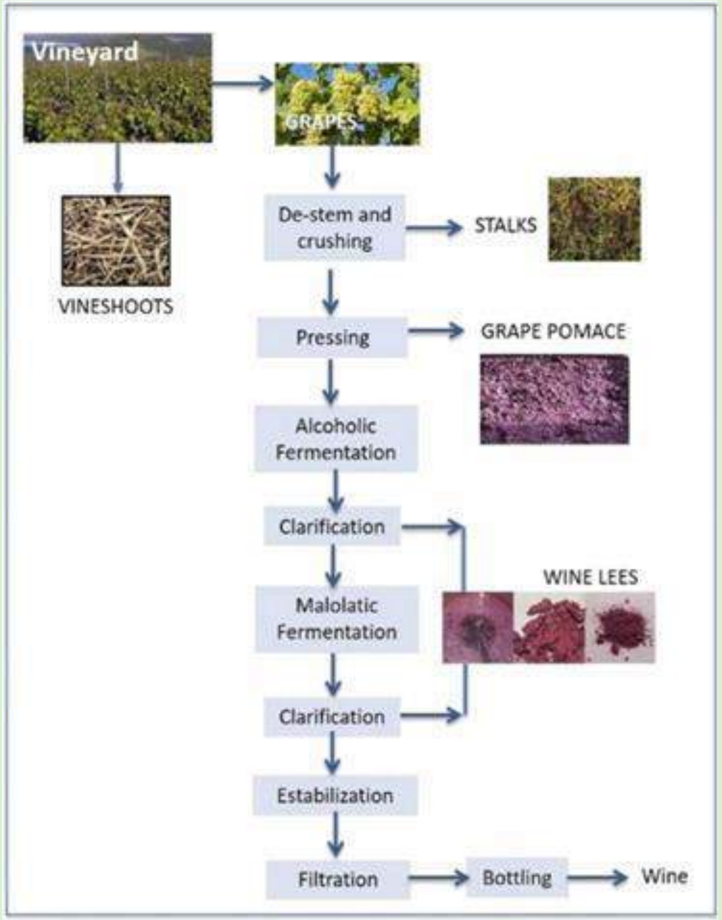
Waterhouse A.L.: Wine phenolics. Ann NY Acad Sci. 2002;957:21–36.

Characteristics of pomace extracts obtained from four grape varieties (Burgund, Pinot Noir, Italian Riesling, and White Feteasca).

Grape Variety	Pomace Condition	Moisture Content (%)	Polyphenols
Burgund	Fresh	62.44	Highest polyphenol content in seeds
White Feteasca	Fresh	54.55	Relatively high polyphenol content
Pinot Noir	Sun-dried (7 days, 30–32°C)	7.19	Lower dry matter loss, polyphenols concentrated
Italian Riesling	Sun-dried (7 days, 30–32°C)	6.51	Polyphenols present despite drying

Teixeira A., Baenas N., Dominguez-Perles R., Barros A., Rosa E., Moreno D.A., Garcia-Viguera C. Natural Bioactive Compounds from Winery By-Products as Health Promoters: A Review. Int J Mol Sci. 2014, 15(9): 15638–15678 **DOI:** 10.3390/ijms150915638

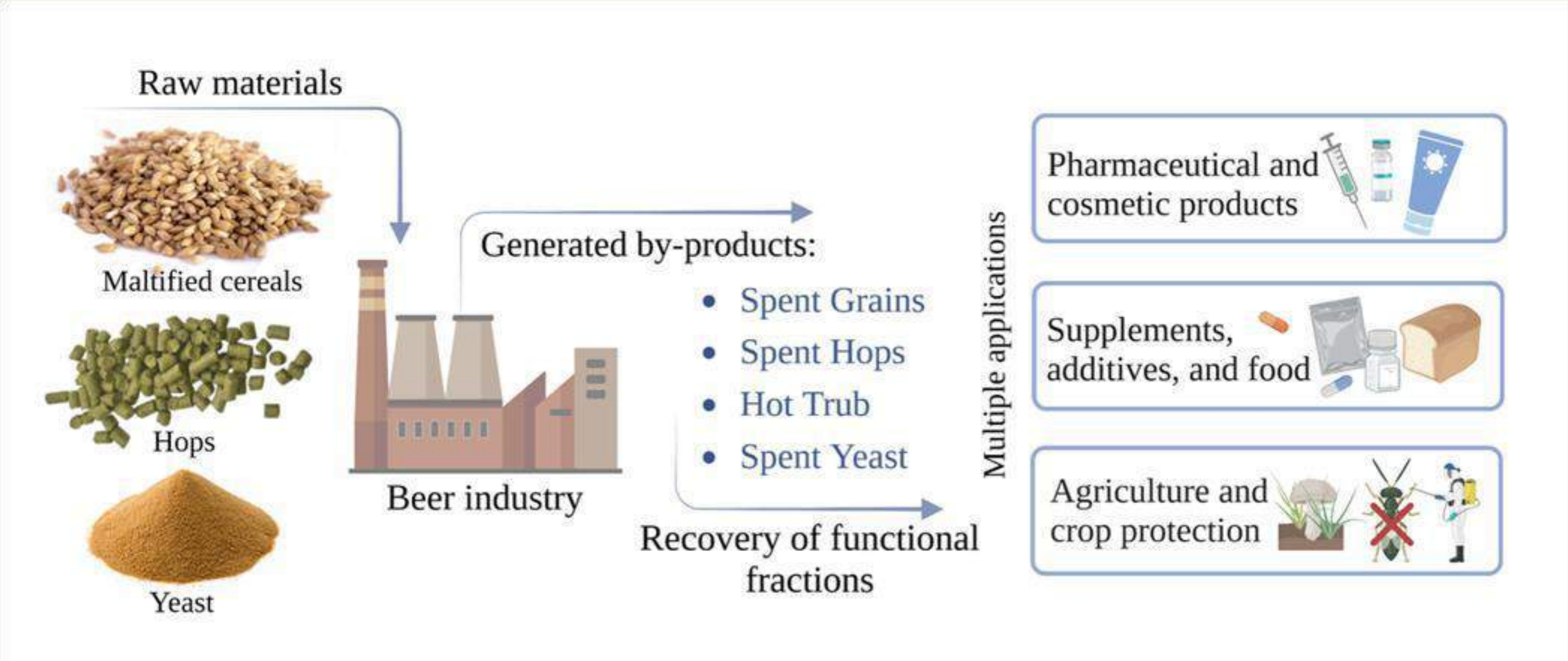
Process flowchart for the wine industry.



Contreras et al., 2022
https://doi.org/10.1016/j.fbp.2022.05.005

Beer industry

The main by-products generated by the beer industry



Salanță et al., 2023, https://doi.org/10.1016/j.fochx.2023.100876

Beer industry

The main by-products generated by the beer industry

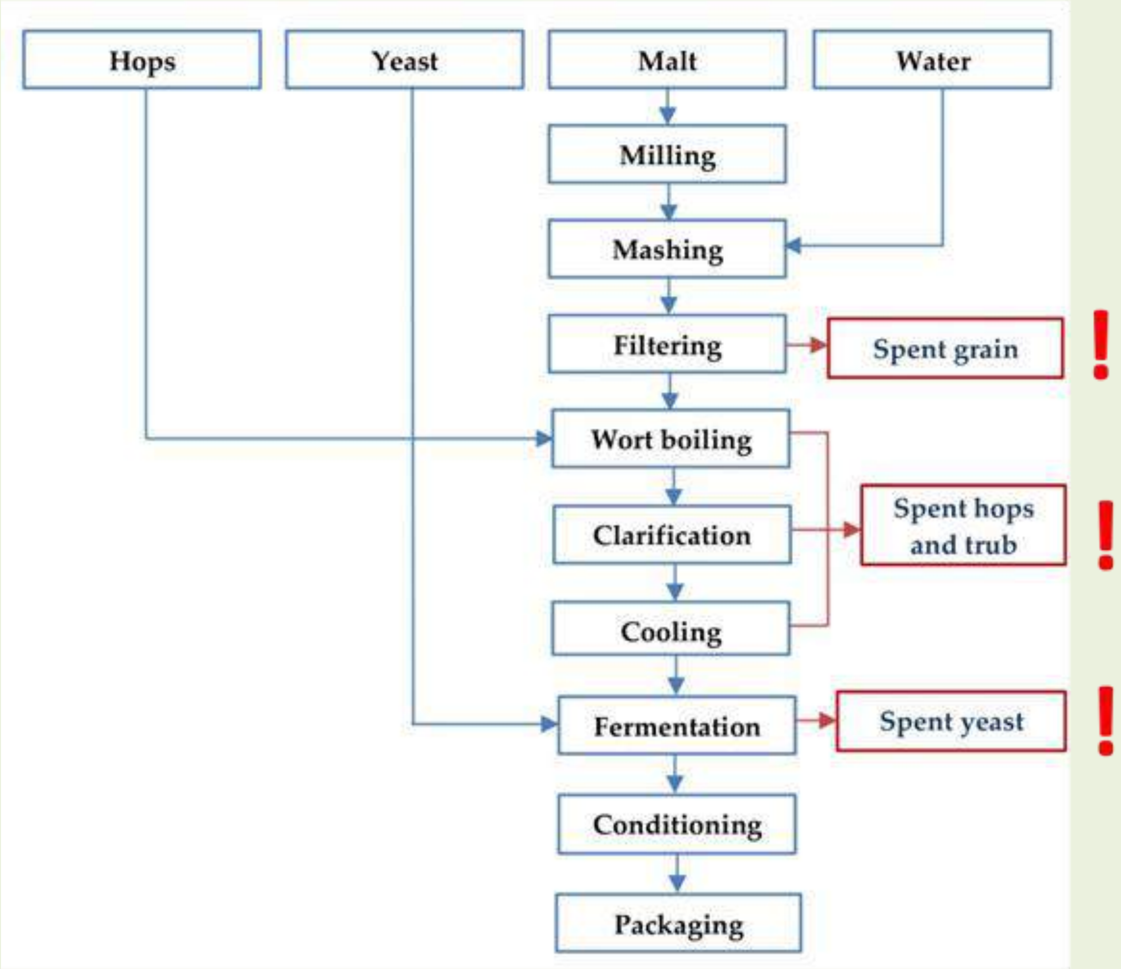
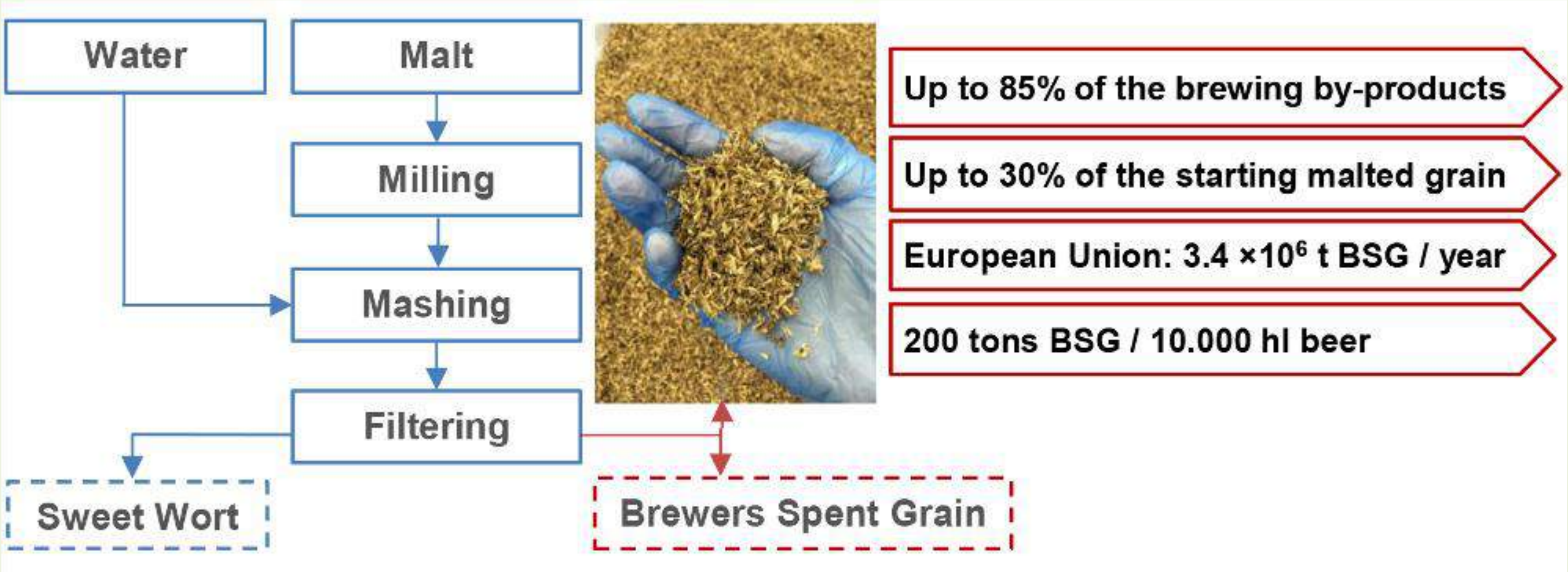


Fig A schematic representation of the brewing process and the generated by-products, DOI: 10.5772/intechopen.69231

Beer industry

The main by-products generated by the beer industry



The main by-products generated by the beer industry, source: original

BSG = barley grain husk in the greatest proportion, minor fractions of pericarp and fragments of endosperm and other residual compounds that were not converted to fermentable sugars in the mashing process

Beer industry

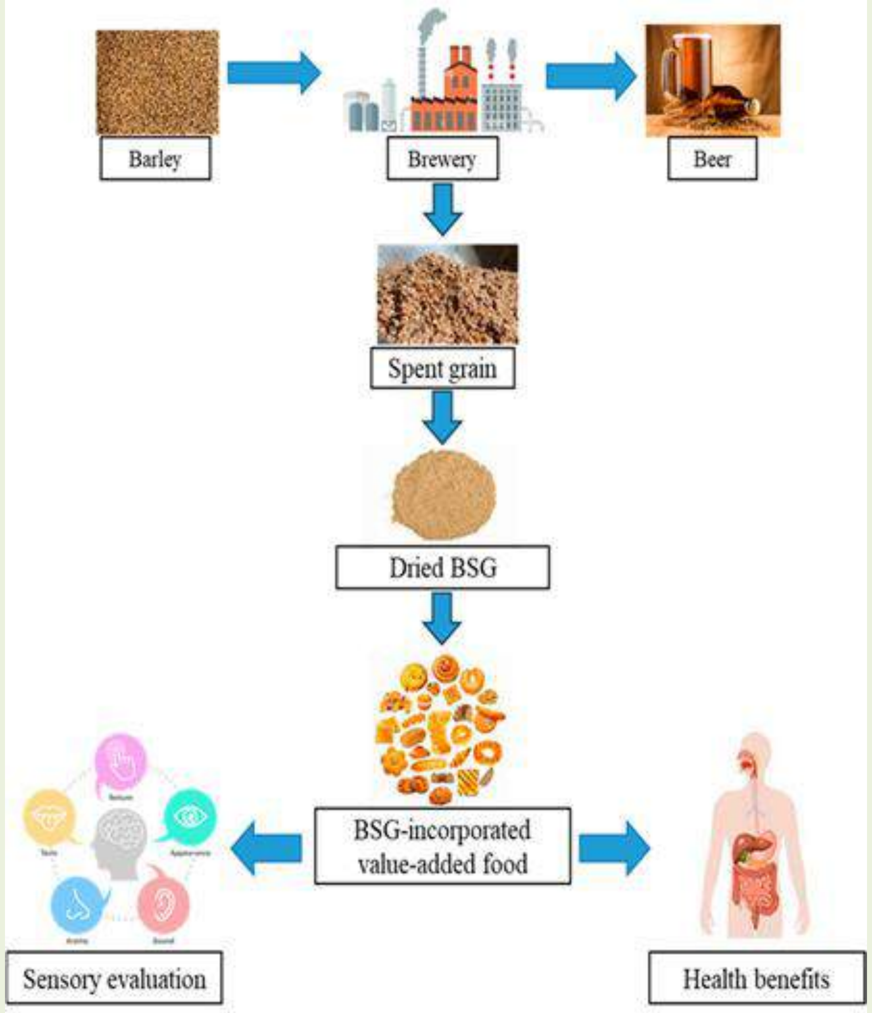
Total phenolic compounds and RSA values for dried BSG and different raw materials

Sample	Total phenols (mg GAE/100)	Flavonoids (mg QE/100 g fw)	DPPH inhibition (%)
Barley	133.93±2.45	6.17±0.11	43.17±0.07
Pilsner malt	148.42±0.51	5.28±0.13	46.36±0.1
Caramunich malt	256.42±6.18	10.72±0.18	57.87±0.07
Carafa malt	335.88±4.41	8.97±0.16	42.07±0.02
Dried BSG	**284.20±3.07**	**13.16±0.27**	**55.95±0.28**
Wheat flour	21.12±1.42	2.85±0.10	32.74±0.24
Wholemeal wheat flour	64.68±3.48	3.18±0.15	37.54±0.36

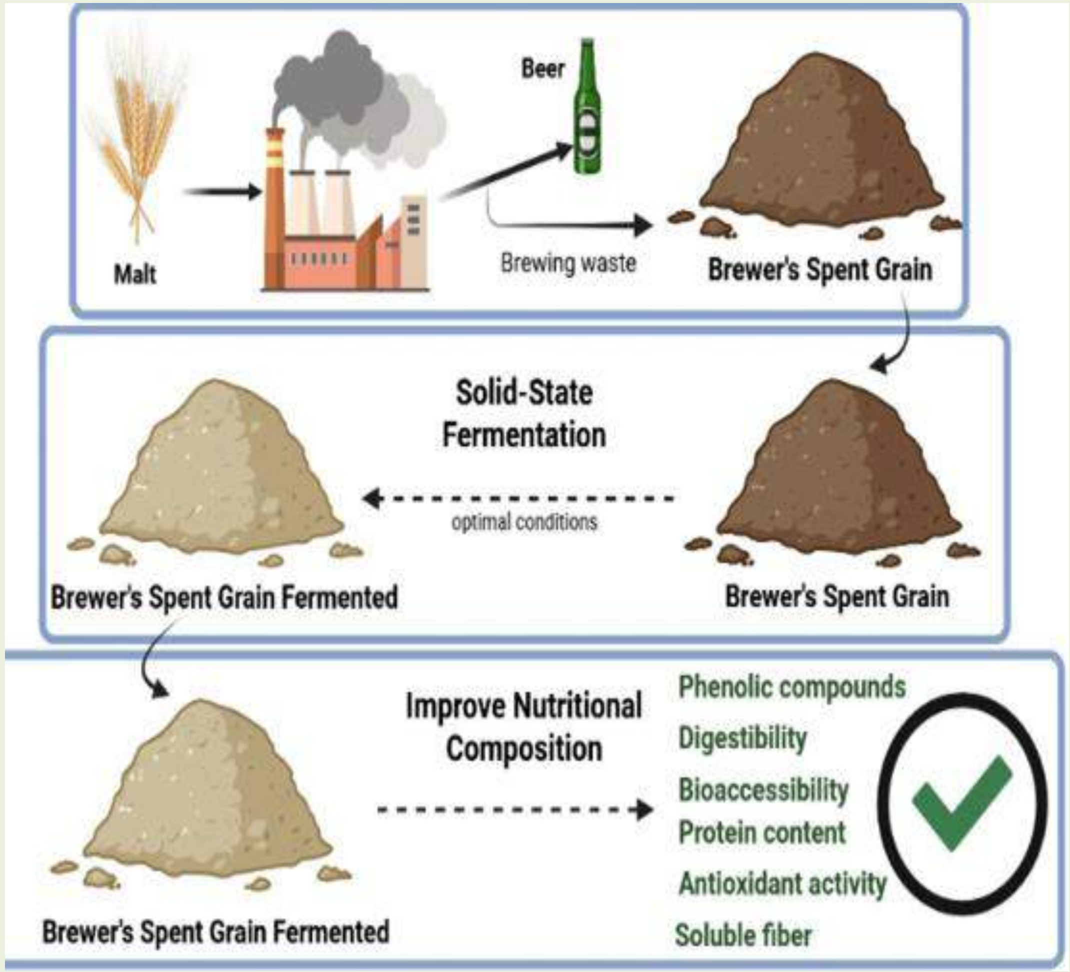
[Fărcas et. al. 2015, Journal of Cereal Science / Macias-Garbett

Beer industry

Potential application of brewery wastes and by-products in biotechnological processes

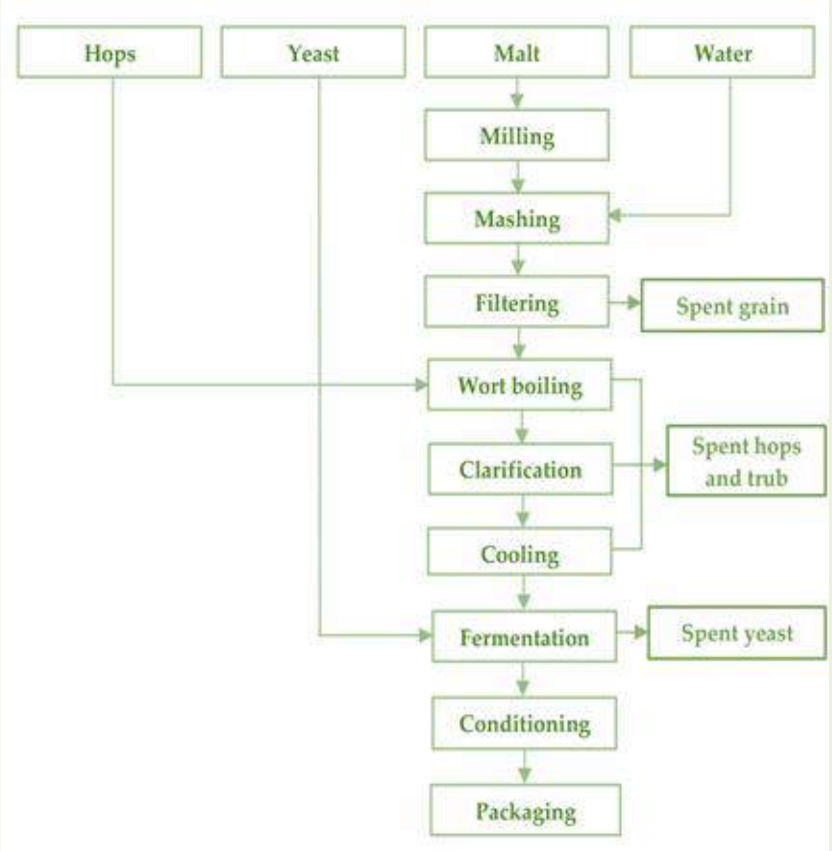


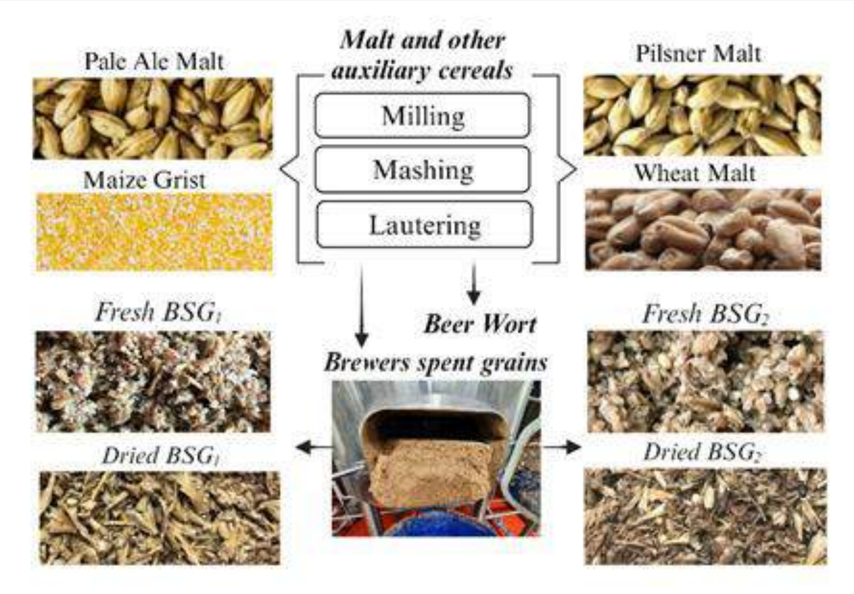
Eche et. al. 2025, Foods.
https://doi.org/10.3390/foods14162900



Barrera-Leon *et. al. 2025,* https://doi.org/10.3390/recycling10050170

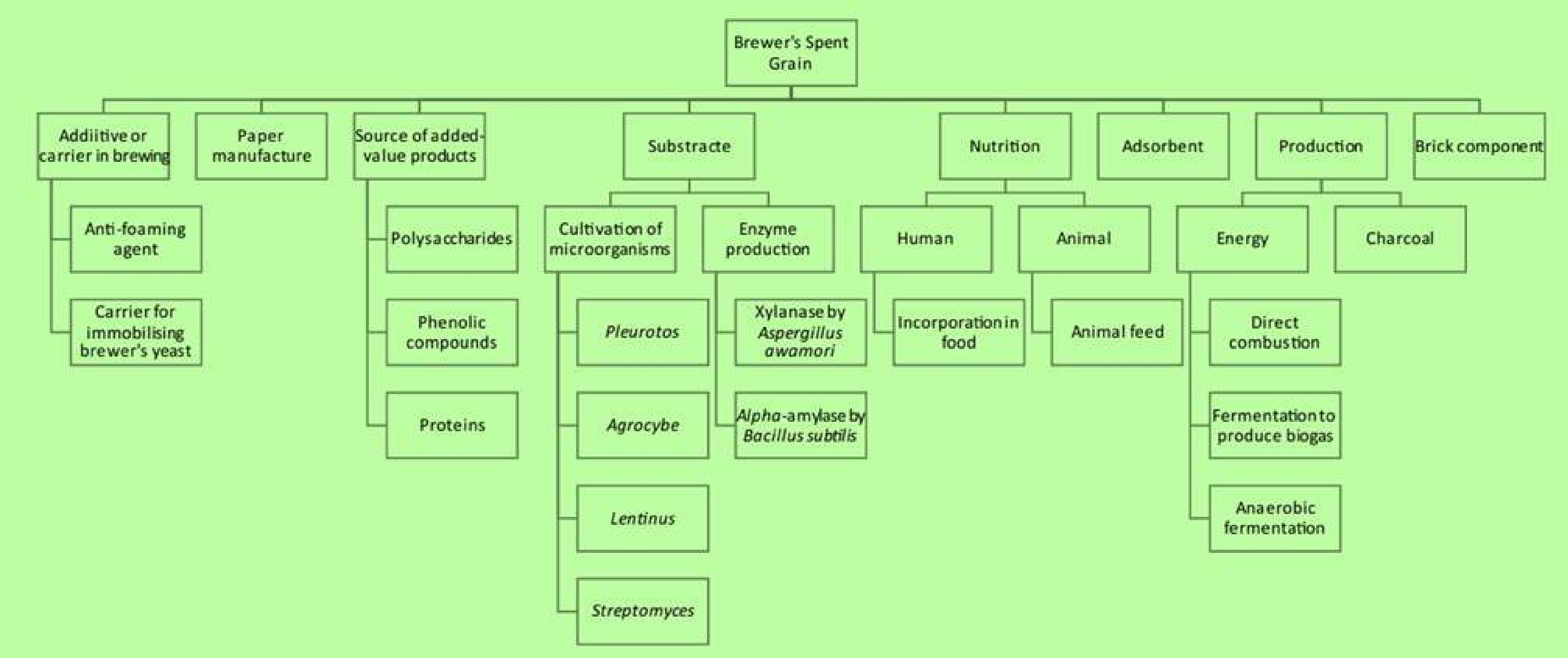
Beer by-products





Schematic representation of the brewing process and the generated by-products (source: original)

Brewers spent grain by-products



Bonifacio-Lopes et al. 2019,
https://ciencia.ucp.pt/ws/files/88847592/19711259.pdf

Olive Oil Industry

2024/2025

Portugal: 170-190.000 tons

Spain: 1.4-1.5 million tons

Infusions

Essential oil extraction

Composting

Bioactive compounds

Fertiliser or irrigation

Soluble and insoluble fibre

Bioactive compounds

source: original

source: original

Fresh pitted olive pomace
(crushed olive paste, "without" oil)

15 - 20% Olive oil

80 - 85% Olive Pomace

Composition:
- ≈60–70% water
- ≈2–3% fat
- Pulp
- Skin

Olive pomace is mainly used for:
– Animal feed
– Biomass production
– Composting
– Biofuel production

Olive Oil Production in Portugal – 2024: 170,000–180,000 tons

The second-largest olive oil production ever recorded in Portugal, according to OLIVUM (Association of Olive Growers and Mills of Portugal)

Approximately **1,700,000 tons of olive pomace** were generated

Phytotoxic **Environmental hazard**

Bioactive compounds

Hydroxytyrosol
– Inhibits lipid peroxidation
– Offers protection against neurodegenerative diseases
– Exhibits antimicrobial activity

Tyrosol
– ↓ Inflammation
– ↓ Oxidative stress

source: original

Table 1. Proximate composition of olive pomace.

g/100 g	Moisture	Total protein	Ash	Total fat	Total fiber	Remaining carbohydrates
Dry weight	-	6.3 ± 0.8	2.7 ± 0.0	3.6 ± 0.1	44.0 ± 0.9	43.4 ± 1.6
Fresh weight	60.9 ± 0.3	2.5 ± 0.3	1.1 ± 0.0	1.4 ± 0.0	17.2 ± 0.3	16.9 ± 0.3

The results are presented in g/100 g of sample in fresh or dry weight, as mean ± standard deviation (*n* = 3).

Table 2. Vitamin E profile of olive pomace.

µg/100 g	α-tocopherol	α-tocotrienol	β-tocopherol	γ-tocopherol	δ-tocopherol	Total vitamin E
Dry weight	4133 ± 138	62 ± 1	50 ± 1	97 ± 2	17 ± 0	4360 ± 143
Fresh weight	1614 ± 54	24 ± 0	20 ± 1	38 ± 1	7 ± 0	1703 ± 56

The results are presented in µg/100 g of sample in fresh or dry weight, as mean ± standard deviation (*n* = 3).

Table 3. Phytochemicals contents and antioxidant activity of olive pomace.

Sample	TPC g GAE/100 g	TFC g CE/100 g	HTC g/100 g	FRAP g FSE/100 g	DPPH•-SA g TE/100 g
Dry weight	3.08 ± 0.13	2.69 ± 0.03	0.36 ± 0.00	4.43 ± 0.57	1.53 ± 0.06
Fresh weight	1.20 ± 0.05	1.05 ± 0.01	0.14 ± 0.00	1.73 ± 0.22	0.60 ± 0.02

TPC, Total phenolics content; TFC, Total flavonoids content; HTC, Hydroxytyrosol content; FRAP, Ferric reducing antioxidant power; DPPH•-SA, 2,2-diphenyl-1-picrylhydrazyl radical scavenging ability; GAE, Gallic acid equivalents; CE, Catechin equivalents; FSE, Ferrous sulphate equivalents; TE, Trolox equivalents. The results are presented as mean ± standard deviation (*n* = 3).

source: Sousa et al., 2023, https://doi.org/10.3390/molecules28062876

Table 4. Fatty acids profile of olive pomace.

Fatty acids (relative %)	Olive pomace
Myristic (C14:0)	0.03 ± 0.00
Palmitic (C16:0)	11.18 ± 0.08
Palmitoleic (C16:1)	0.59 ± 0.03
Heptanoic (C17:0)	0.10 ± 0.00
Stearic (C18:0)	2.82 ± 0.15
Oleic (C18:1n9c)	73.07 ± 0.40
Linoleic (C18:2n6c)	9.97 ± 0.47
Arachidic (C20:0)	0.51 ± 0.05
α-linolenic (C18:3n3)	0.92 ± 0.10
cis-11-Eicosenoic (C20:1n9)	0.38 ± 0.01
Behenic (C22:0)	0.28 ± 0.04
Lignoceric (C24:0)	0.16 ± 0.02
∑ SFA	15.07 ± 0.15
∑ PUFA	10.89 ± 0.46
∑ MUFA	74.03 ± 0.31
MUFA/PUFA	6.81 ± 0.33

SFA, Saturated fatty acids; MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids. The results are expressed in relative % as mean ± standard deviation (n = 3) in dry weight.

source: Sousa et al., 2023, https://doi.org/10.3390/molecules28062876

Coffee Industry

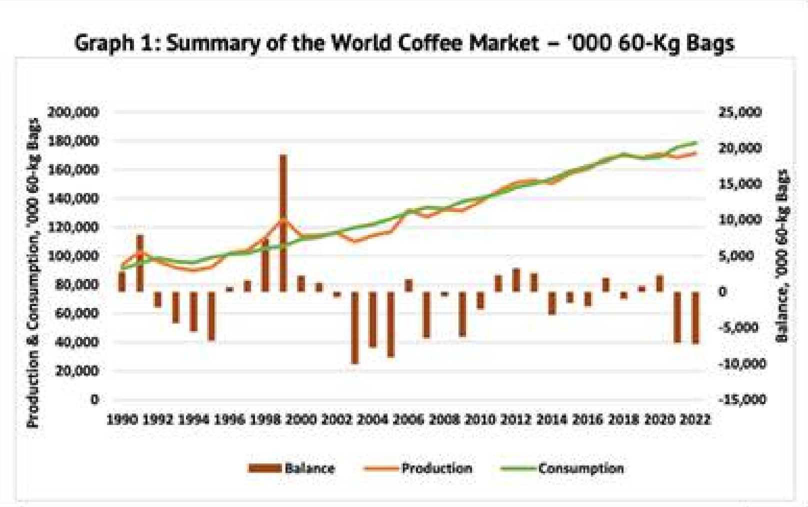
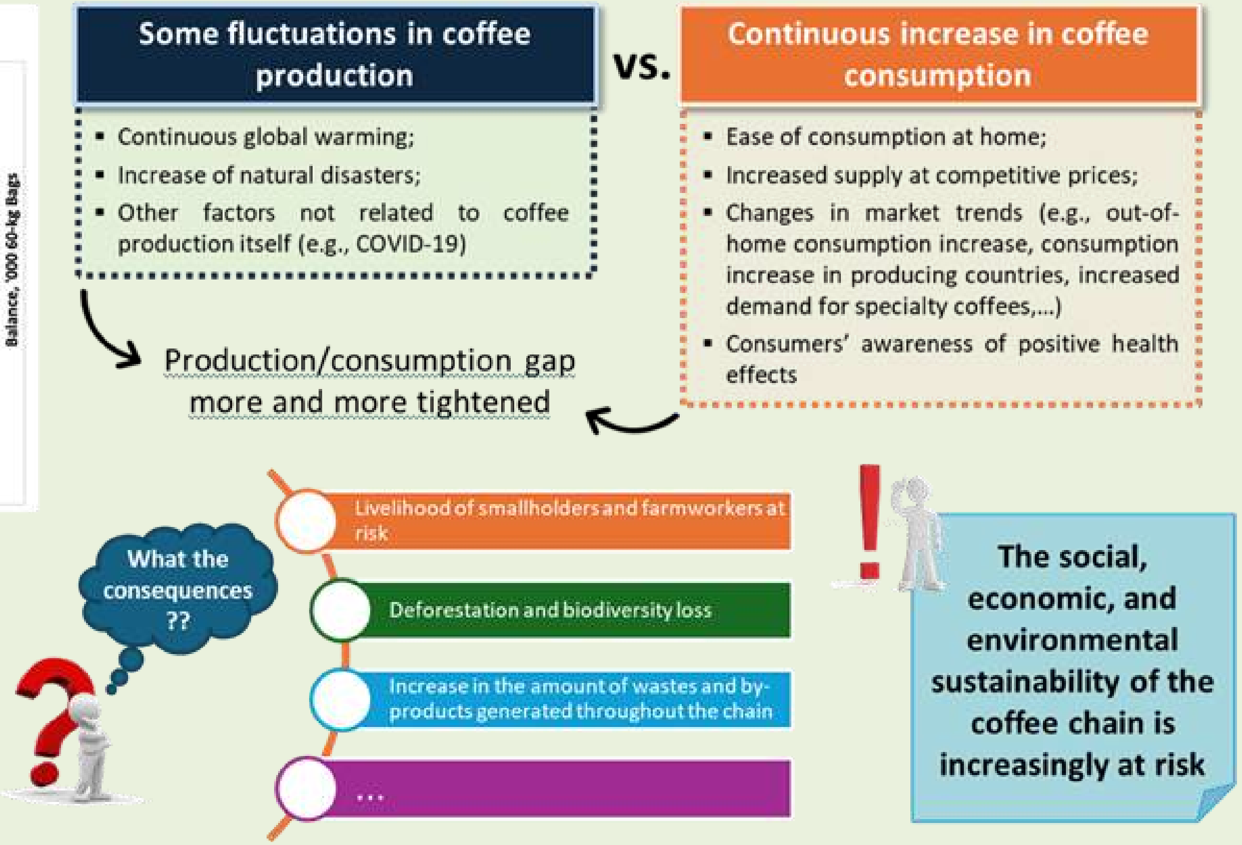


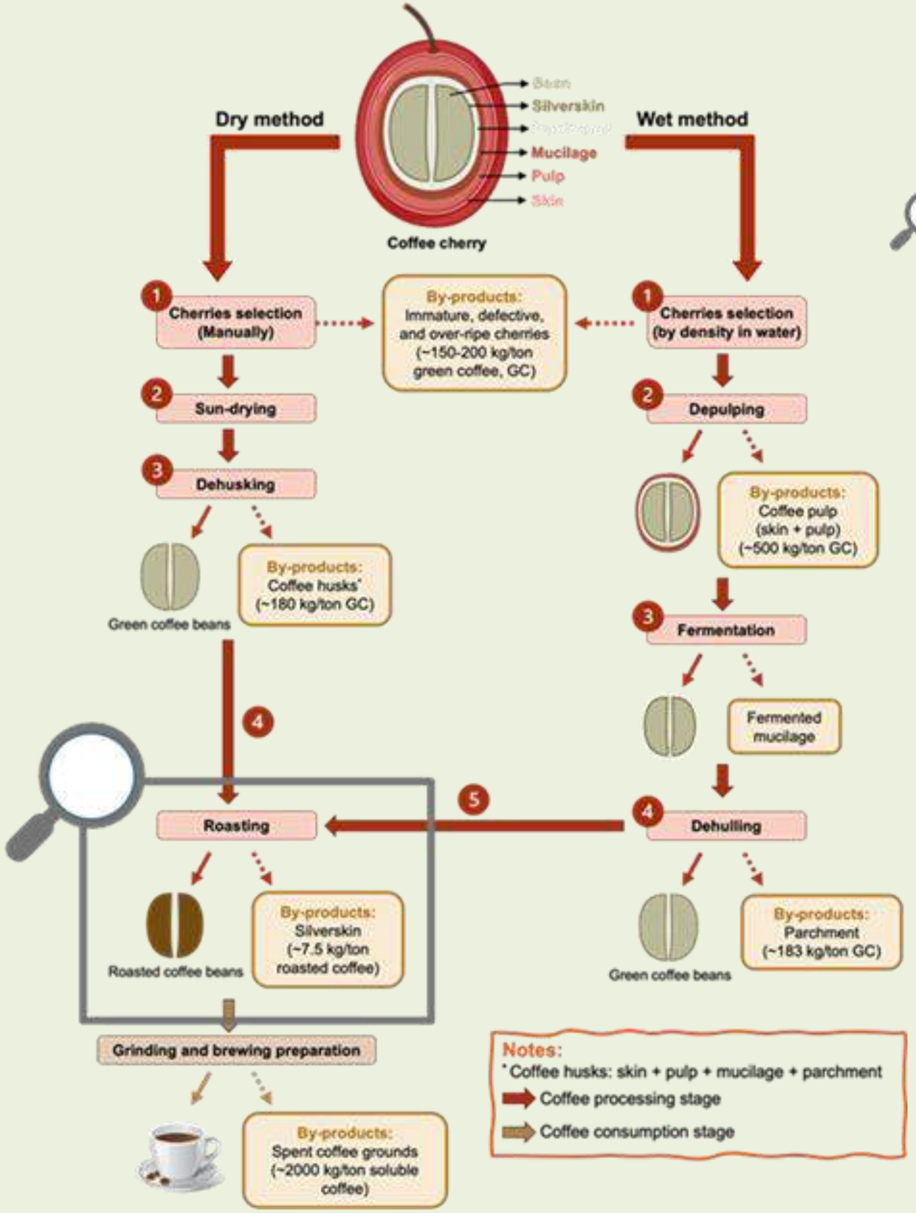
Table I: Summary of the World Coffee Market

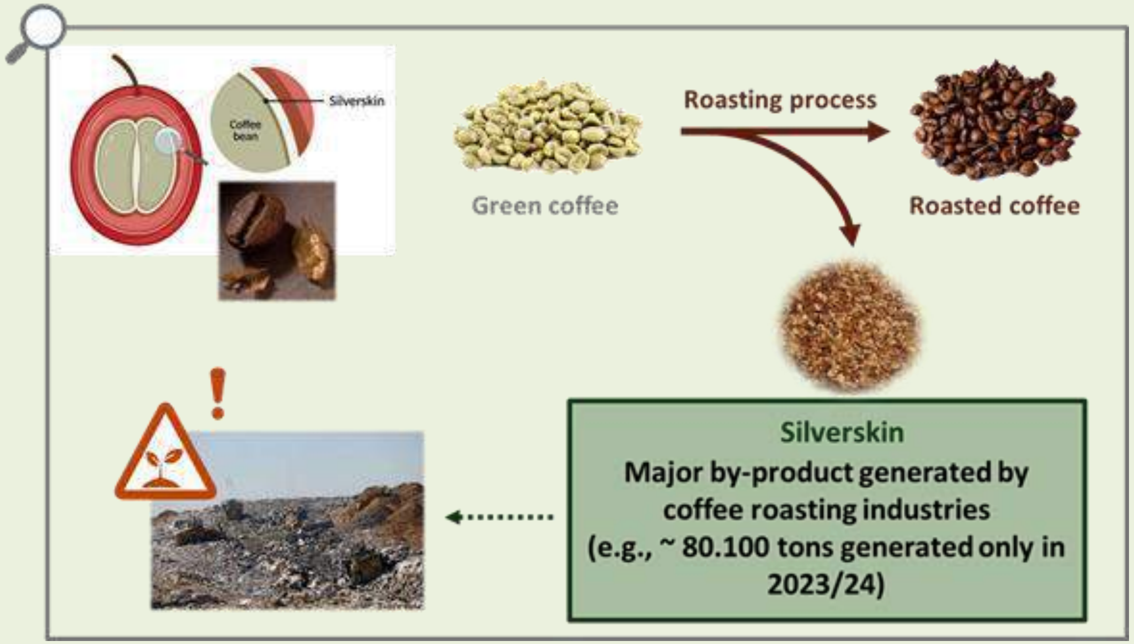
	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24
Million 60-Kg Bags						
Production	169.8	168.4	170.8	168.0	168.2	178.0
Consumption	171.2	168.6	169.9	176.6	173.1	177.0
Balance	-1.3	-0.2	0.9	-8.6	-4.9	1.0
Growth Rates, Year-on-Year						
Production	5.9%	-0.9%	1.4%	-1.7%	0.1%	5.8%
Consumption	3.3%	-1.5%	0.8%	4.0%	-2.0%	2.2%



source: Barreto Peixoto JA et al. *Compr, Rev. Food Sci. Food Saf*. 2023; 22: 287-332; ICO (2023). *Coffee Report and Outlook – April 2023;* ICO (2023). *Coffee Report and Outlook – December 2023.*

Coffee chain sustainability – What is coffee silverskin and why to study it?





source: Barreto Peixoto JA et al. Compr, Rev. Food Sci. Food Saf. 2023; 22: 287-332; Bessada S et al. Sci Total Environ. 2018; 645: 1021-1028 doi: 10.1111/1541-4337.13069

Coffee chain sustainability – What is coffee silverskin and why to study it?

Table 1. Nutritional composition of coffee by-products (% dw).

	Silverskin
Ash	9.47 ± 0.06
Protein	16.31 ± 0.12
Fat	2.91 ± 0.09
Total dietary fiber	65.87 ± 0.00
Insoluble dietary fiber	56.86 ± 0.00
Soluble dietary fiber	9.01 ± 0.00
Available carbohydrates	5.44 ± 0.24

Table 2. Total phenolic compounds and in vitro antioxidant activity (DPPH• inhibition and FRAP assays) of coffee by-products (g/100 g dw).

	Silverskin
TPC (CGAE)	1.28 ± 0.01
TFC (CE)	0.70 ± 0.01
FRAP (FSE)	4.05 ± 0.12
$DPPH^{\bullet}$-SA (TE)	0.19 ± 0.05

Table 3. Caffeine (g/100 g), caffeoylquinic acids (mg/100 g), and 5-hydroxymethyl- furfural (mg/100 g) content of coffee by-products.

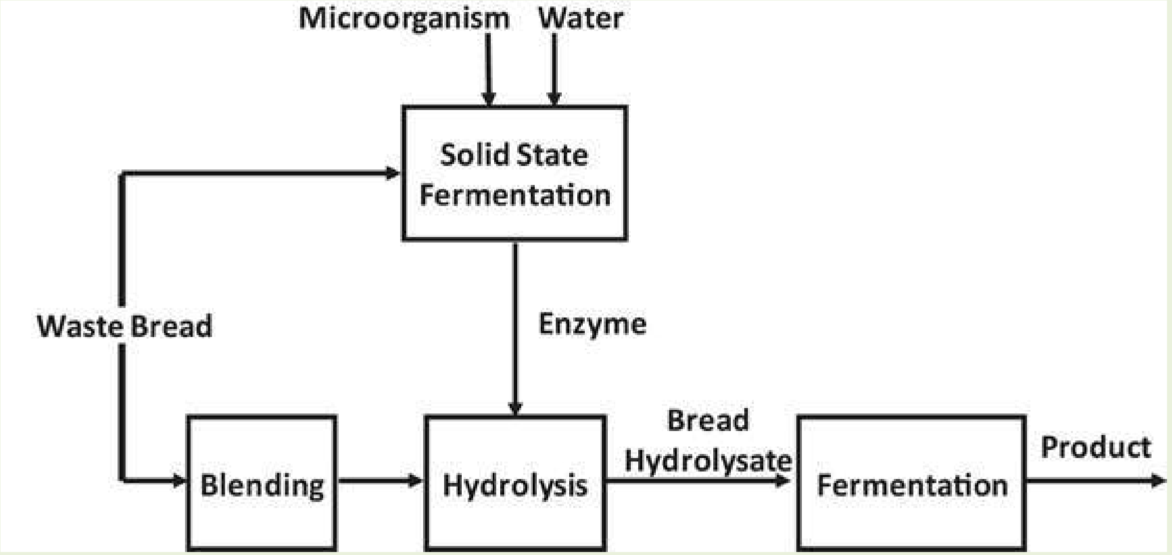
	Silverskin
Caffeine	0.71 ± 0.02
3-CQA	9.44 ± 0.22
5-CQA	52.53 ± 0.83
4-CQA	17.71 ± 0.30
HMF	39.52 ± 1.07

Results are the average of 3 independent experiments ± SD. In each line, different superscript letters represent significant differences between samples ($p < 0.05$). TPC, total phenolics content; CGAE, chlorogenic acid equivalents; TFC, total flavonoids content; CE, catechin equivalents; FRAP, ferric reducing antioxidant power; FSE, ferrous sulphate equivalents; $DPPH^{\bullet}$-SA, 2,2 diphenyl-1picrylhydrazyl radical scavenging activity; TE, Trolox equivalents. CQA, caffeoylquinic acid; HMF, 5-hydroxymethylfurfural; n.d., non-detected.

source: Machado M et al. Foods. 2023; 12: 2354 doi: 10.3390/foods12122354

Bread and bakery Industry

- Main byproducts: bread crusts, wheat bran, and spent grains.
- Storage conditions: proper ventilation, moisture control to prevent mold, temperature control
- Regulatory challenges: EU food waste regulations, reprocessing guidelines, hygiene standards



Melikoglu et al, 2023

https://doi.org/10.1016/j.fbp.2013.04.008

Bread and bakery Industry

Excess bread – waste

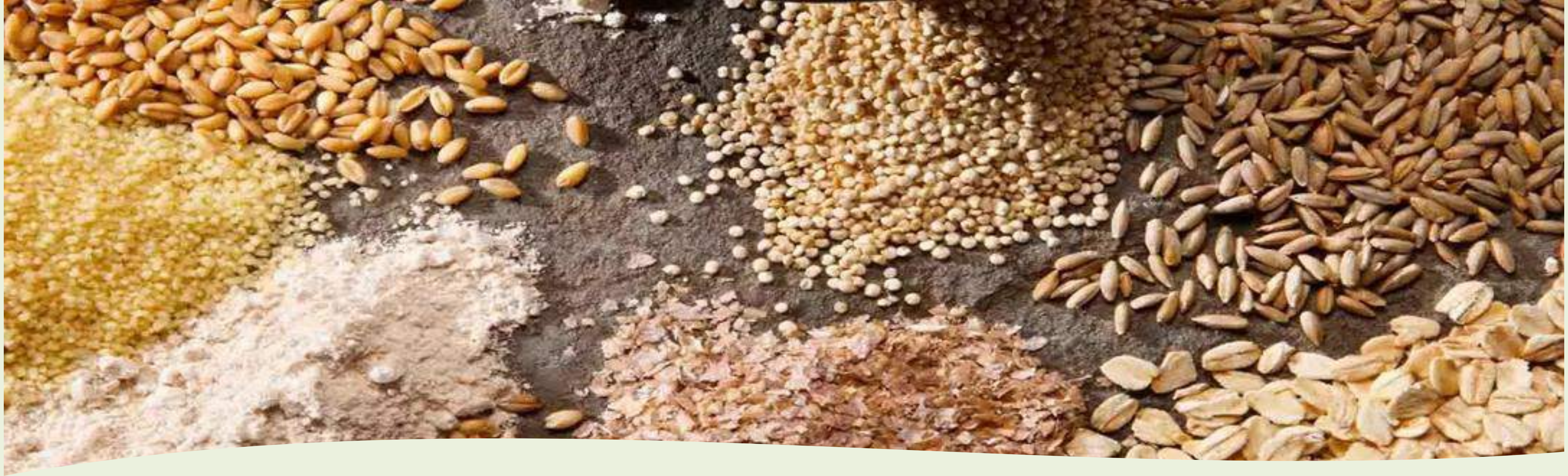
A significant by-product in the commercial and domestic context is stale or waste bread itself.
This can be upcycled into various new products to reduce food waste.

Animal Feed: - discarded bread is a source of carbohydrates for livestock feed.
New Food Products: - it can be processed into **breadcrumbs, croutons, bread puddings, or stuffing.**
Brewing industry: - stale bread is used by some breweries to brew beer.
Industrial Feedstock: - bread waste can be used as a feedstock for microorganisms to **produce other chemicals** such as lactic acid, hydrogen, and more ethanol, or even **non-food i**tems like textiles.

https://www.sfig.dk/index/bread-by-products

Pastry products – waste

New food semi-finished products: these can be recovered and used in “brezar” and “ponci”, which are important intermediate mixtures used in the production of confectionery products.



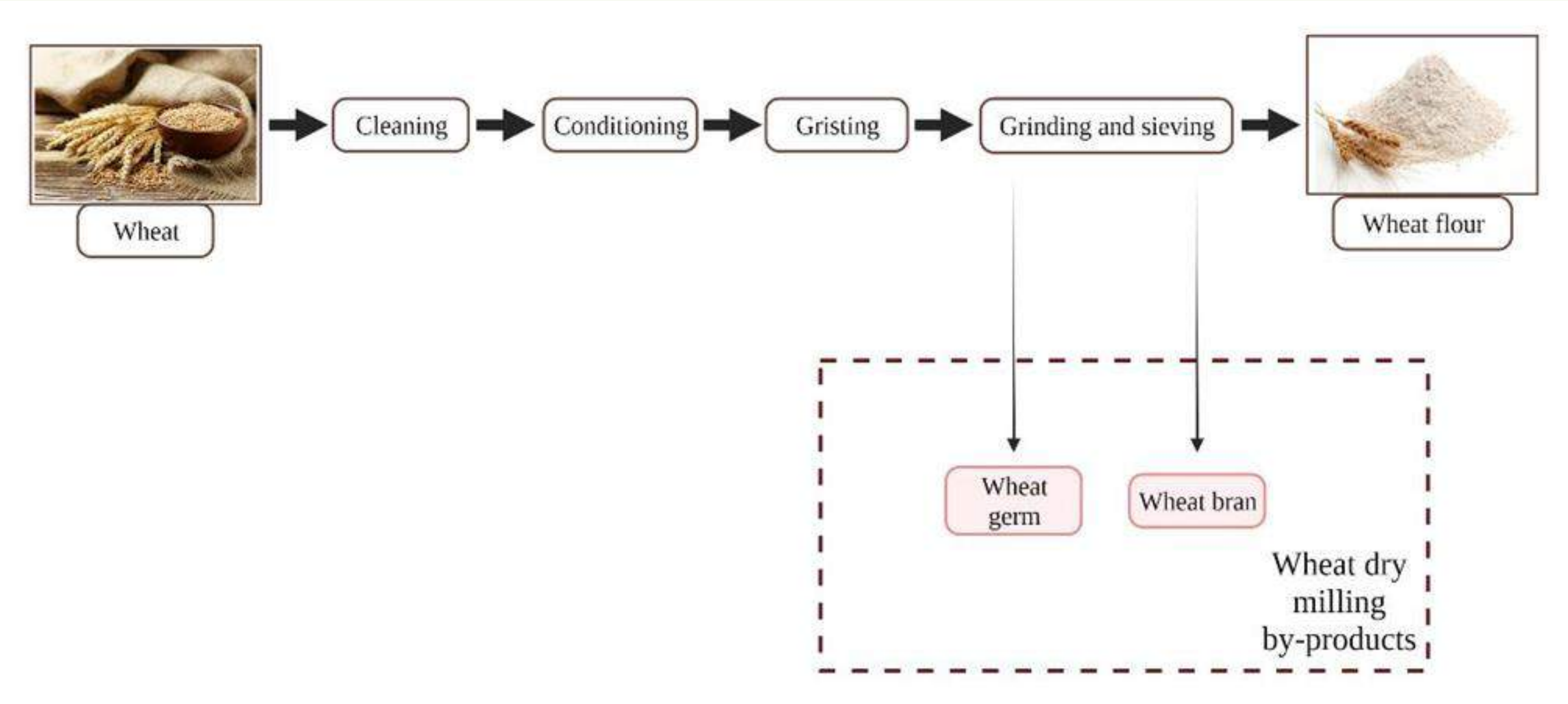
Cereal processing

Types of cereal by-products:

- ✓ Wheat by-products;
- ✓ Corn by-products;
- ✓ Rice by-products;
- ✓ Other cereals by-products.

- Depending on the milling process (dry or wet milling) the final nutritional value of the by-products varies greatly.
- Therefore, the fractions obtained during dry or wet milling can find many applications in food and nonfood products apart from use only as feed.

Wheat by-products



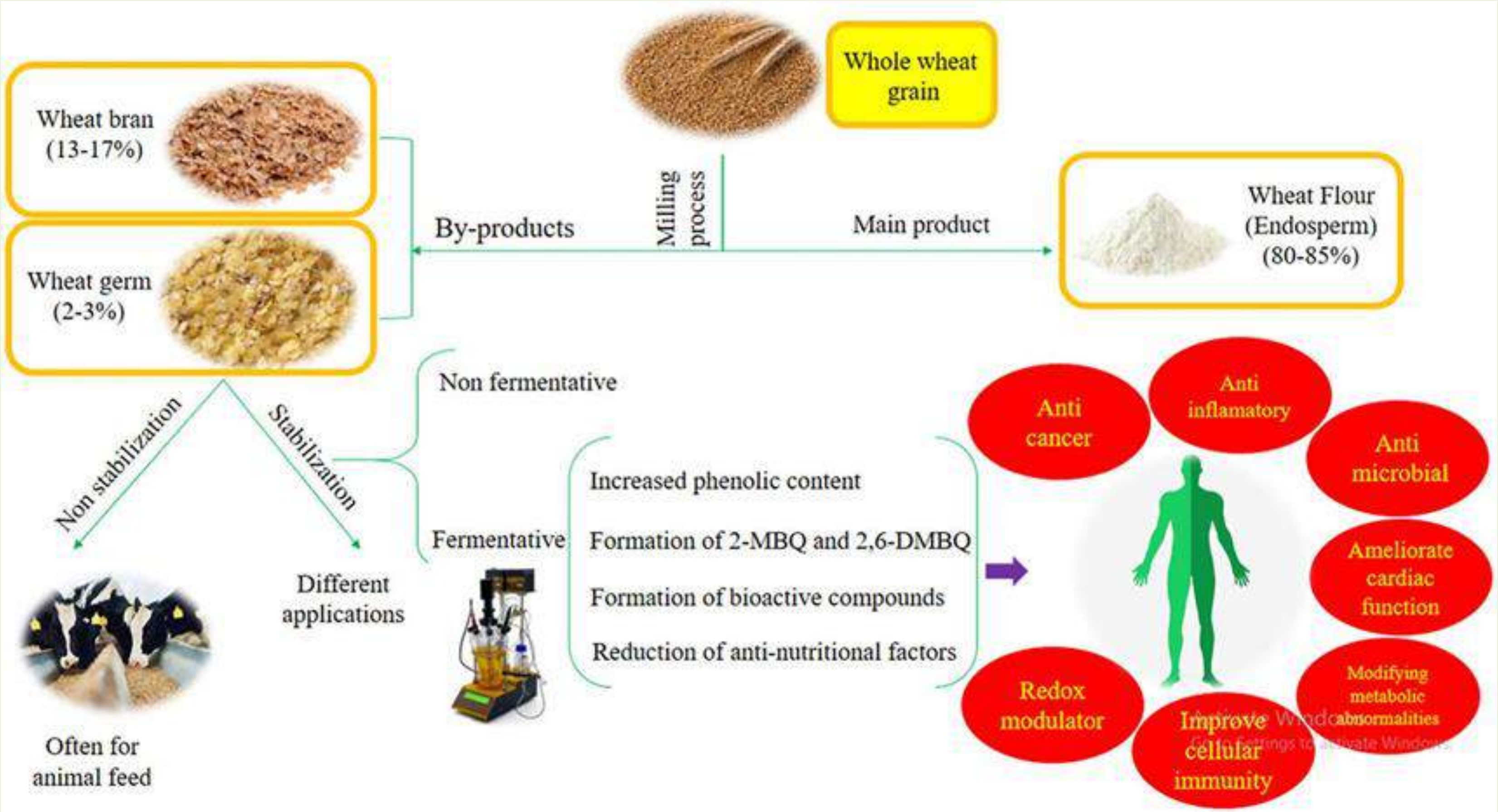
After milling the wheat, the following results:

- ✓starchy endosperm;
- ✓bran;
- ✓germs;
- ✓hulls and polish debris.

Types of by-products resulted after wheat processing (Farcas, A. et al., 2021)

https://doi.org/10.3390/nu13113934

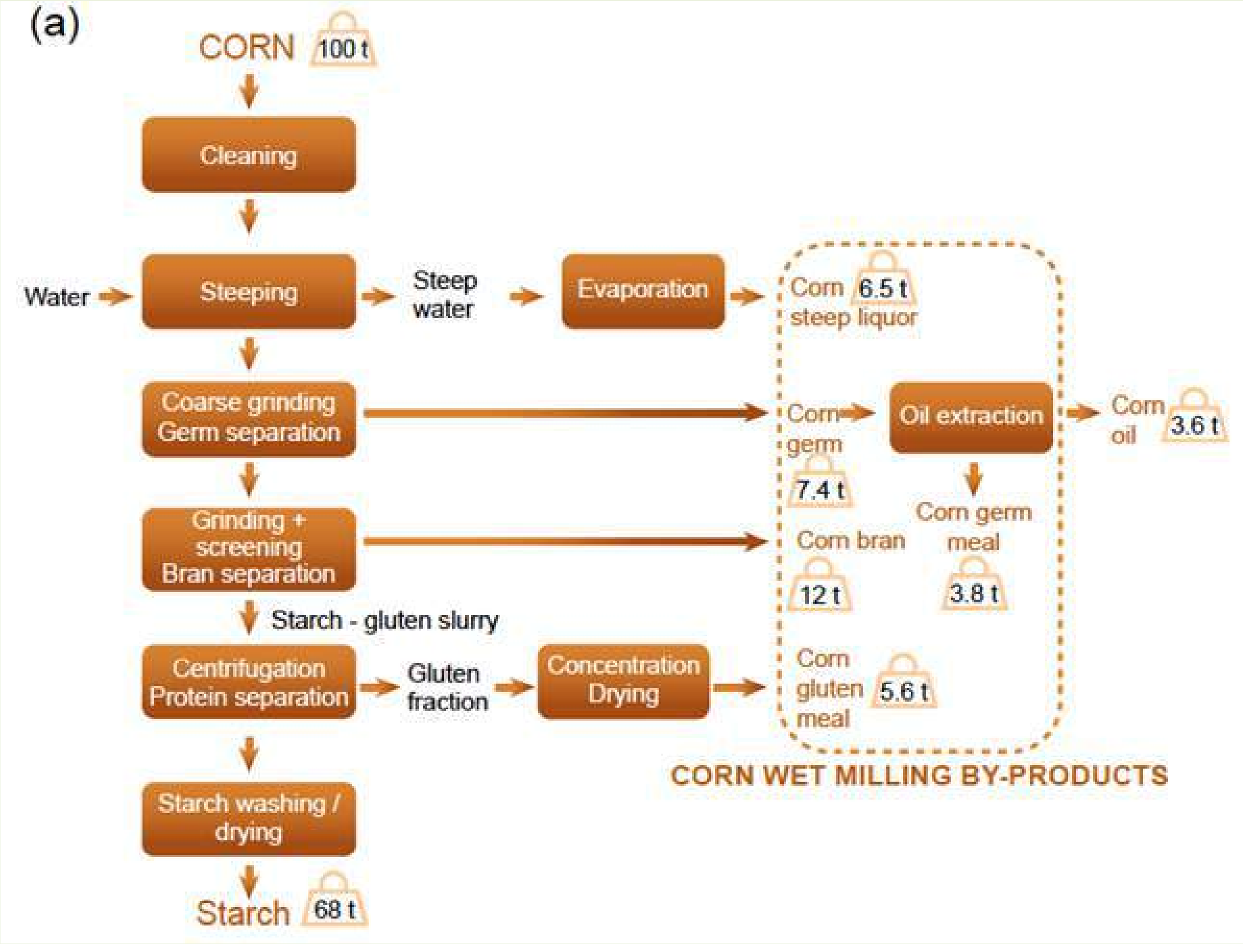
Wheat by-products - valorization



Khosroshah, E.D. et al., 2023

https://doi.org/10.1016/j.tifs.2022.12.001

Corn by-products



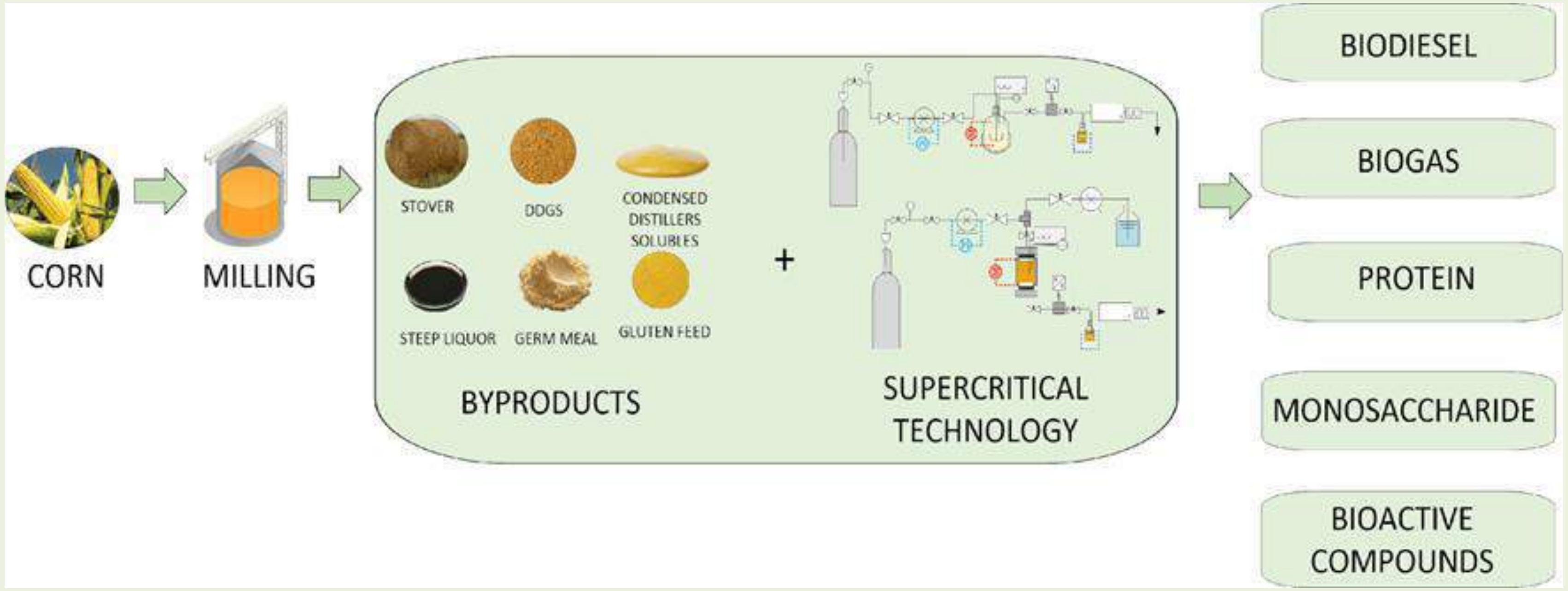
Types of by-products resulted after corn processing
(Dapčević-Hadnađev, T. et al., 2018)

https://doi.org/10.1016/B978-0-08-102162-0.00002-2

After milling the corn, the following results:

- ✓ starch (endosperm fractions)
- ✓ bran
- ✓ **Other by-products,** including **corn steep liquor, corn germ (meal and oil, corn bran,** and **corn gluten meal.**

Corn by-products - valorization

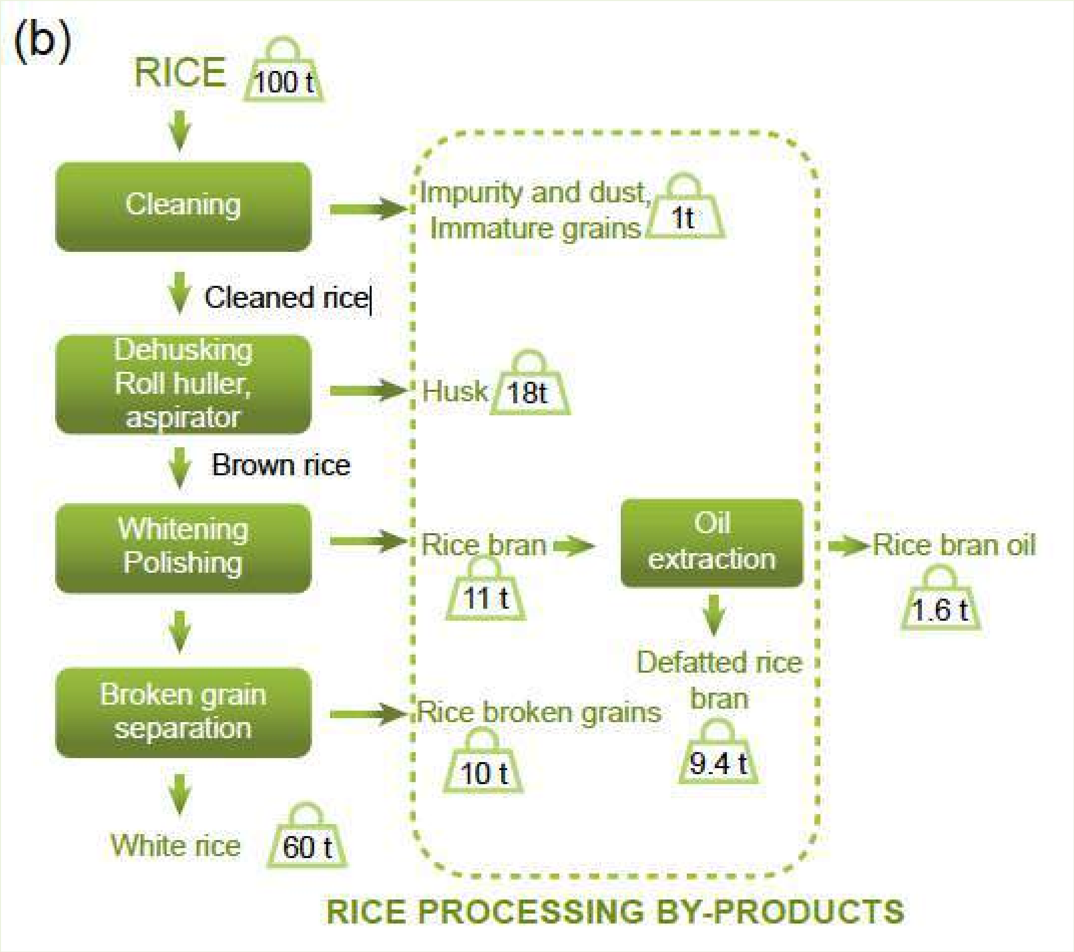


Santana, A.L. et al., 2023
https://doi.org/10.3390/pr11010289

Rice by-products

After milling the rice, the following results:

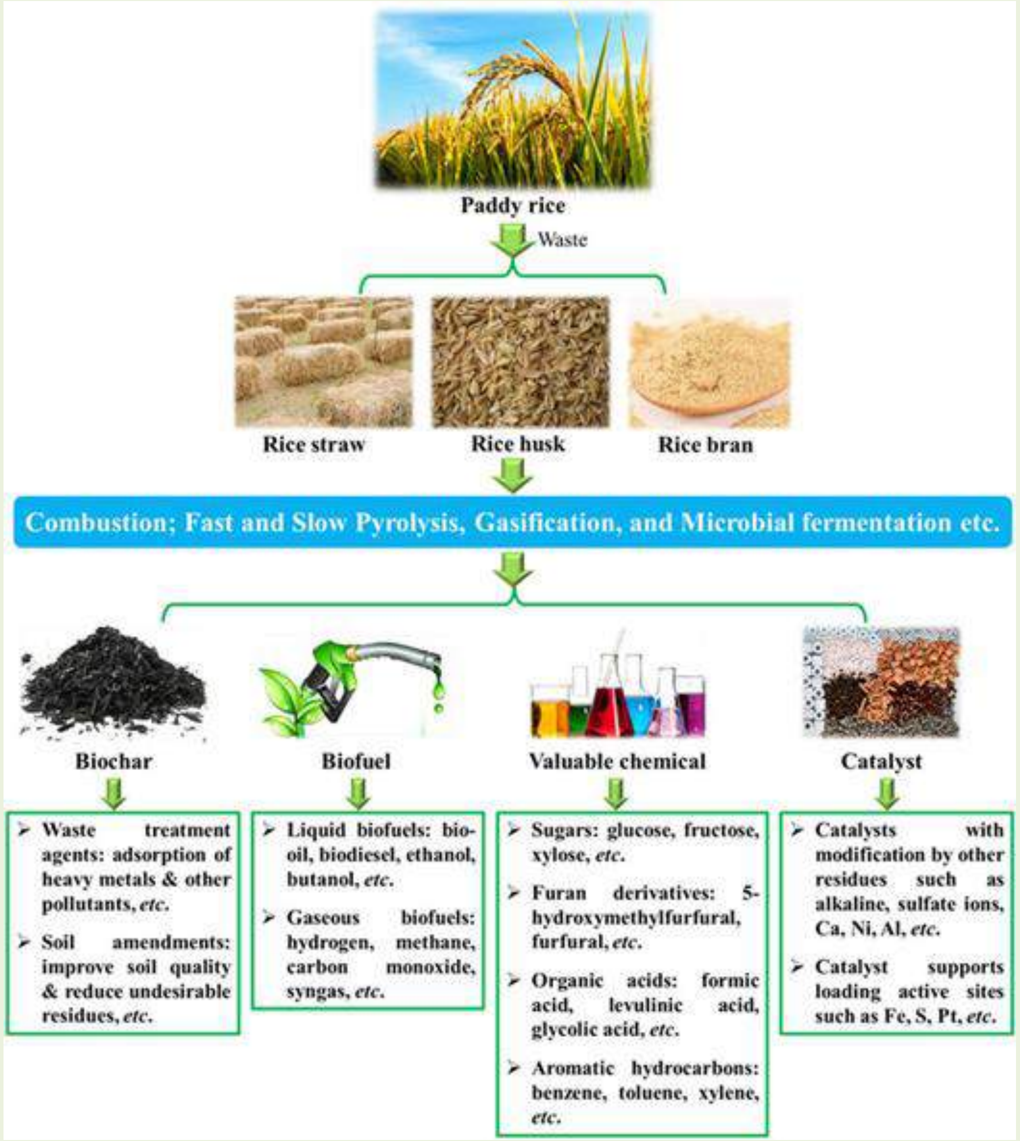
✓rice endosperm or white rice;
✓rice husk;
✓rice bran;
✓rice germ.



Types of by-products resulted after rice processing (Dapčević-Hadnađev, T. et al., 2018)

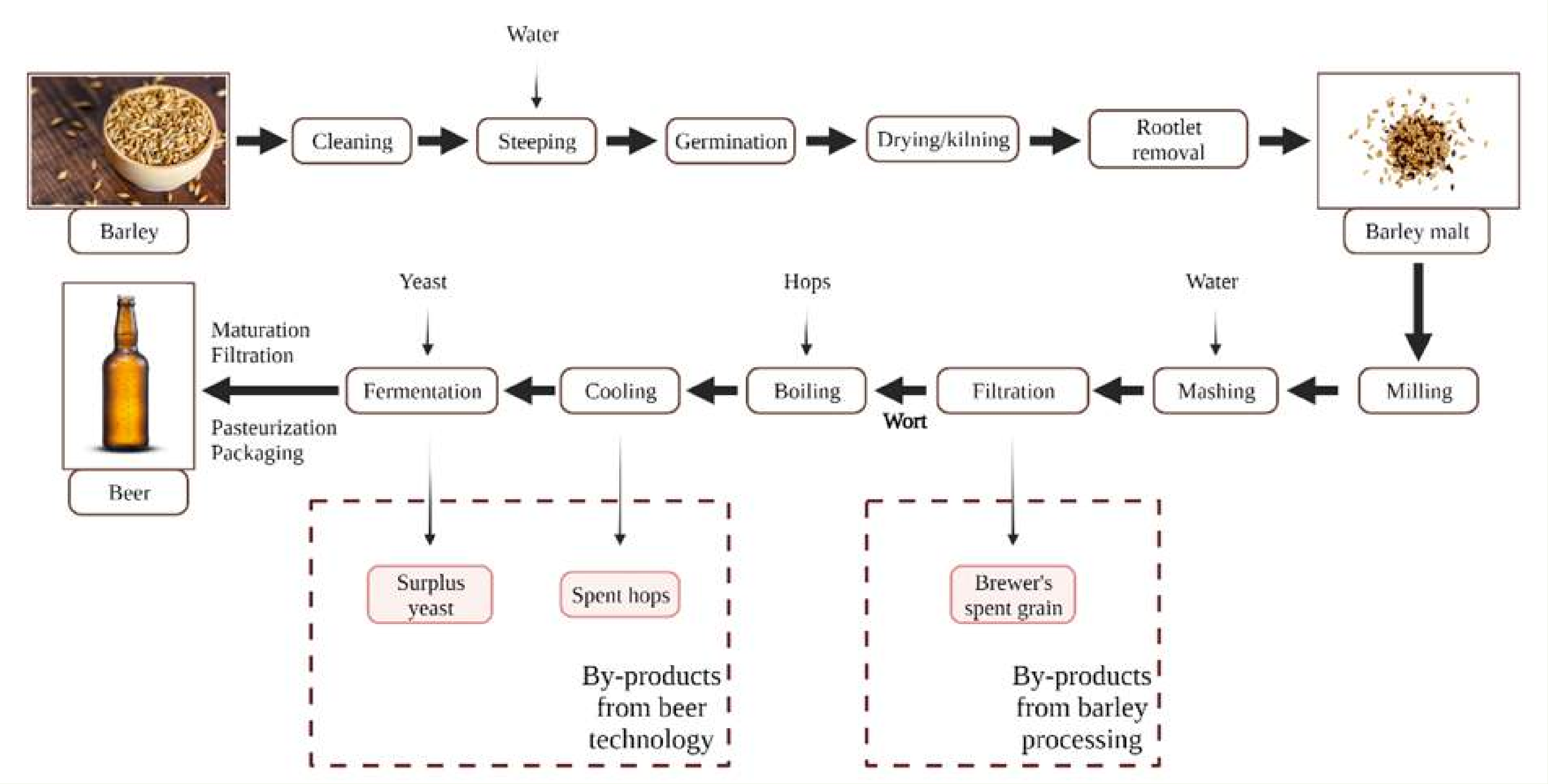
https://doi.org/10.1016/B978-0-08-102162-0.00002-2

Rice by-products - valorization



Zhang, W. et al., 2023 https://doi.org/10.3389/fchem.2023.1225073

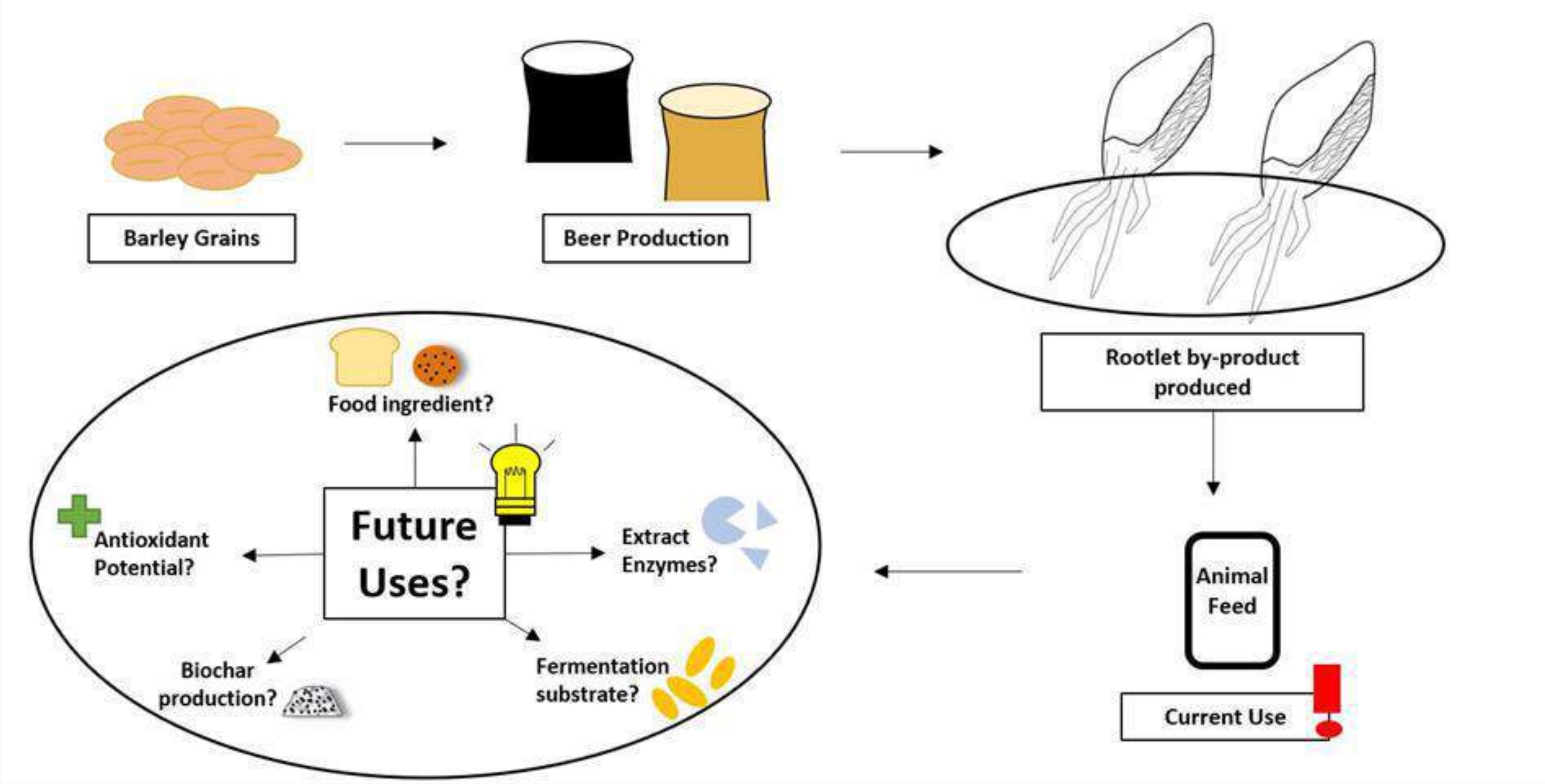
By-products after barley processing



Types of by-products resulted after barley processing (Farcas, A. et al., 2021)

https://doi.org/10.3390/nu13113934

Barley grain by-products - valorization

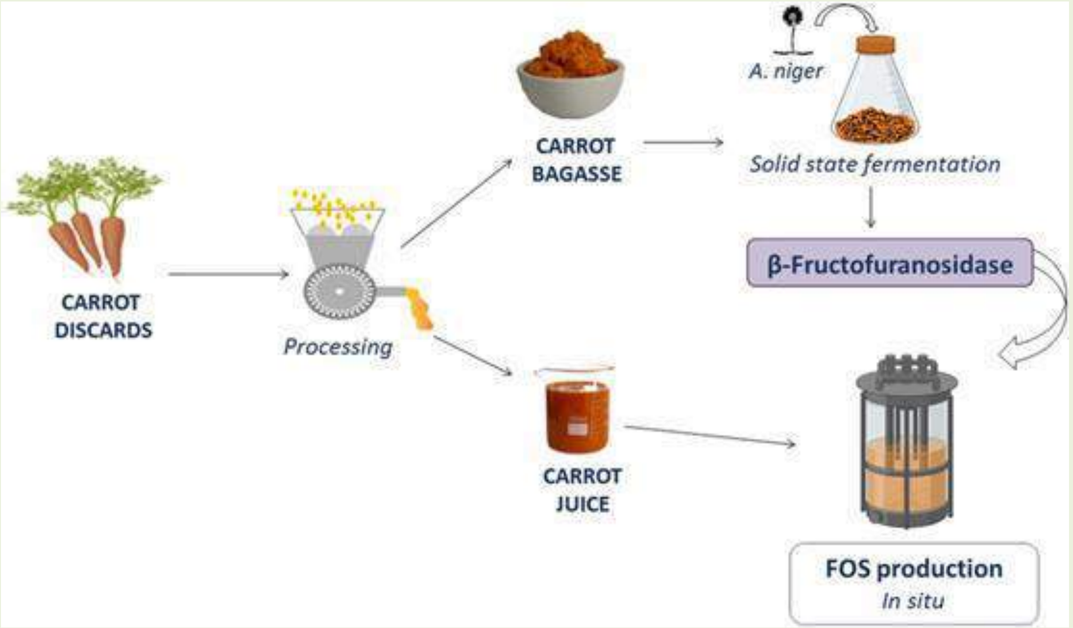


Neylon, E. et al., 2020

https://doi.org/10.3390/fermentation6040117

Fruit & Vegetable Processing

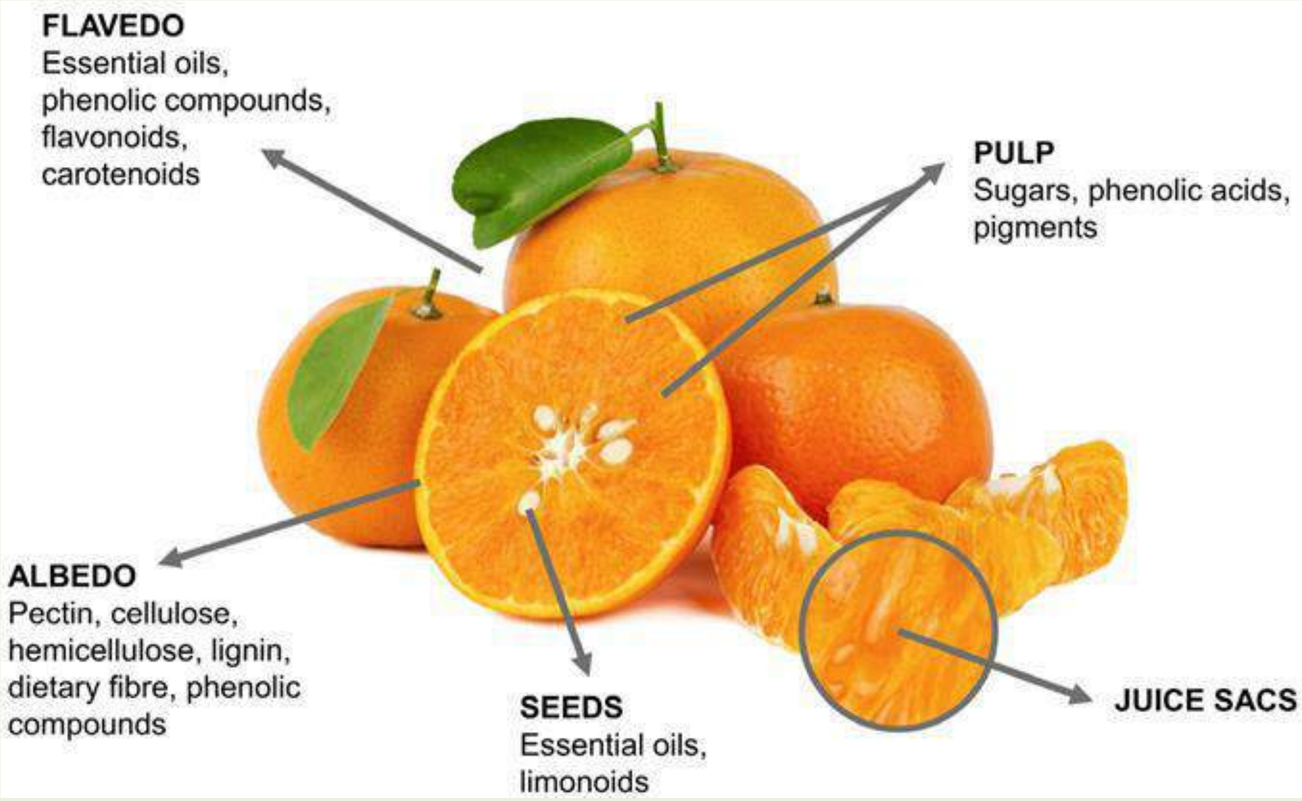
- Main byproducts: Peels, pulp, seeds, stems.
- Storage conditions: Cold storage for perishable byproducts, drying for long-term preservation, controlled humidity
- Regulatory challenges: Waste management regulations, composting and biofuel guidelines, traceability standards.



Guerra et al, 2023

https://doi.org/10.1016/j.fbp.2023.01.011

By-products on the Citrus Processing



By-products Based on Citrus Processing

Solid residues

1 → 2 → 3

Pulp, peel, seeds, and albedo (the white part of the peel).

Origin: Mainly generated after **juice extraction** and during **peeling** and segmenting processes.

Potential uses: Source of **dietary fiber, pectin, essential oils, biofuels, flour for animal feed, and composting.**

Liquid residues

Washing wastewater, pressing waters, and juice serum.

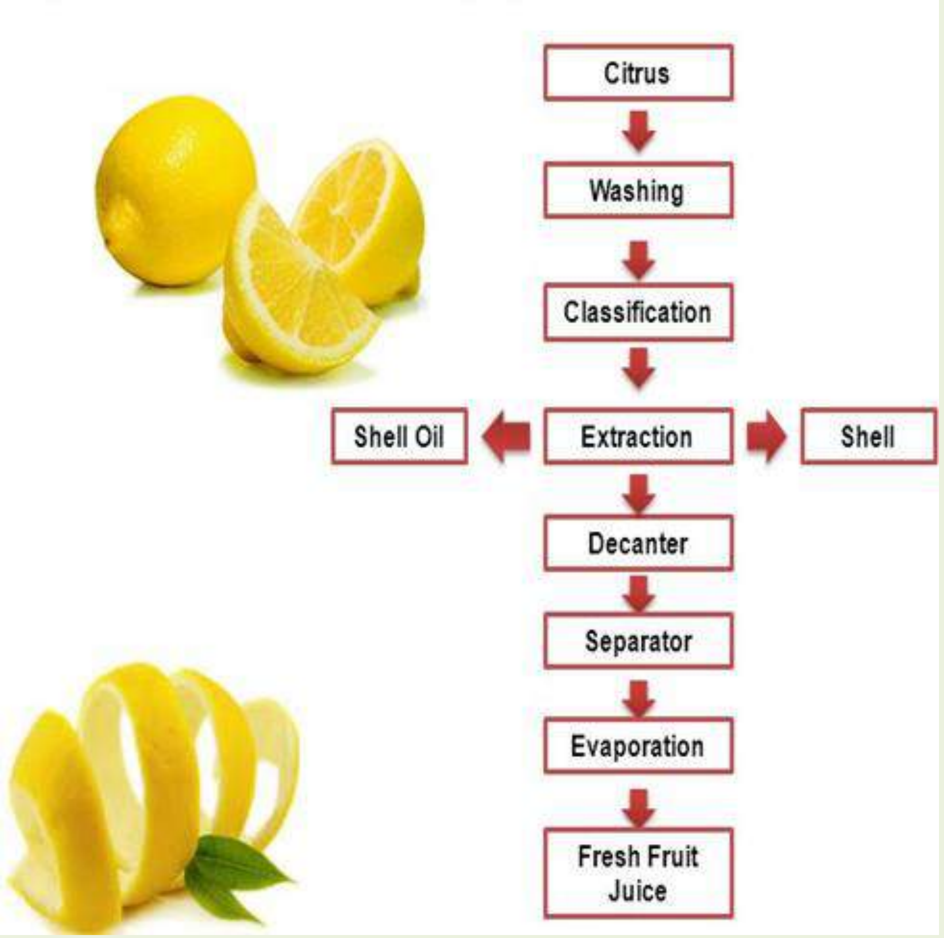
Origin:

- Derived from **juice production, essential oil extraction**, and **solvent-based extraction processes.**

Potential uses:

- Recovery of **phenolic compounds, antioxidant extraction, fermentation for biogas** or **bioethanol production,** and **wastewater treatment.**

Juice Extraction Process



Washing and Sorting:

Citrus fruits are washed to remove dirt, pesticides, and contaminants.

Sorting is done to eliminate damaged or unripe fruits.

Peeling and Extraction:

Fruits are either pressed (for oranges, grapefruits) or mechanically peeled (for lemons, limes).

Juice is extracted through pressing or centrifugal methods.

This step generates **pulp and peel residues**.

Separation and Filtration:

The extracted juice is filtered to remove excess pulp.

The remaining **pulp contains fibers, sugars, and bioactive compounds.**

Pulp Composition

Water (85-90%). Gives it a soft texture and contributes to its perishable nature.

Sugars (glucose, fructose, sucrose, ~5-10%). Provide natural sweetness.

Fiber (soluble and insoluble, ~5-8%). Important for gut health and prebiotic properties.

Bioactive compounds:

Flavonoids (hesperidin, naringin). Antioxidant and anti-inflammatory properties.

Vitamins (Vitamin C, B-complex). Essential for immune and metabolic functions.

Peel Composition

Cellulose and Hemicellulose (40-50%). Structural components, useful for fiber production.

Pectin (20-30%). Used as a gelling agent in food and pharmaceutical industries.

Essential Oils (~2-5%). *Contain limonene, used in cosmetics, perfumes, and cleaning products.*

Phenolic compounds. Powerful antioxidants with health benefits.

POMACE

Origin: Pressing and Filtration

Bagasse is the fibrous residue left after juice extraction.

It consists mainly of **cellulose, hemicellulose, and lignin,** making it a valuable source of dietary fiber.

Potential Uses:

Animal feed: Due to its fiber and carbohydrate content.
Biofuels: Used to produce bioethanol and biogas.
Composting and soil enrichment: Provides organic matter to agricultural soils.
Paper and bioplastic production: Its fiber content makes it a raw material for biodegradable packaging.

SEEDS

Citrus seeds contain 20-40% oil, 5-10% protein (essential amino acids), flavonoids and tocopherols.

Extraction of Citrus Seed Oil: cold pressing, Solvent extraction or Supercritical CO_2 extraction

Industrial Applications:

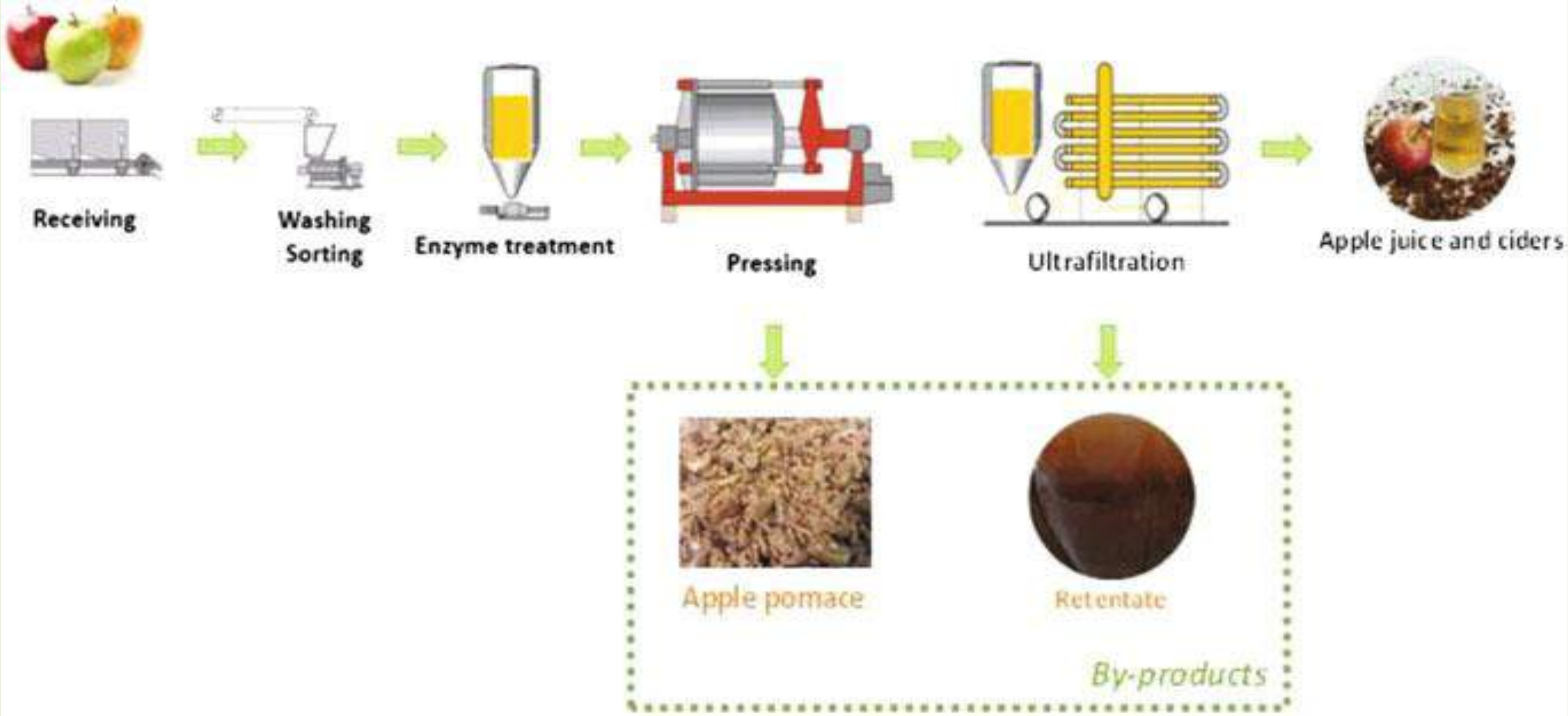
Cosmetics: Citrus seed oil is used in skincare products for its antioxidant and moisturizing effects.

Nutraceuticals: Rich in omega-3 and omega-6 fatty acids, beneficial for heart health.

Food industry: Used as a cooking oil or an ingredient in functional foods.

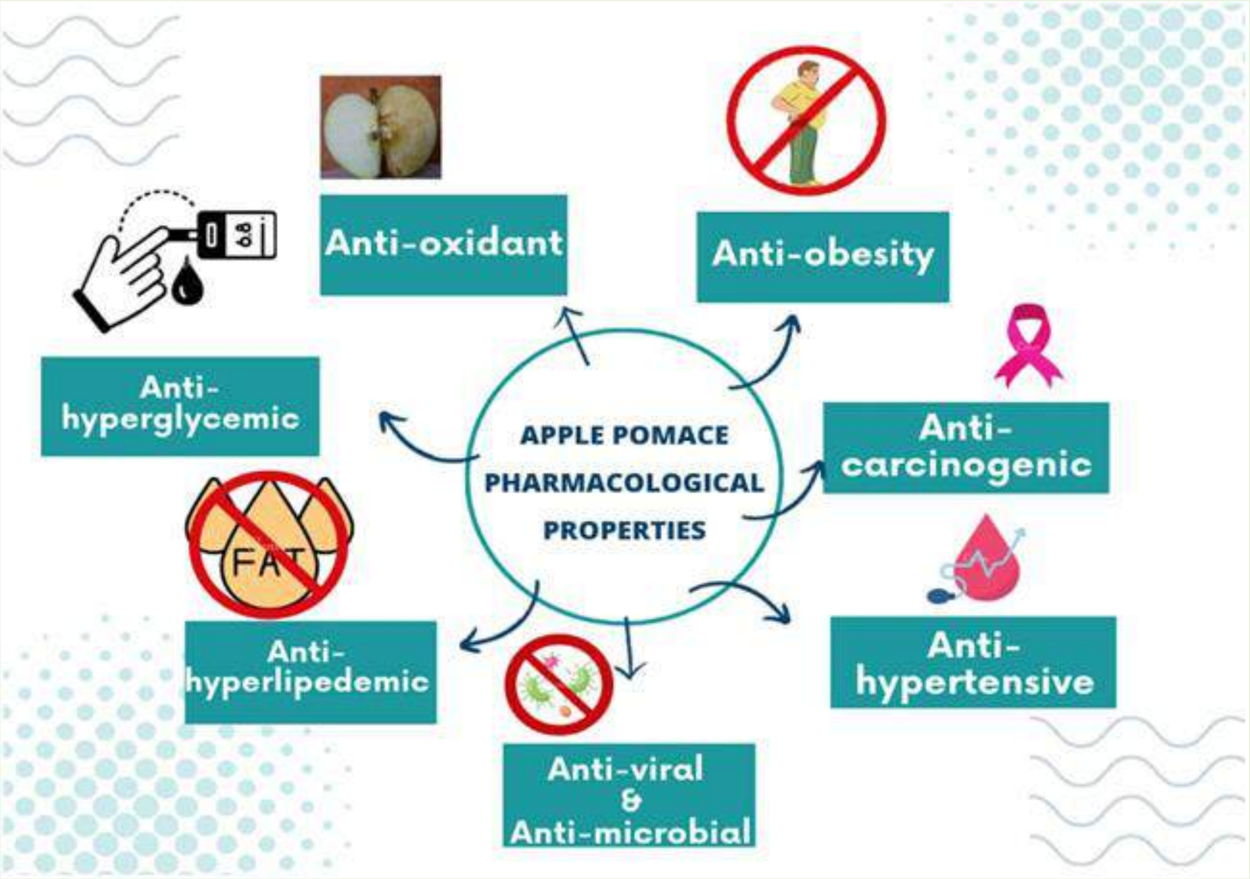
By-products Based on the Apple Processing

- Despite their importance in terms of consumption, the recovery of bioproducts remains modest.



Schematic representation of apple juice extraction and processing steps and their main by-products, Fernandez et al., 2024

Apple by-products



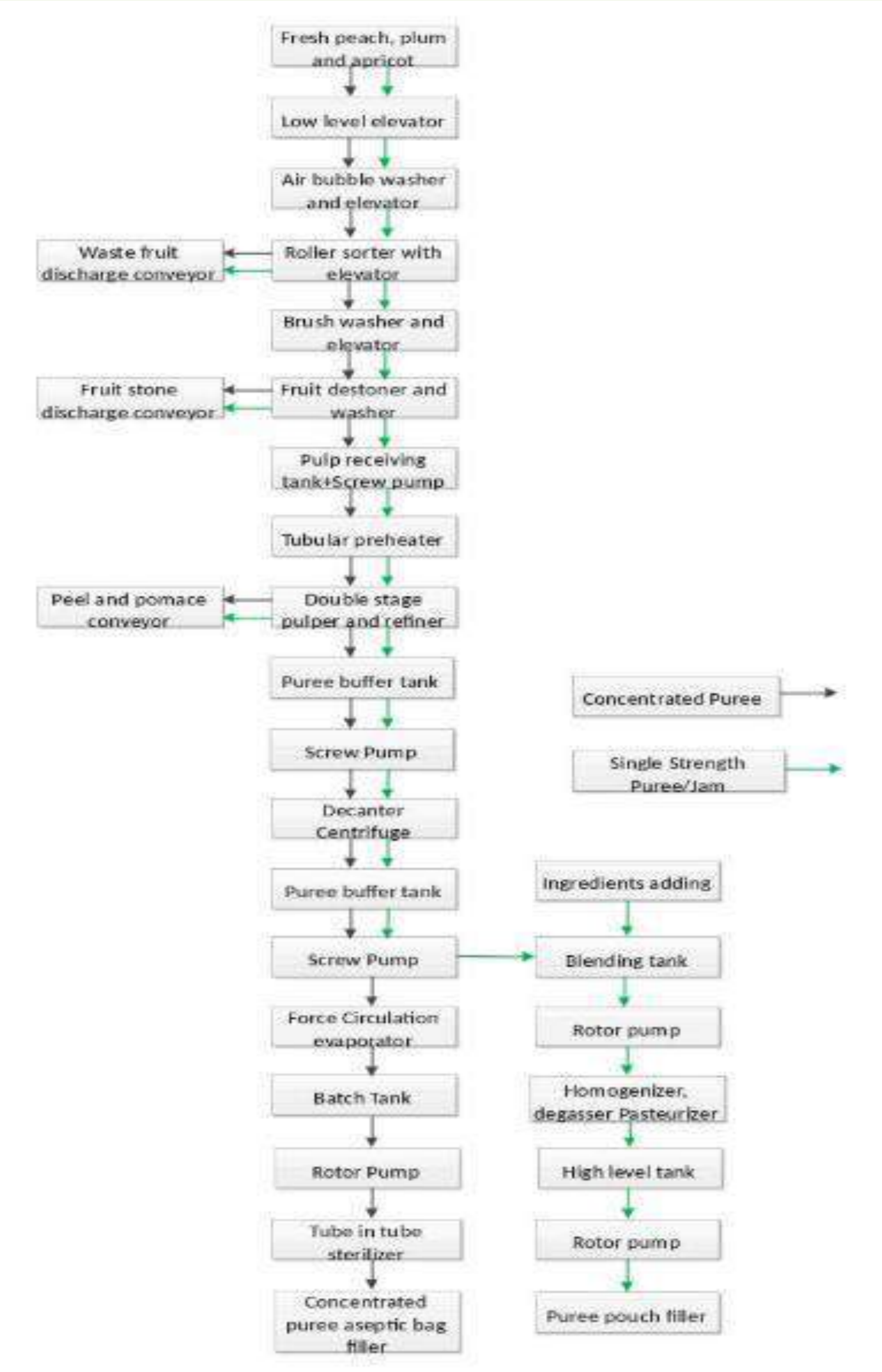
Kauser, et al., 2024.

https://doi.org/10.1016/j.focha.2023.100598

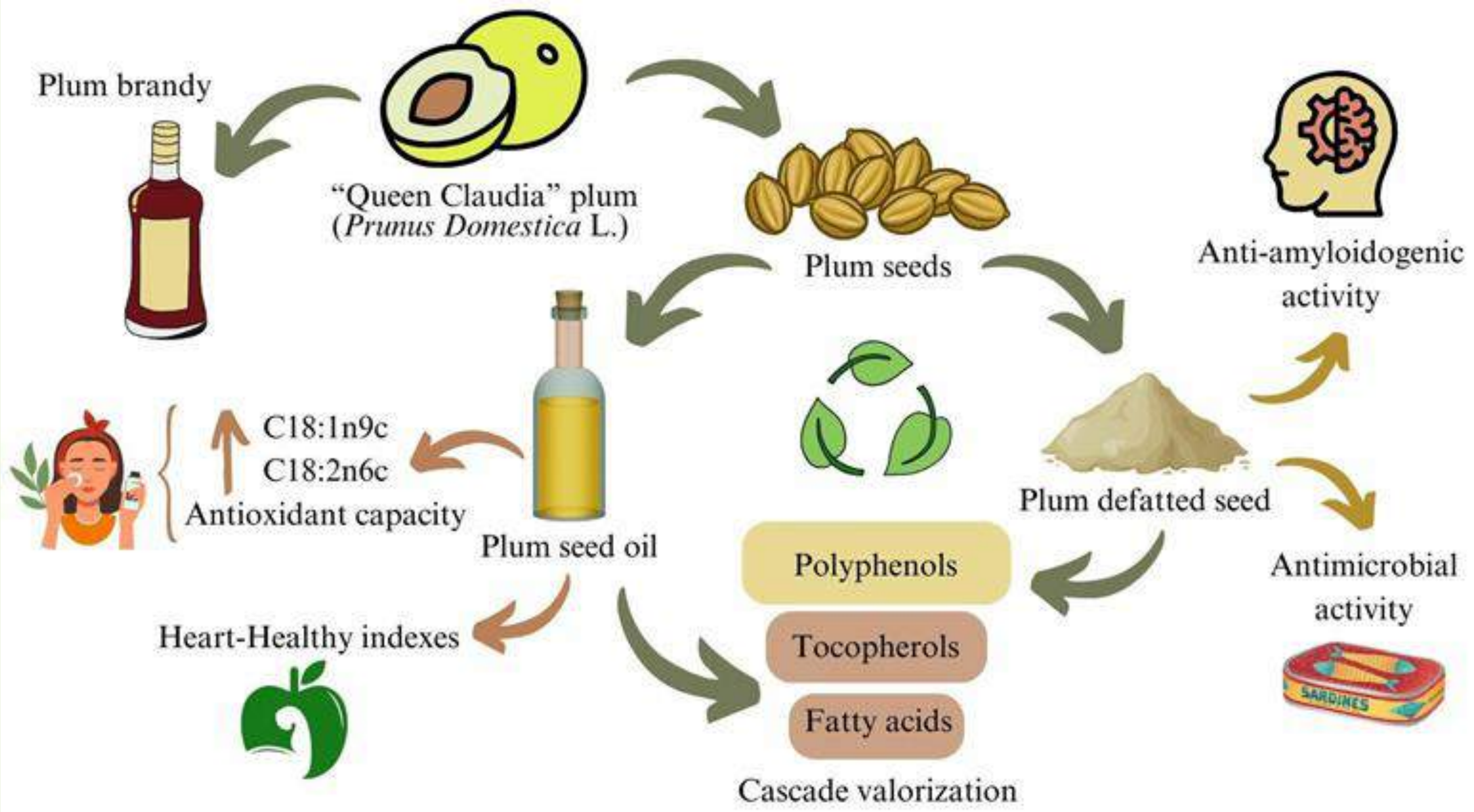
Plum by-products

During industrial processing of plums, **tones of pomaces (press cake residues from the juice industry**), **seeds (stones),** and **brandy distillery wastes** (spent fruit pulp/peels) are produced and discarded.

Also during processing into dry fruits, jams and juices, tones of fruit pits are generated (**agro-industrial by-products**).



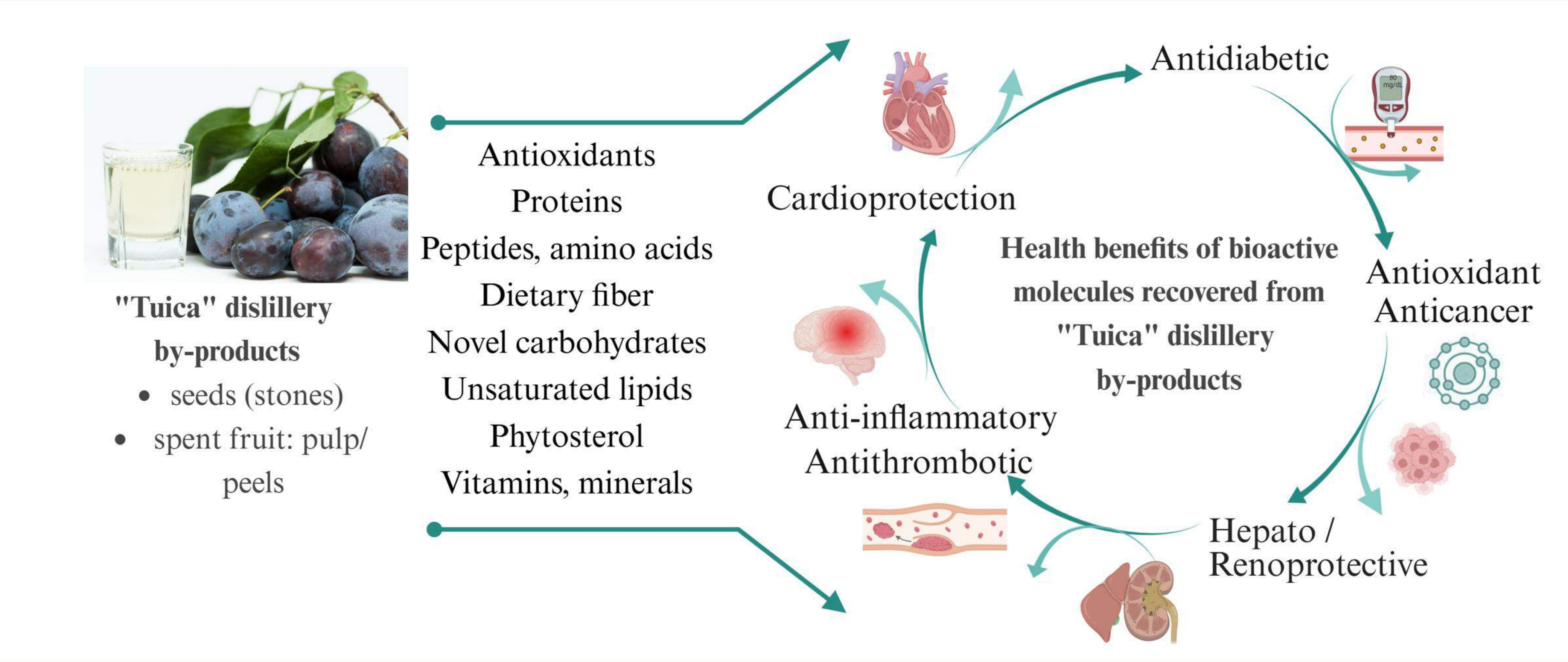
Plum seeds by-products



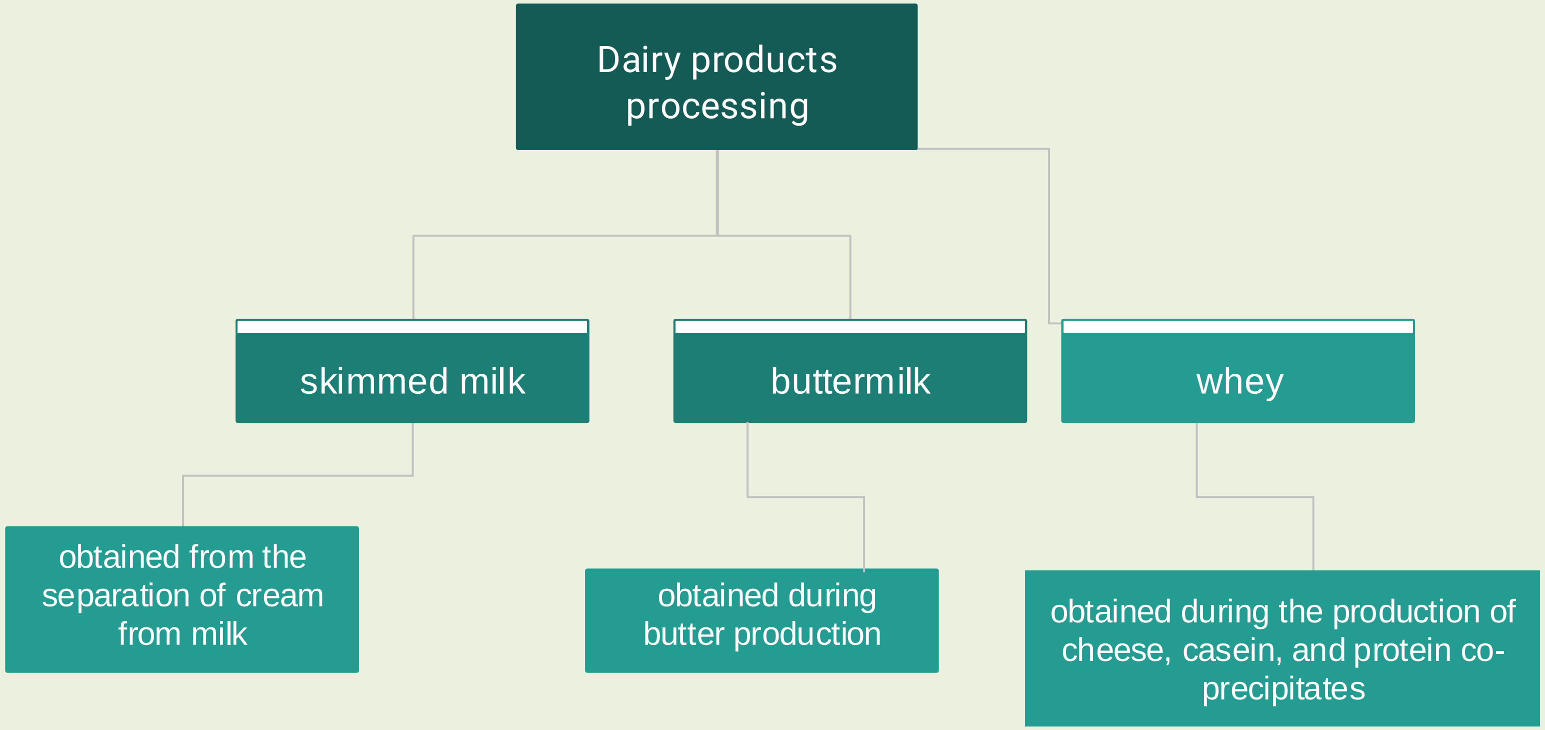
Rodríguez-Blázquez, S et al, 2024.

https://doi.org/10.3390/ijms25021236

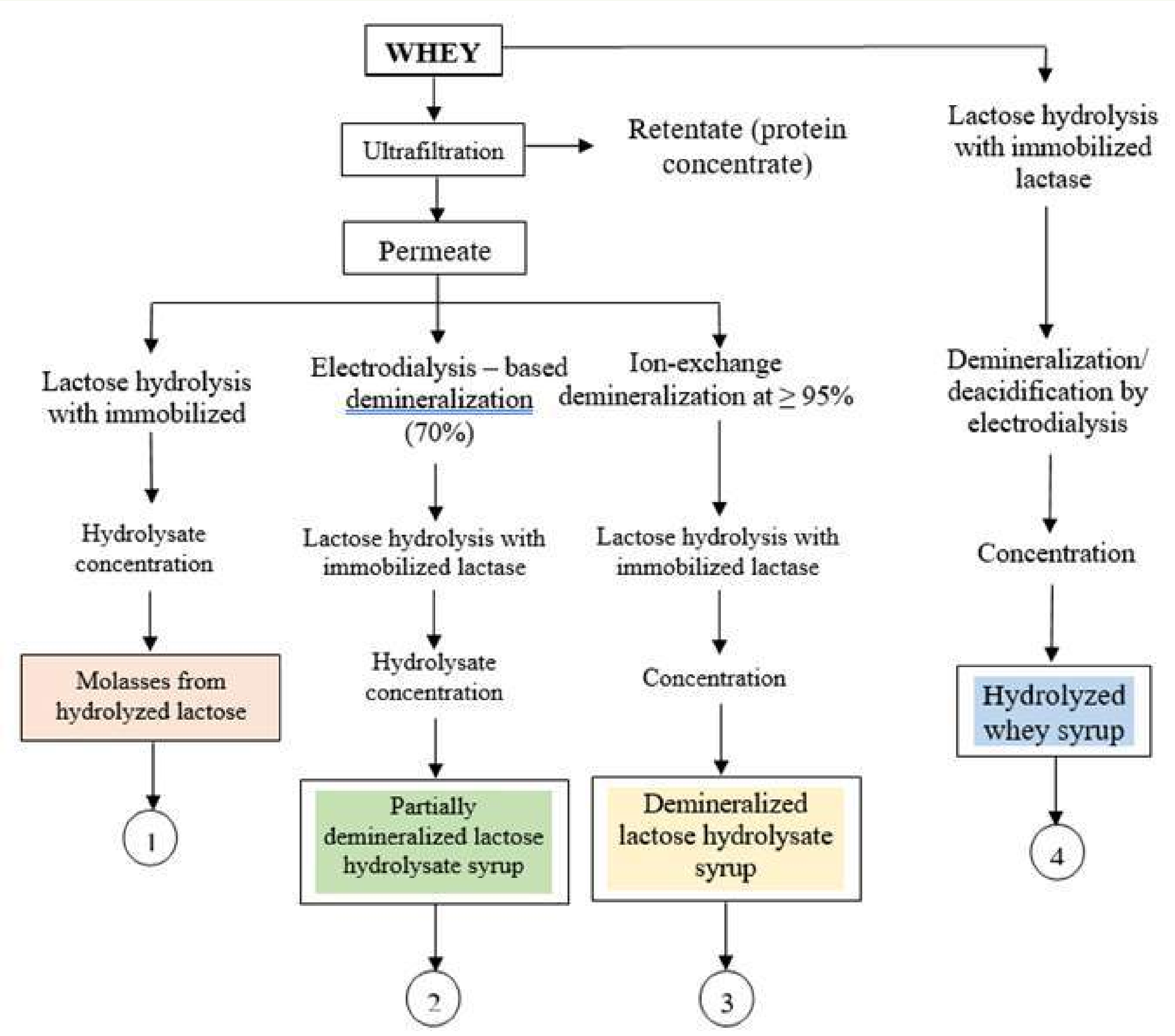
“Tuica” distillery by-products – Bioactive compounds



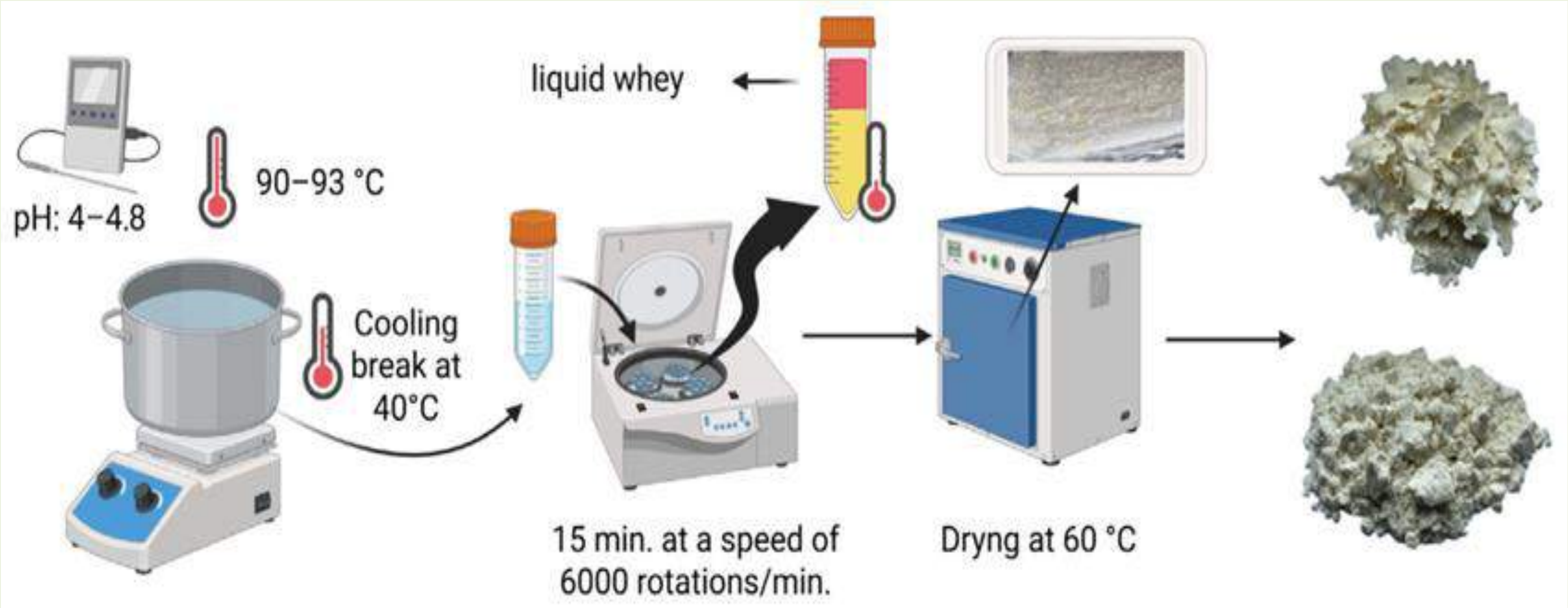
Diary by-products



Technological flowchart for whey and permeate processing



WHEY PROCESSING INTO POWDER



WHEY PROPERTIES

*α-lactalbumin

*β-lactoglobulin

*Immunoglobulins

High-quality complete protein (all essential amino acids).

Typical composition:

*0.6–0.8% proteins;

*4.5–5% lactose

*0.5–0.6% minerals

*Vitamins

(B2 and B12),

*Minerals (calcium and phosphorus)

Functional Properties
*Excellent **solubility**

***Emulsifying** capacity

***Foaming** capacity

***Antioxidant** activity

***Antimicrobial** activity

Characteristics of whey obtained from cow's milk processing

The main **chemical characteristics** of whey

Constituents (%)	Sweet whey	Acid whey
Water	93 - 94	94 – 95
Dry matter	6 - 7	5 – 6
Lipids	0 – 0,3	0 – 0,1
Proteins	0,8 – 0,1	0,8 – 0,1
Lactose	4,5 – 4,9	3,8 – 4,2
Mineral substances	0,5 – 0,7	0,7 – 0,8
Lactic acid	traces	0,8

Physico-chemical characteristics

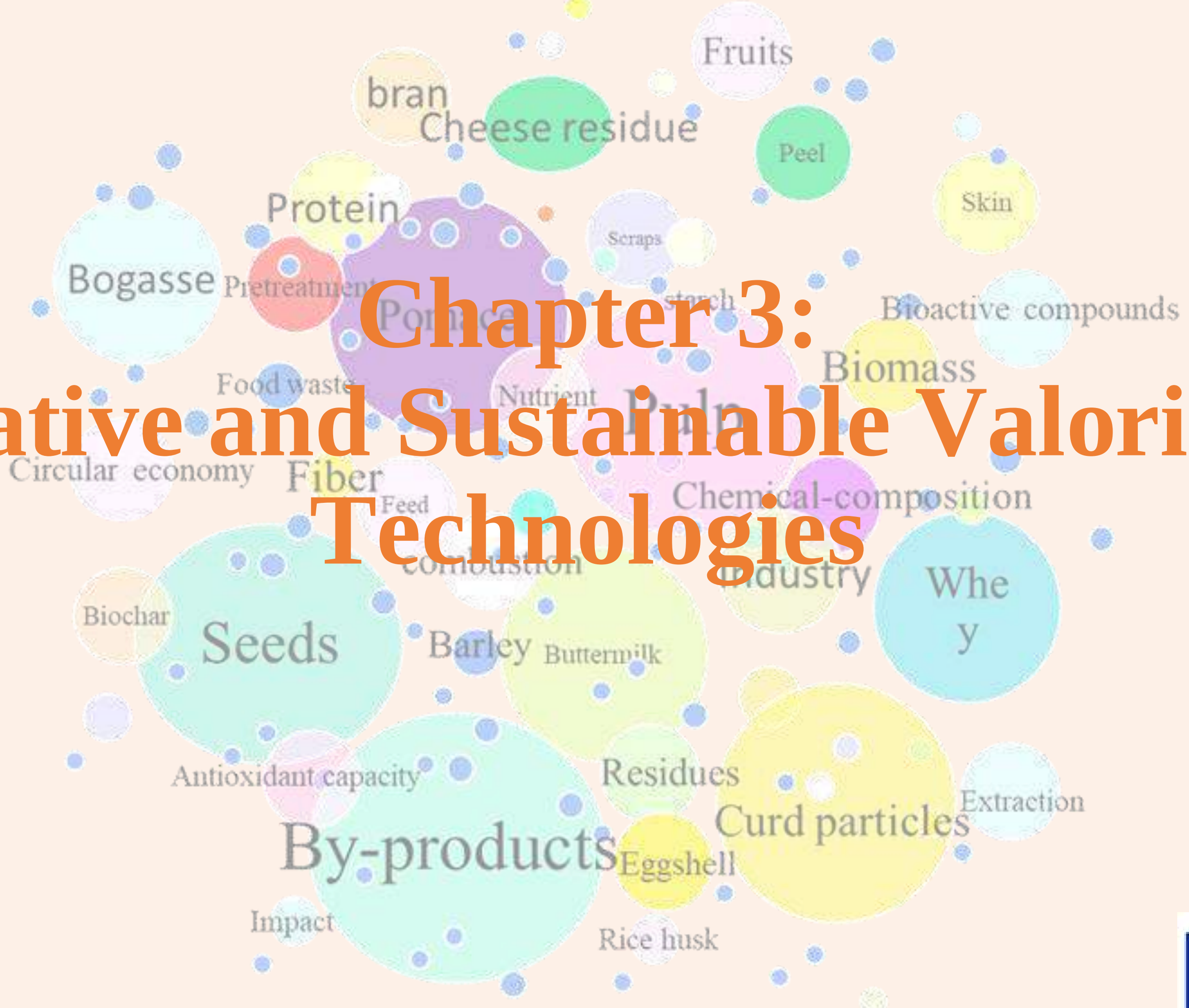
- **Density (ρ):** 1.023 g/cm³
- **Acidity:** 100 °T
- **Dry matter:** minimum 6.3%

Microbiological characteristics

Whey is a favorable medium for the development of various types of microorganisms. Depending on the origin of the whey, the microorganisms present can be very diverse. The most frequently encountered are: molds, yeasts, lactic acid bacteria, coliform bacteria, and butyric bacteria.

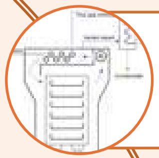
Project code: 2024-1-RO01-KA220-HED-000246776

Chapter 3:
Innovative and Sustainable Valorization Technologies



Co-funded by the European Union

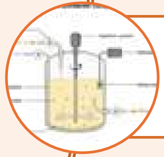
Methodologies for valorizing by-products



1. Drying: This operation is a well-known alternative for obtaining dried products with a long shelf life, significantly reducing losses during harvest periods and lowering the costs of treating the resulting waste. The types of drying used are: convention al oven drying, convective oven drying with hot air, vacuum oven drying, conditioning by freeze-drying, spray driyng.

2. Encapsulation: is a process in which a core material is packed into food-grade wall material. Microencapsulation and encapsulation technologies refer to the techniques used to entrap solid, liquid, or gaseous substances within a continuous coating matrix, forming capsules that range in size from the micrometer to millimeter scale.

3. Extraction:

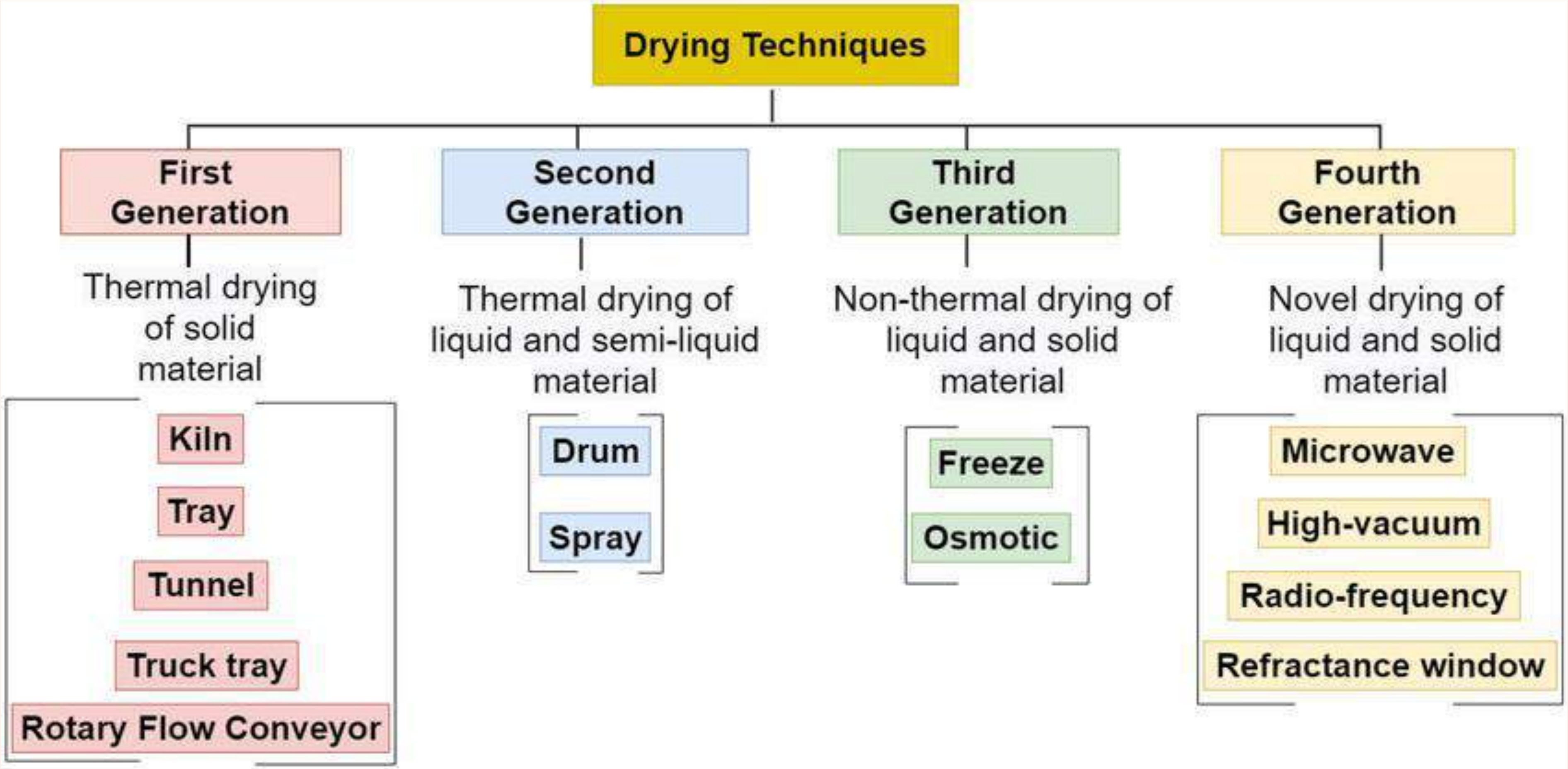


4. Fermentation: is an engineering term used to describe the processes that utilize a chemical change induced by microorganisms, in particular bacteria, yeasts or molds, that produces a specific product, usually including aeration potentiating microorganism proliferation.

5. Extrusion

***6. Food packaging*:** Agro-industrial waste is as an alternative for developing biodegradable, renewable, and sustainable packaging materials to address the growing demand for environmentally friendly solutions in the food sector.

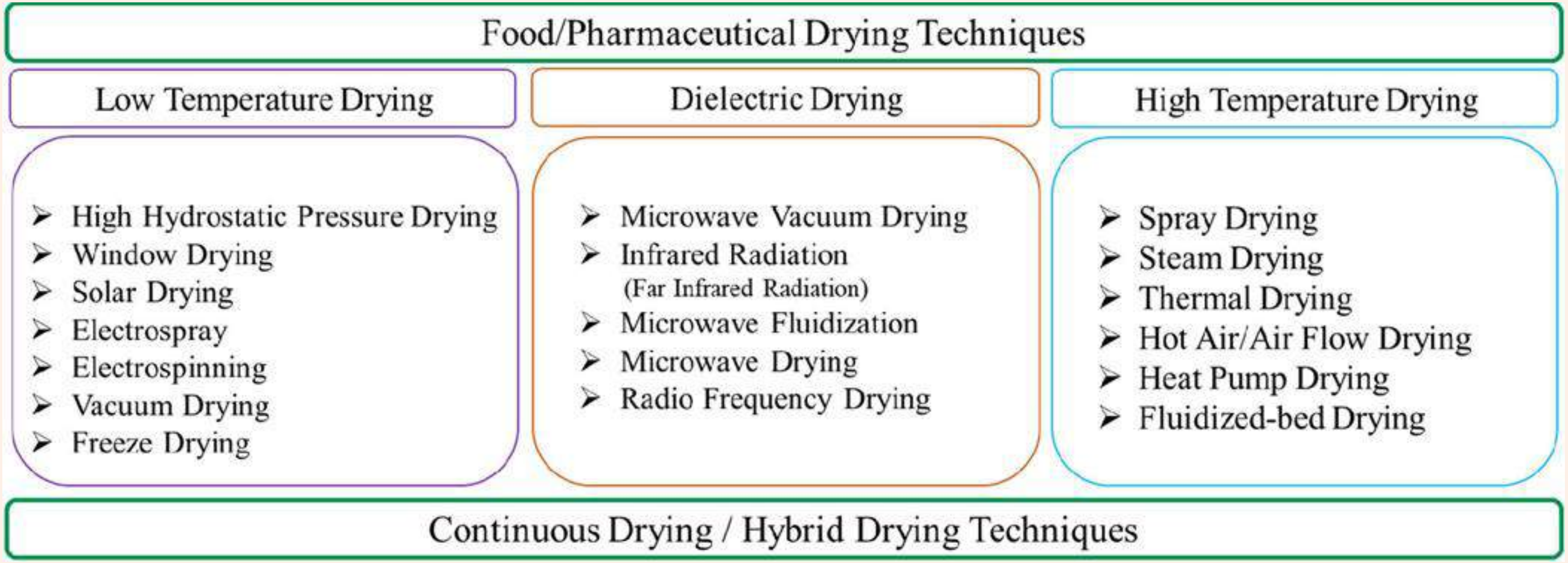
1. DRYING techniques: Evolution



Ruchika Zalpouri et al., 2021

DOI:10.1007/s12393-022-09313-3

Drying techniques categorization regarding the type of heating system: **low temperature, high temperature, and dielectric-based drying mechanisms**



Fathi et al., 2021

DOI:10.1111/1541-4337.12898

Conventional methods of drying

Drum drying

- ✓ Steam is applied to increase the internal surface temperature of the drum.
- ✓The material adheres to the drums as it is sprayed on and dries within.
- ✓The degree of separation between the drums, steam pressure, and drum rate of rotation can be modified to achieve the required output.

Cabinet drying

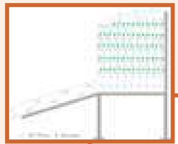
- ✓A product is spread out on trays or shelves and subjected to controlled heat and air flow to remove moisture.
- ✓Limits: Batch processing, uneven drying, quality loss, higher space requirement for equipment installation, limited application.

Hot air oven drying

Used for producing powders, dried fruits to be used in food manufacturing, baking, or as ingredients in various products.

✓It is believed to be successful process in retaining the quality and flavour while efficiently remove moisture.

Limitations relatively slow, especially for the materials with high moisture content, it takes considerable amount of time. The process can be energy intensive for large scale drying processes and can lead to highe



Solar drying

- ✓Used for products such as vegetables, fruits, tobacco, tea, coffee, fruit, nuts, cereals, and rice, needs a low temperature energy and has played a vital role in human life and technology since ancient times.
- ✓Solar drying does not just depend on solar energy. It can also be applied in combination with other energy sources such as fuel.

Besides, solar drying provides higher drying efficiency, uniformity, energy conservation, and less spac

Richter Reis et al., 2022

https://doi.org/10.1016/j.foodcont.2022.109254

Conventional methods of drying

Vacuum drying

✓A valuable method for producing high-quality dried concentrates and powder, while preserving the original flavour and nutritional content.

✓Vacuum drying work at a low temperature compared to most of the drying methods and helps in preservation of natural flavour, color, and nutritional content.

✓Vacuum drying takes place at reduced pressure conditions that result in lowering of boiling point of the water and facilitates the evaporation of water at a lower temperature, preventing heat damage to the produced powder.

Spray drying

✓Is a most common and versatile method used for drying liquid products.

✓Advantages-produce quality, shelf stability with preserved flavour and color

✓The main characteristics of spray drying includes its rapid drying capabilities that make it suitable for larger scale production, particle size control of dried powder based on specific requirements, short exposer to heat, longer shelf life and its versatility to various products including instant beverages, flavouring and ingredients in the food industry

✓Stages: (1) atomization of input feed; (2) droplets mix (spraying gas, air/neutral nitrogen) and free/coated moisture; (3) spraying the mixture, air,and droplet to nozzle; and (4) product recovery

Freeze drying

process used to remove moisture, while preserving their structure, flavour and nutritional and bioactive content by the process of sublimation.

✓**This method is convenience for industrial application**.

✓**Advantages**-quality preservation, higher shelf stability, better rehydration capacity, low bulk density and less chances of microbial contaminations.

- **Limitation:** equipment and processing cost, time, energy consumption, equipment complexity etc. are some of the for the use of freeze drying at small industrial level
- It is a **three-step process**, including freezing (between −70 and −80∘C such that all components have a crystalline ice structure), primary (removes by sublimation the water from the solution), and secondary drying (removes the remaining water, bound in a crystalline hydrate, or in an amorphous solid).

Fluidized bed drying

fluidization. It runs by continuous feeding of wet particulate contacting with a warm surface or hot air blown through to maintain the material in a fluidized state. Fluidized bed drying is used in the food, pharmaceutical, and chemical industries for drying humid powders and solid capsules/particles.

✓The fluid-bed dryer provides efficient heat and mass transfer, short drying time, high drying rate, high efficiency, and uniform condensation.

✓The operation units require high thermal power, high fluidizing gas flow rate, and high solids transport rate to and from the dryer.

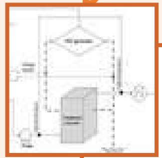
Richter Reis et al., 2022

https://doi.org/10.1016/j.foodcont.2022.109254

Novel methods of drying and advantages

Spray freeze drying

- ✓Is an innovative and advanced drying method used to preserve the characteristics and quality of various materials including powders, pharmaceuticals, and biomaterials.
- ✓This process combines the elements of spray drying and freeze drying to achieve rapid drying while maintaining the integrity of the dried materials.
- ✓Advantages over conventional methods of drying are rapid freezing of spray dried powder, minimising heat exposure, higher rehydration ratio, low bulk density and light weight making suitable for storage and transportation along with reducing risk of microbial contaminations and any oxidative damage to preserve its color, texture, nutritional and bioactive components



Pulse electric field (PEF) drying

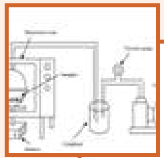
- ✓Involves the application of high-voltage pulses to the food placed between two electrodes. PEF drying is considered an innovative drying techniques which includes the combination of PEF technology with drying process. The electric pulse cause the permeabilization of the cell membrane and allow the intercellular water to move out freely which is than dried mainly using spray or freeze drying.
- ✓Advantages: helps in retention of flavour, color, nutritional and bioactive components by minimising the heat exposure during drying process. It accelerates the drying process by increasing the mobility of intercellular water, which can significantly reduce drying time.

Microwave drying

is novel techniques of drying that uses the microwave energy to remove moisture from food matrices while preserving its quality and characteristics . When the food is exposed to a microwave, the electromagnetic waves penetrate it and produce heat resulting in vaporisation of water.

- ✓Utilizes unconventional electric equipment with a frequency in the range 108–1010 Hz. The MW heating mechanism, also known as bulk heating, generates heat in the whole material by converting energy to heat when MWfrequency interacts with the material.

Advantages: it's rapid and efficient drying, making it suitable for higher speed production. Microwaves provide uniform



Microwave vacuum drying

- ✓Microwave with radiofrequency between 300 and 30,000 MHz is used in the MW vacuum drying techniques as a heat source instead of conventional heating systems.
- ✓MW provides uniform energy throughout the material and solvent due to the vaporizing moisture in the inner layer of the material's pores. Besides, MW vacuum drying could be almost 50% faster and more efficient due to combined vacuum drying (high-pressure vacuum) to help remove the moisture.
- ✓Advantages: provides products with homogeneous, high-quality texture as well as maintains the material's chemical composition compared to conventional vacuum drying. VMW has been more recently used in food industries for the functions of heating, extracting, drying, and sterilizing.

Richter Reis et al., 2022

https://doi.org/10.1016/j.foodcont.2022.109254

Novel methods of drying and advantages

Infrared drying

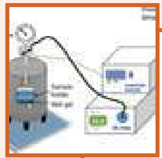
- ✓IR wavelengths, around 1–6 μm, interact with the internal layer of the product, promoting the temperature increase and consequently moisture evaporation
- ✓Far infrared radiation (FIR), due to its capacity to allow a uniform heating distribution, is being applied as a drying option.
- ✓It must be taken into consideration that FIR drying is faster than the hot air-drying, more expensive and energy-consuming than freeze-drying, and has a higher drying rate compared to conventional drying techniques.

The FIR drying technique is used instead of conventional drying in pharmaceutical and food industries, especially fruit, vegetable, and meat processing, due to less energy cost and higher spee

Conductive hydro-drying

is a novel drying process that transmits heat directly from a heated surface to material. The material retain heat, increasing internal warmth and causing moisture to evaporate.

- ✓CHD drying involves uniformly spreading of the material on a heat-resistant, clear plastic conveyor belt and exposing it to infrared radiation of a specified wavelength. This results in efficient penetration and heating without overheating or harming the product.
- ✓Heating continuously causes water to evaporate, yielding dried powder. CHD powders have key qualities such as quality preservation, energy efficiency, reduced oxidation, customisation, and hygiene.



Supercritical fluid drying

for manufacturing powders. It has multiple applications, including powdered fruit juice for instant beverages, food manufacture, and dietary supplements. CO_2 is employed as a supercritical fluid, exhibiting liquid and gas properties at specified pressures and temperatures. The temperature and pressure are regulated to expand the supercritical fluid, resulting in the precipitation of components and separation of CO_2 from dry powder. CO_2 is naturally non-toxic, making this technique ideal for creating high purity products. Minimal heat exposure reduces oxidation, maintaining the freshness and colour of the powder.

Microwave fluidization

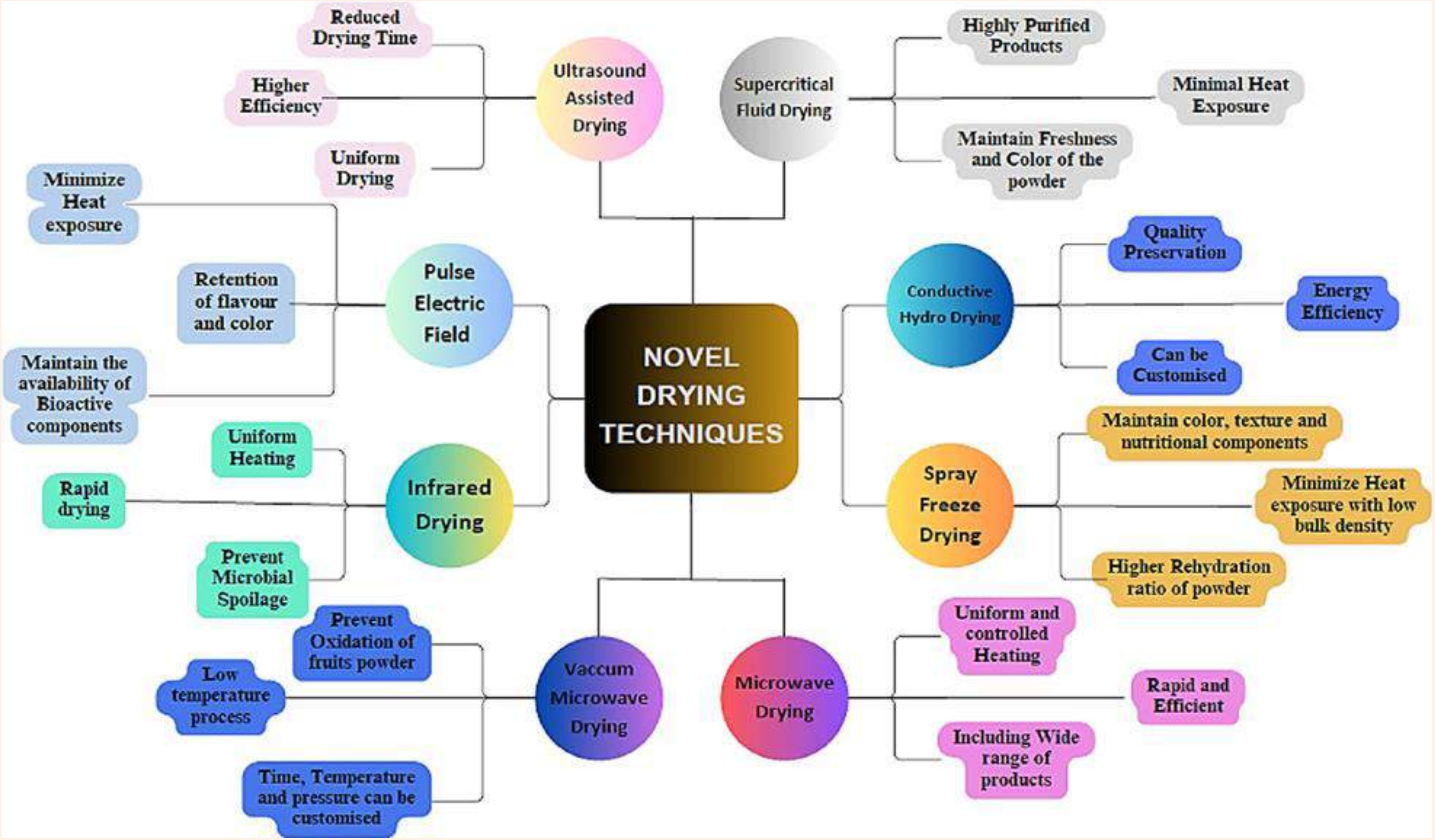
- ✓Uses MW instead of traditional heat generators in fluidized bed dryers. The electromagnetic radiation is the source of energy, resulting in an internal vibration (energy) that heats up the material and induces the internal moisture from inside to outside.
- ✓The drying temperature is similar to hot air drying but passes faster, resulting in faster drying.
- ✓The MW fluidization technology is declared as an effective, safe, and practical technique for drying fresh vegetables and fruits and for improving sample uniformity and drying efficiency.

Microwave hot-air spouted bed-drying, compressed air pulse-spouted MW vacuum drying, and MW mechanical-vibration fluidizat

Richter Reis et al., 2022

https://doi.org/10.1016/j.foodcont.2022.109254

Advantages of using novel drying methods in production of powder

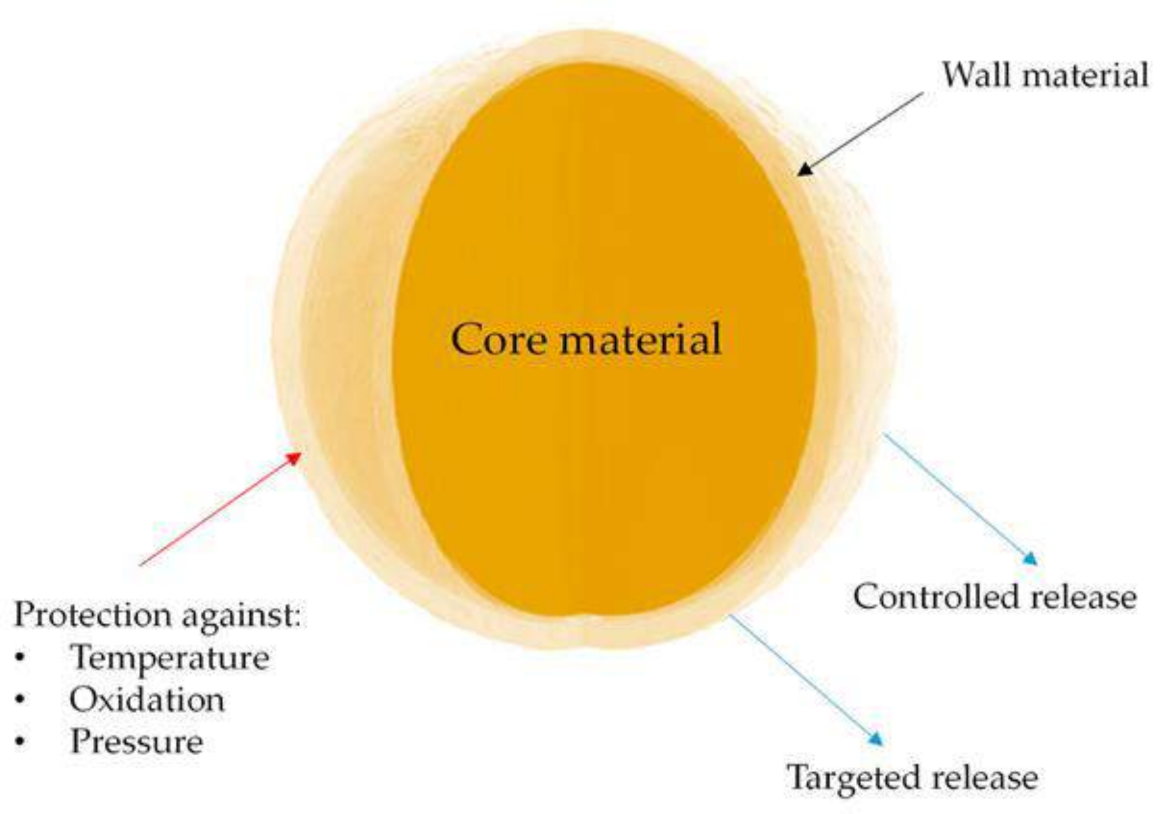


Bhavesh Khatri et al., 2024

https://doi.org/10.1007/s44187-024-00223-3

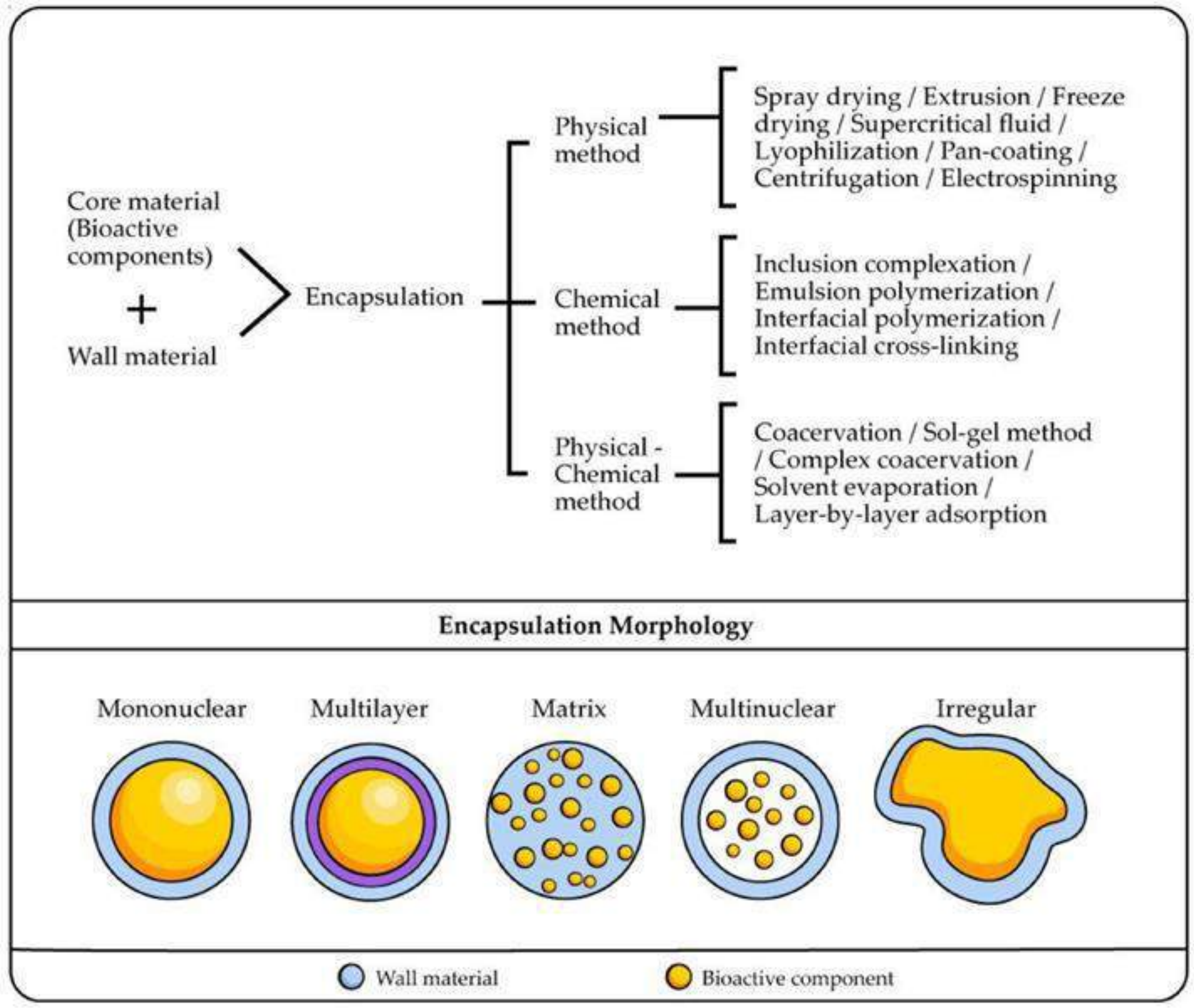
2. ENCAPSULATION for by-products

Basic concept of microencapsulation for bioactive compounds



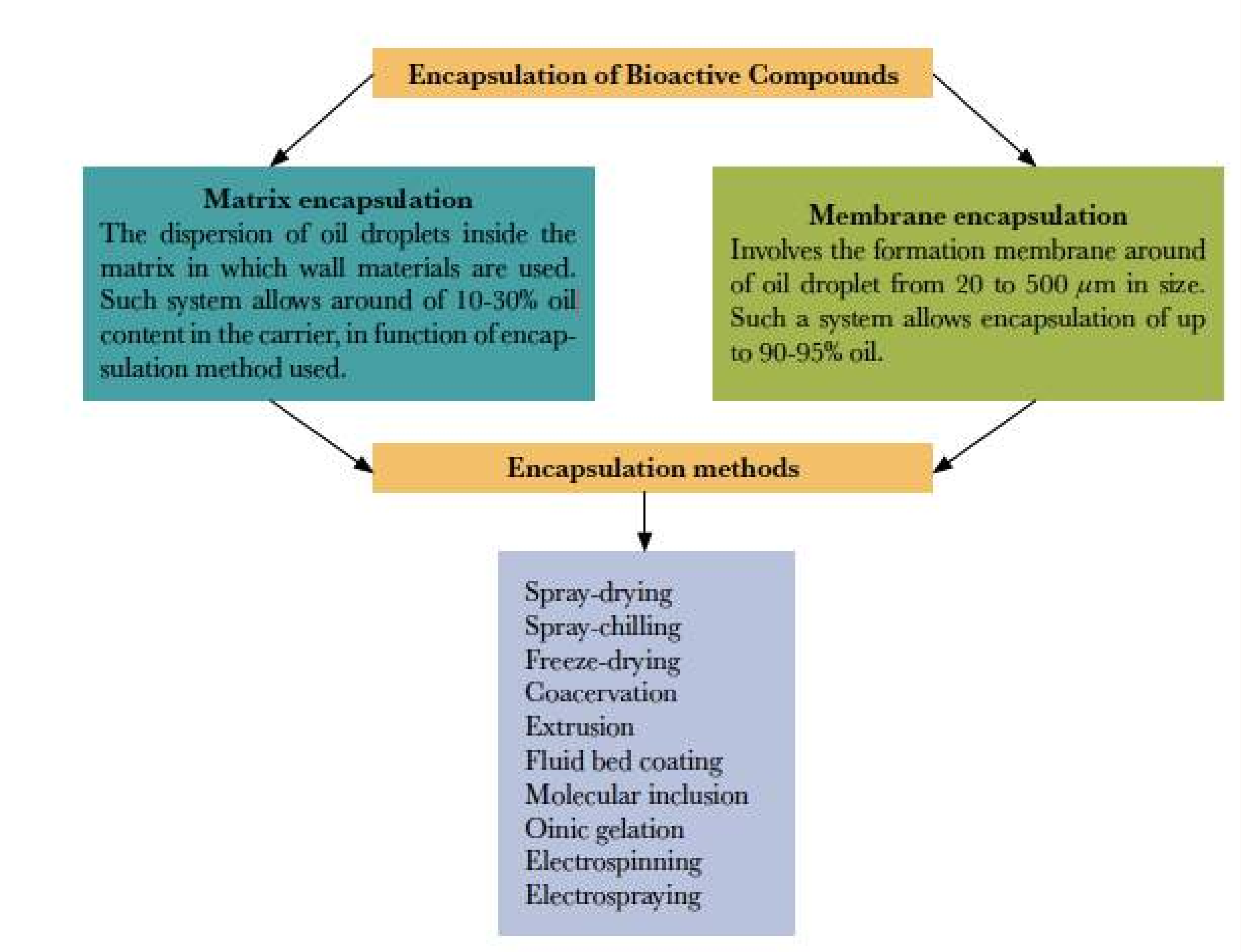
Mehta et al., 2022, https://doi.org/10.3390/app12031424

General classification of encapsulation

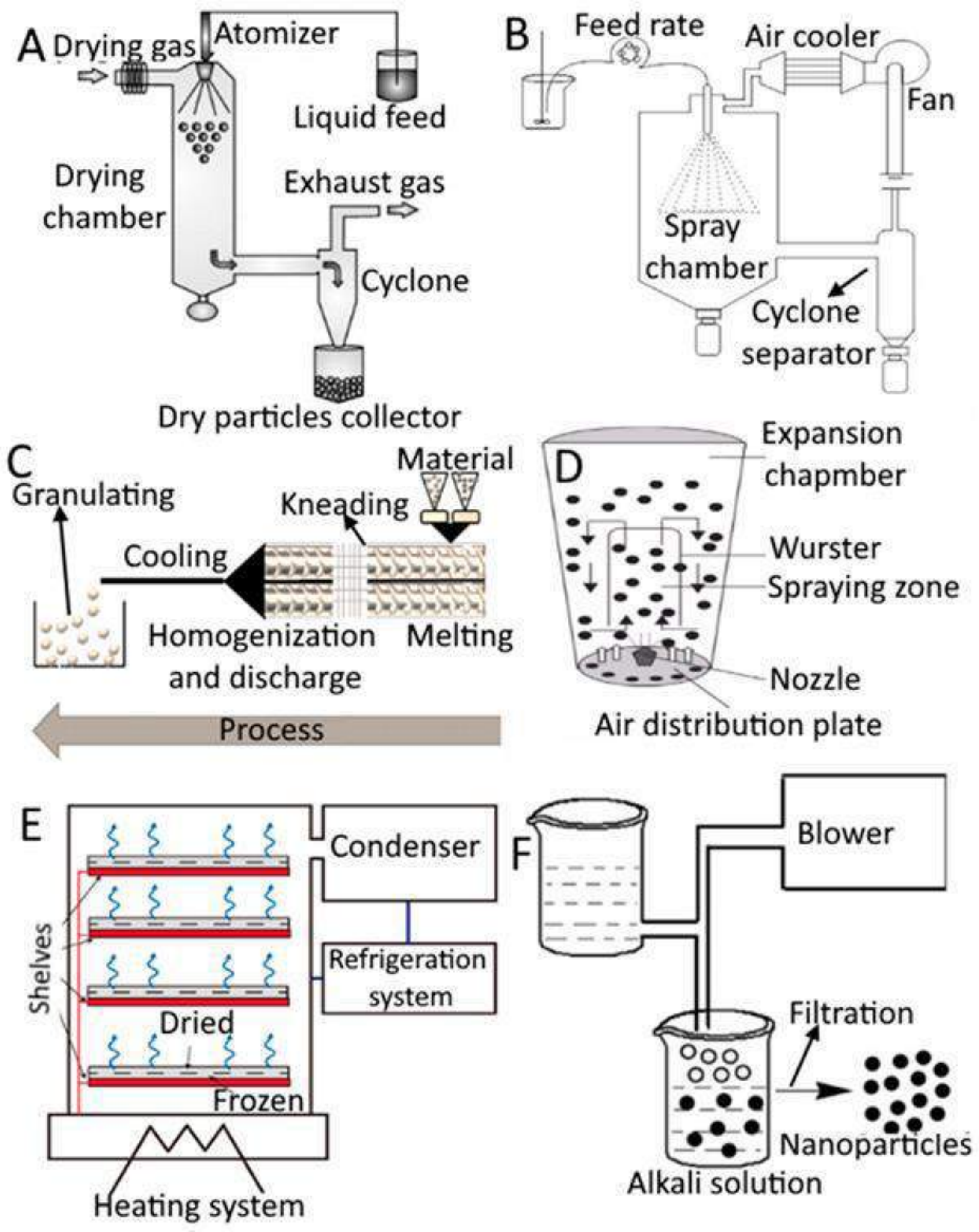


Zabot et al., 2022,
https://doi.org/10.3390/polym14194194

Encapsulation methods



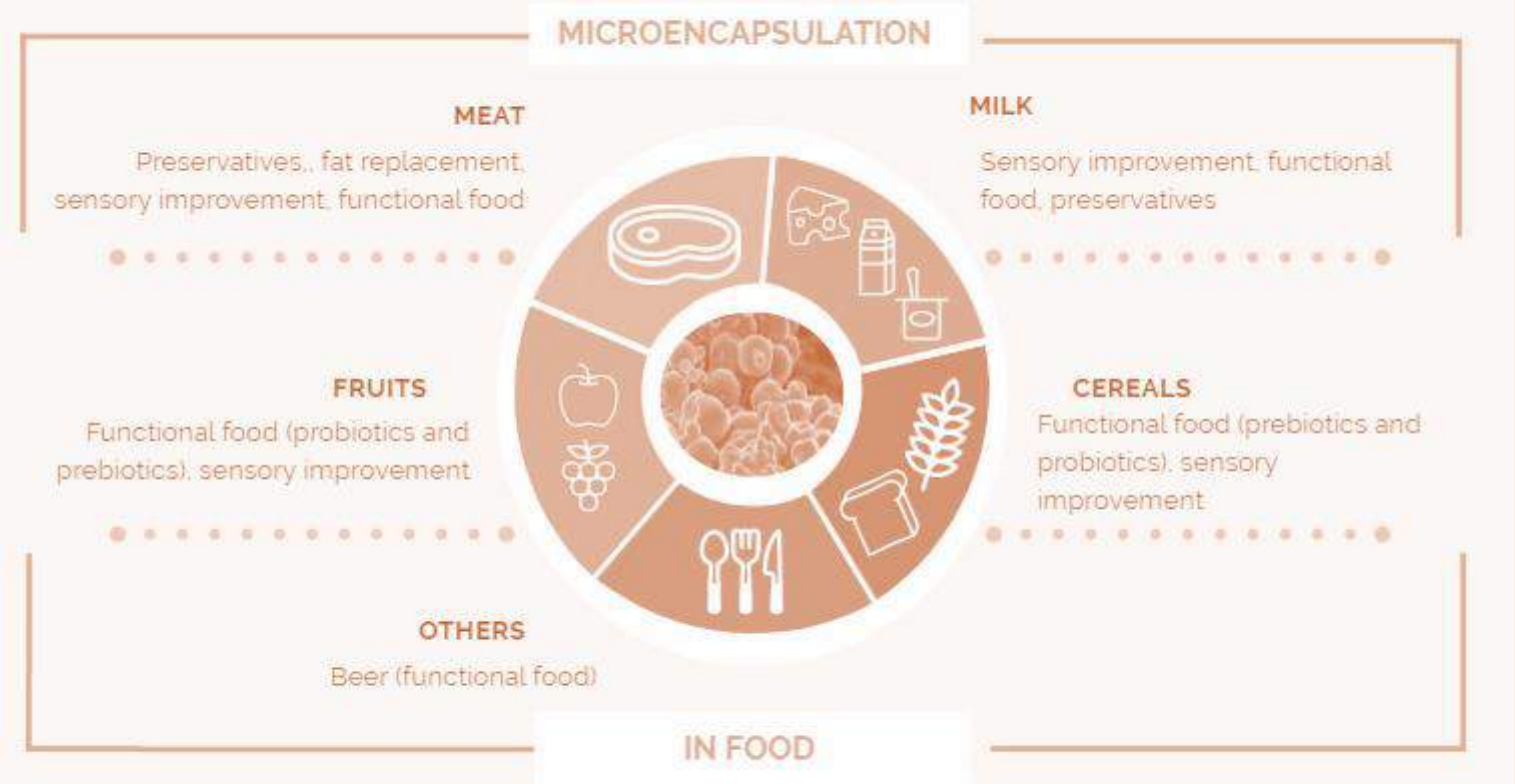
Fabela-Morón et al., 2022.
https://doi.org/10.32854/agrop.v15i10.2407



Methods for encapsulation

A. Spray drying
B. Spray chilling/cooling
C. Extrusion
D. Fluidized bed coating
E. Lyophilization
F. Coacervation

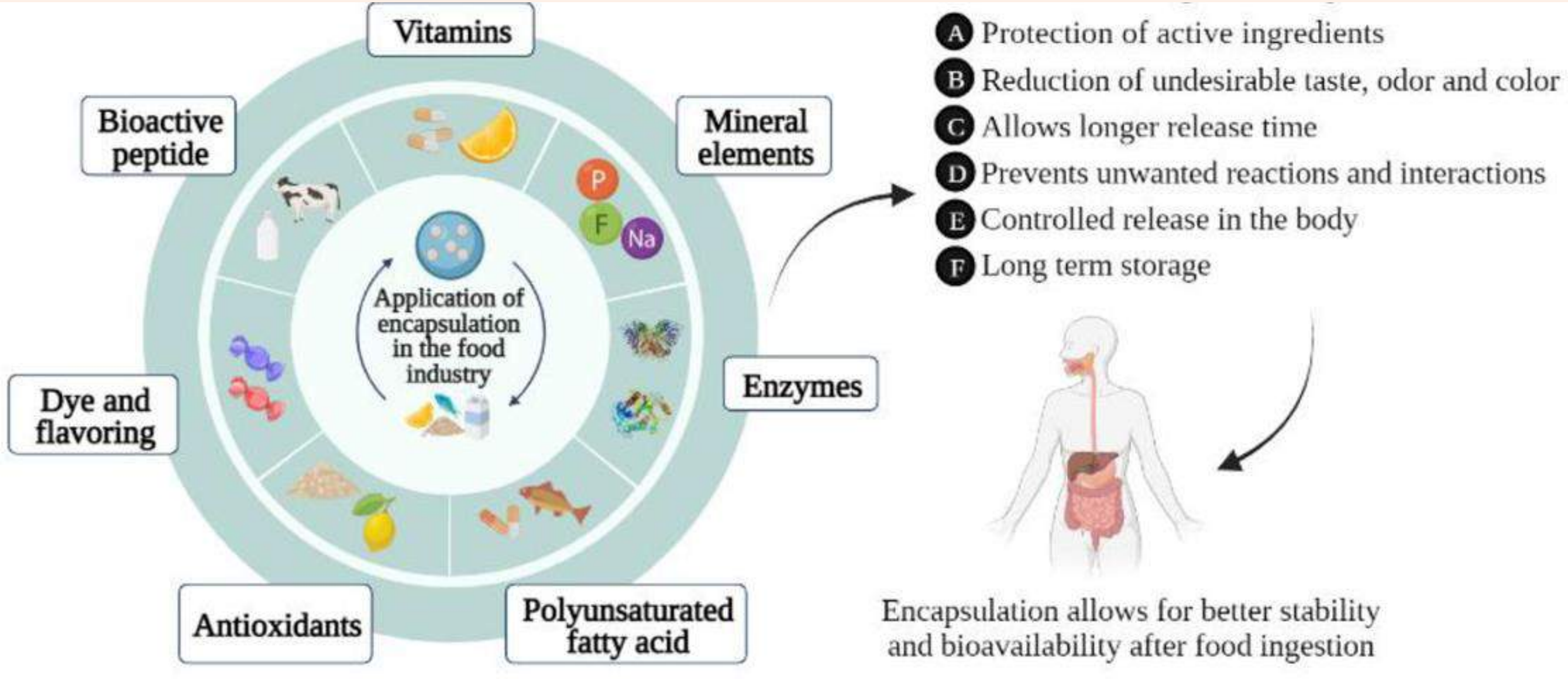
Borah et al., 2023.
https://doi.org/10.3390/foods12203823



(Calderón-Oliver et al., 2022)

10.3390/molecules27051499

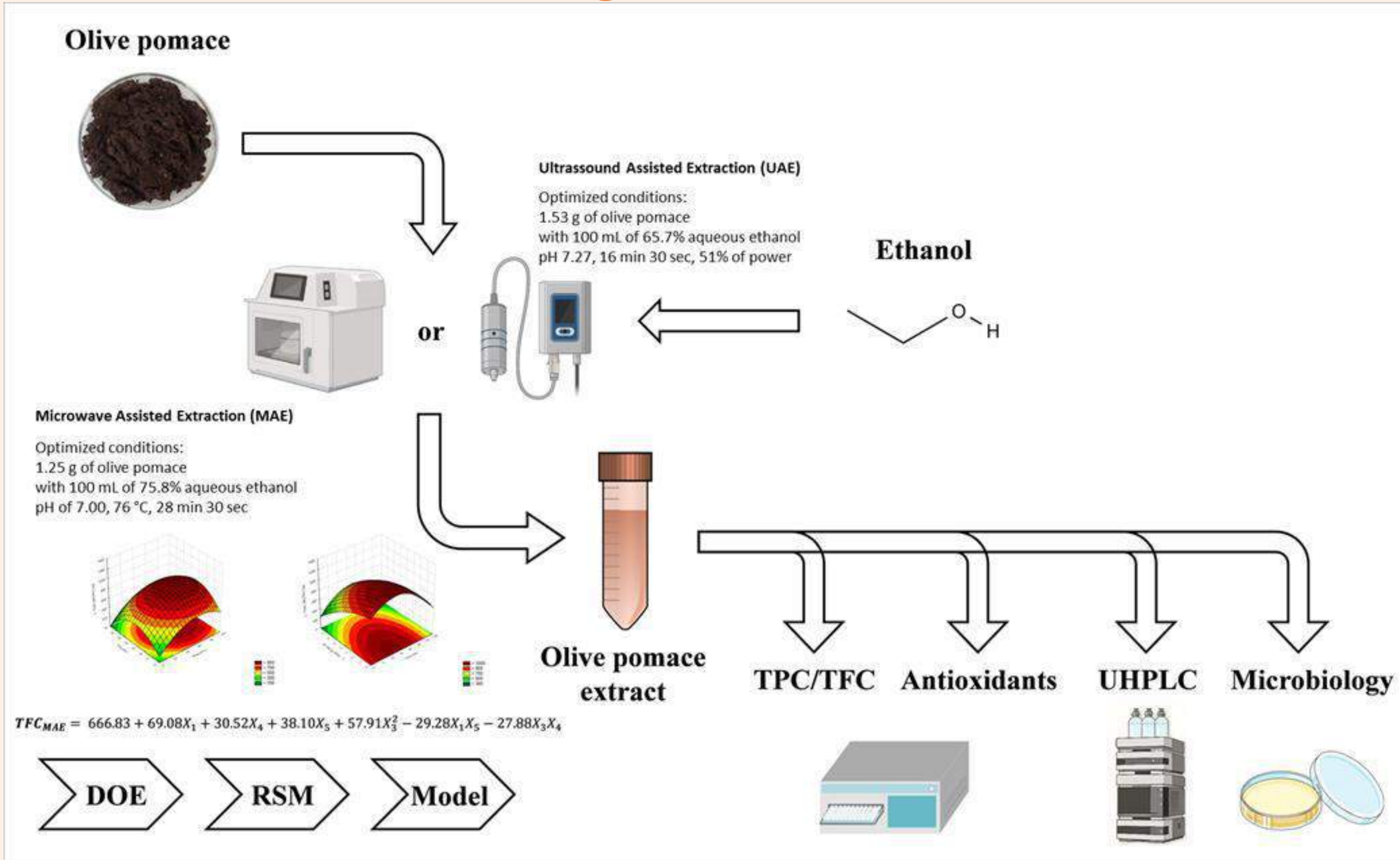
The main advantages of encapsulation



Zabot et al., 2022

10.3390/polym14194194

3. EXTRACTION Technologies

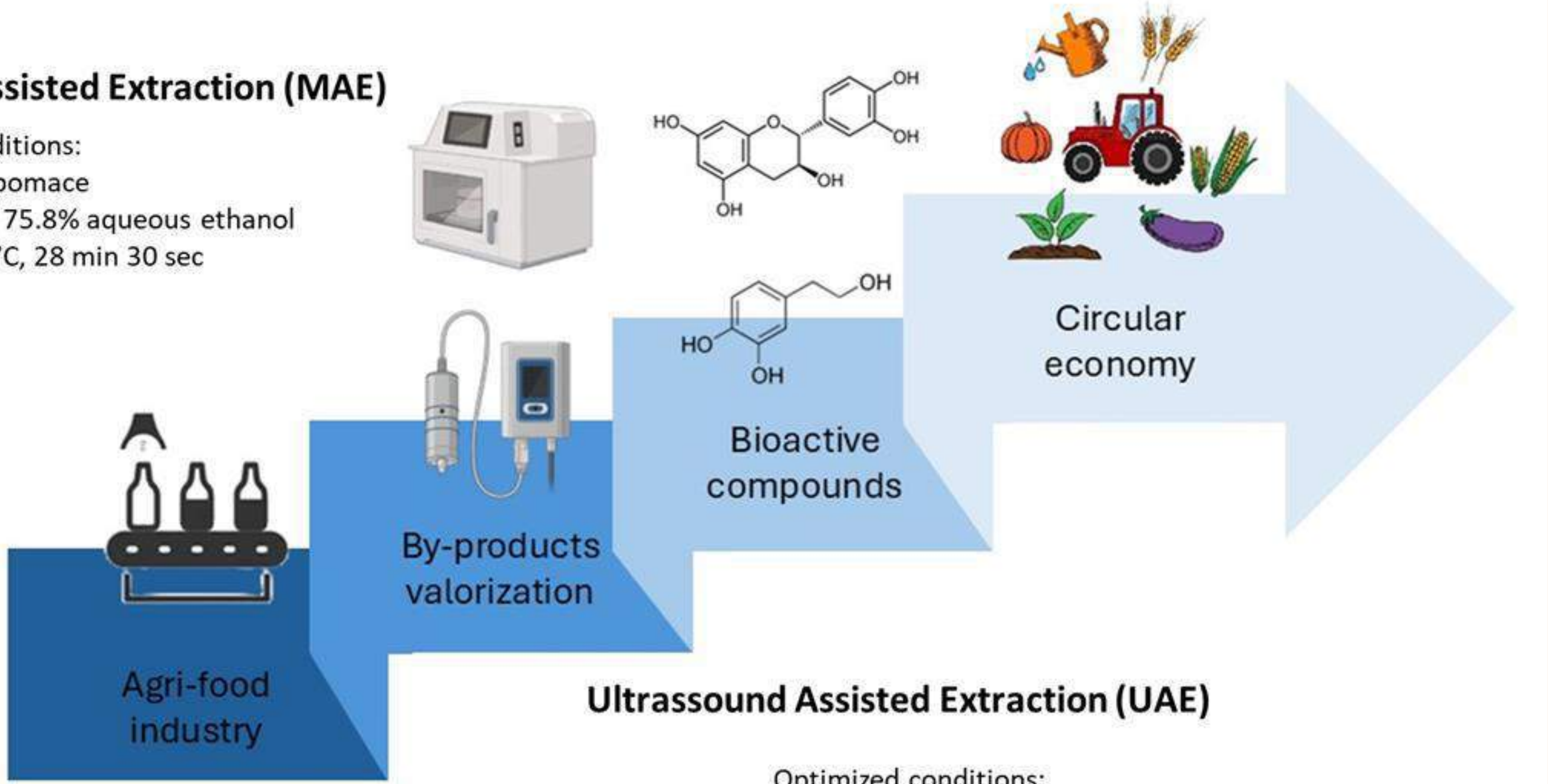


source: original

3. EXTRACTION Technologies

Microwave Assisted Extraction (MAE)

Optimized conditions:
1.25 g of olive pomace
with 100 mL of 75.8% aqueous ethanol
pH of 7.00, 76 °C, 28 min 30 sec

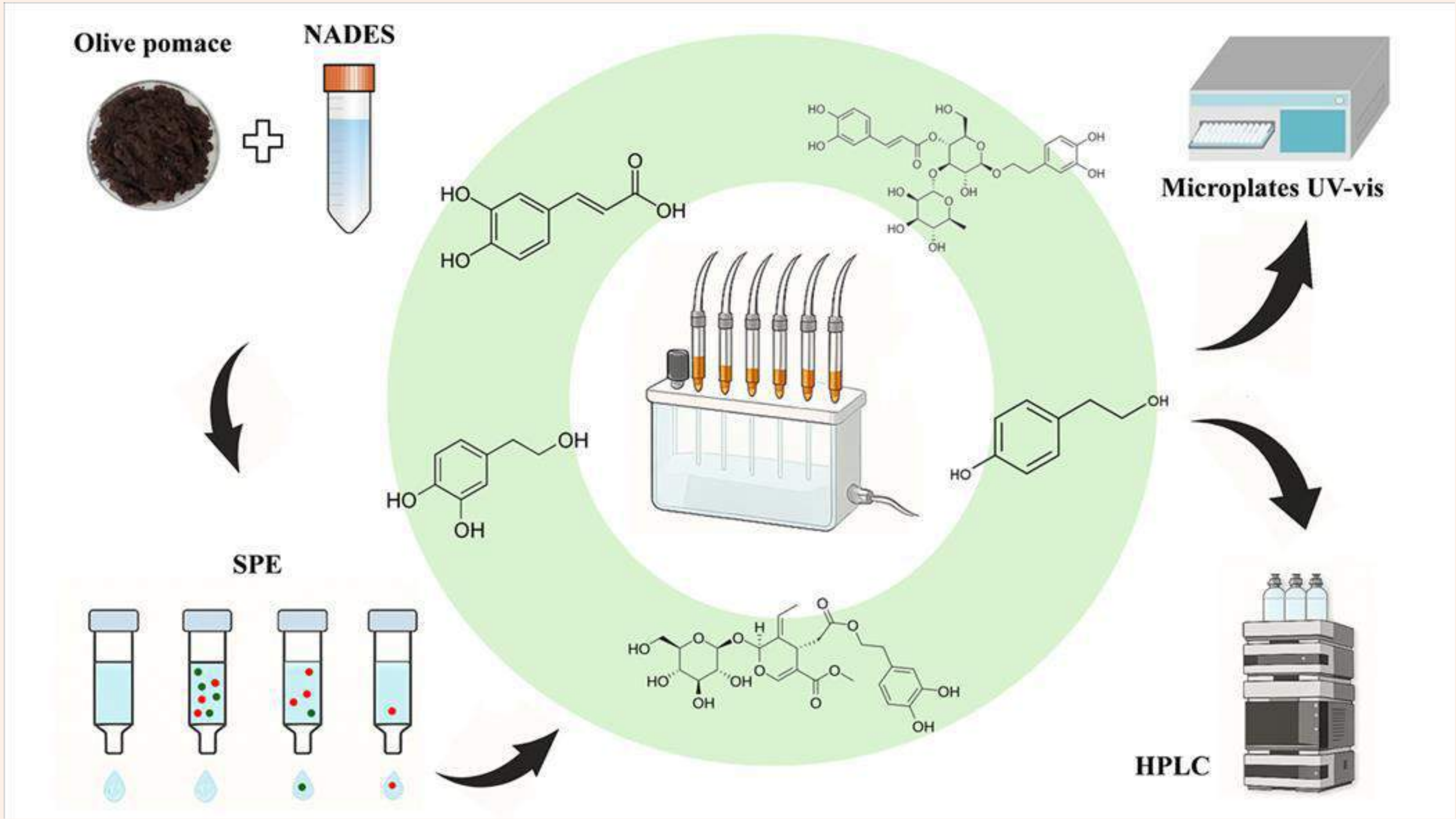


Ultrassound Assisted Extraction (UAE)

Optimized conditions:
1.53 g of olive pomace
with 100 mL of 65.7% aqueous ethanol
pH 7.27, 16 min 30 sec, 51% of power

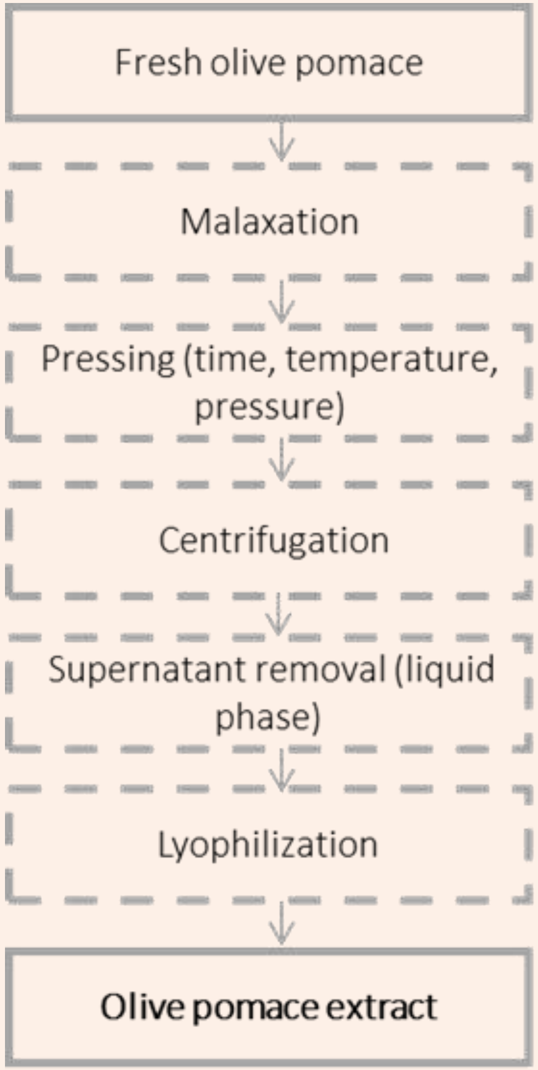
source: original

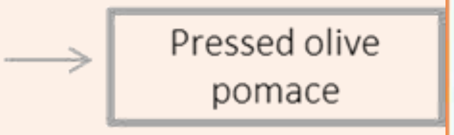
3. EXTRACTION Technologies



source: Soares TF et al. Microchem. J. 2026; 220: 116479 doi: 10.1016/j.microc.2025.116479

3. EXTRACTION Technologies






Food Bioscience 61 (2024) 104759

Contents lists available at ScienceDirect

Food Bioscience

journal homepage: www.elsevier.com/locate/fbio

Comprehensive analysis of the phytochemical composition and antitumoral activity of an olive pomace extract obtained by mechanical pressing

Diana Melo Ferreira [a], Juliana Barreto-Peixoto [a], Nelson Andrade [a,b], Susana Machado [a], Cláudia Silva [a,b], Joana C. Lobo [a], Maria A. Nunes [a], Gerardo Álvarez-Rivera [c,e], Elena Ibáñez [c], Alejandro Cifuentes [c], Fátima Martel [b,d], M. Beatriz P.P. Oliveira [a], Rita C. Alves [a,*]

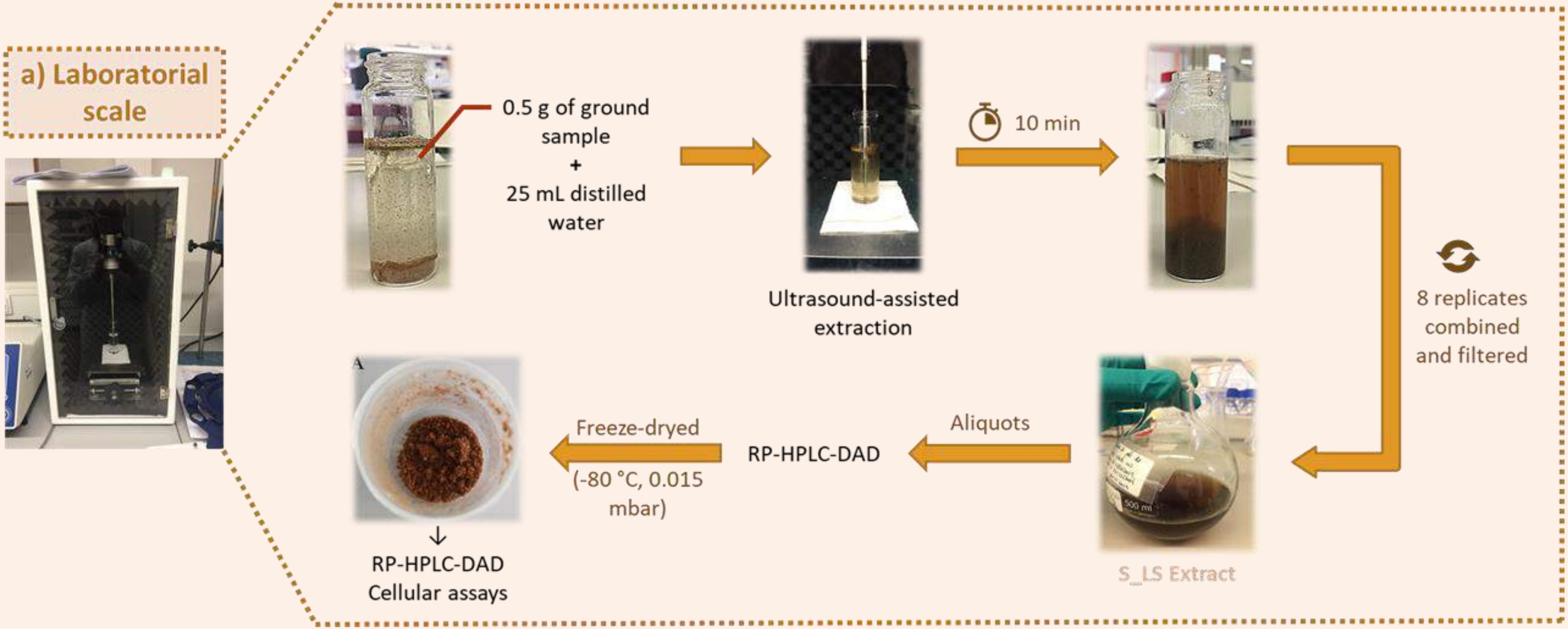
Total fat (g/100 g)	7.99 ± 0.05
Total vitamin E (mg/100 g)	2.0 ± 0.4
α-tocopherol	1.8 ± 0.4
α-tocotrienol	0.065 ± 0.001
β-tocopherol	0.049 ± 0.002
γ-tocopherol	0.09 ± 0.01
Palmitic acid (C16:0) (relative %)	12.69 ± 0.06
Stearic acid (C18:0) (relative %)	3.05 ± 0.01
Oleic acid (C18:1n9c) (relative %)	72.14 ± 0.04
Linoleic acid (C18:2n6c) (relative %)	9.31 ± 0.05

Ash (g/100 g)	11.4 ± 0.02
Total protein (g/100 g)	0.94 ± 0.02
Total carbohydrates (g/100 g)	79.71 ± 0.03
Brix of sugar (%)	28.1 ± 0.8
pH	5.40 ± 0.03
Total phenolics (g GAE/100 g)	2.9 ± 0.1
Hydroxytyrosol (mg/100 g)	215 ± 9
Total flavonoids (g CE/100 g)	2.29 ± 0.08
FRAP (g FSE/100 g)	2.3 ± 0.1
DPPH (g TE/100 g)	1.0 ± 0.2
ABTS (g TE/100 g)	0.193 ± 0.001

source: Ferreira DM et al. Food Biosci. 2024; 61: 104759 doi: 10.1016/j.fbio.2024.104759

3. EXTRACTION Technologies

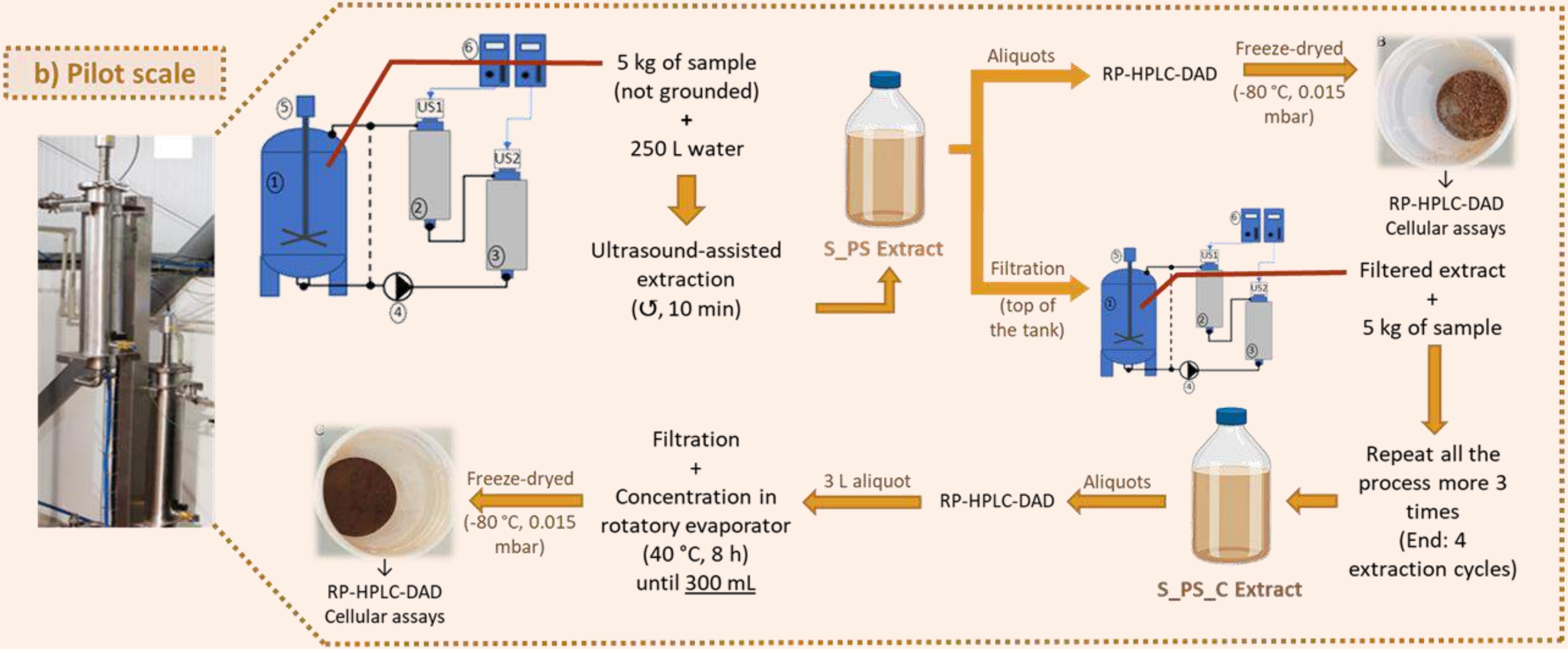
1) Extracts preparation by Ultrasound-assisted extraction (UAE)



source: Peixoto JAB et al. Foods. 2022; 11: 1671 doi: 10.3390/foods11121671

3. EXTRACTION Technologies

1) Extracts preparation by Ultrasound-assisted extraction (UAE)

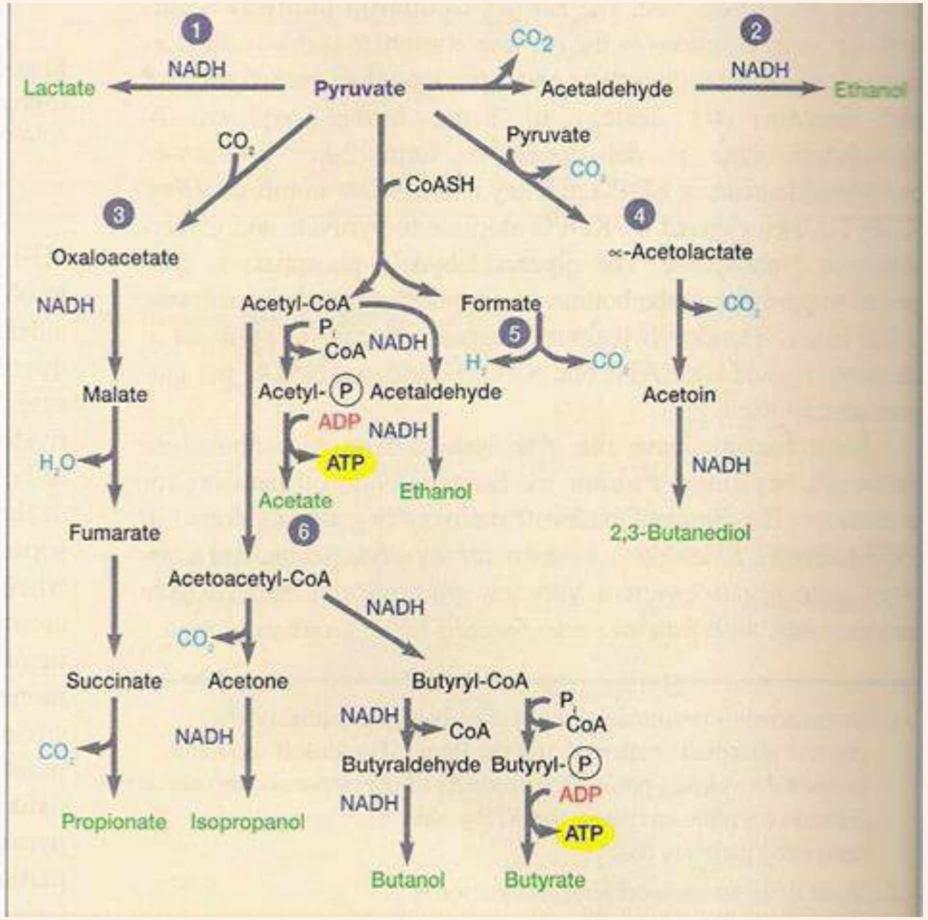


source: Peixoto JAB et al. Foods. 2022; 11: 1671 doi: 10.3390/foods11121671

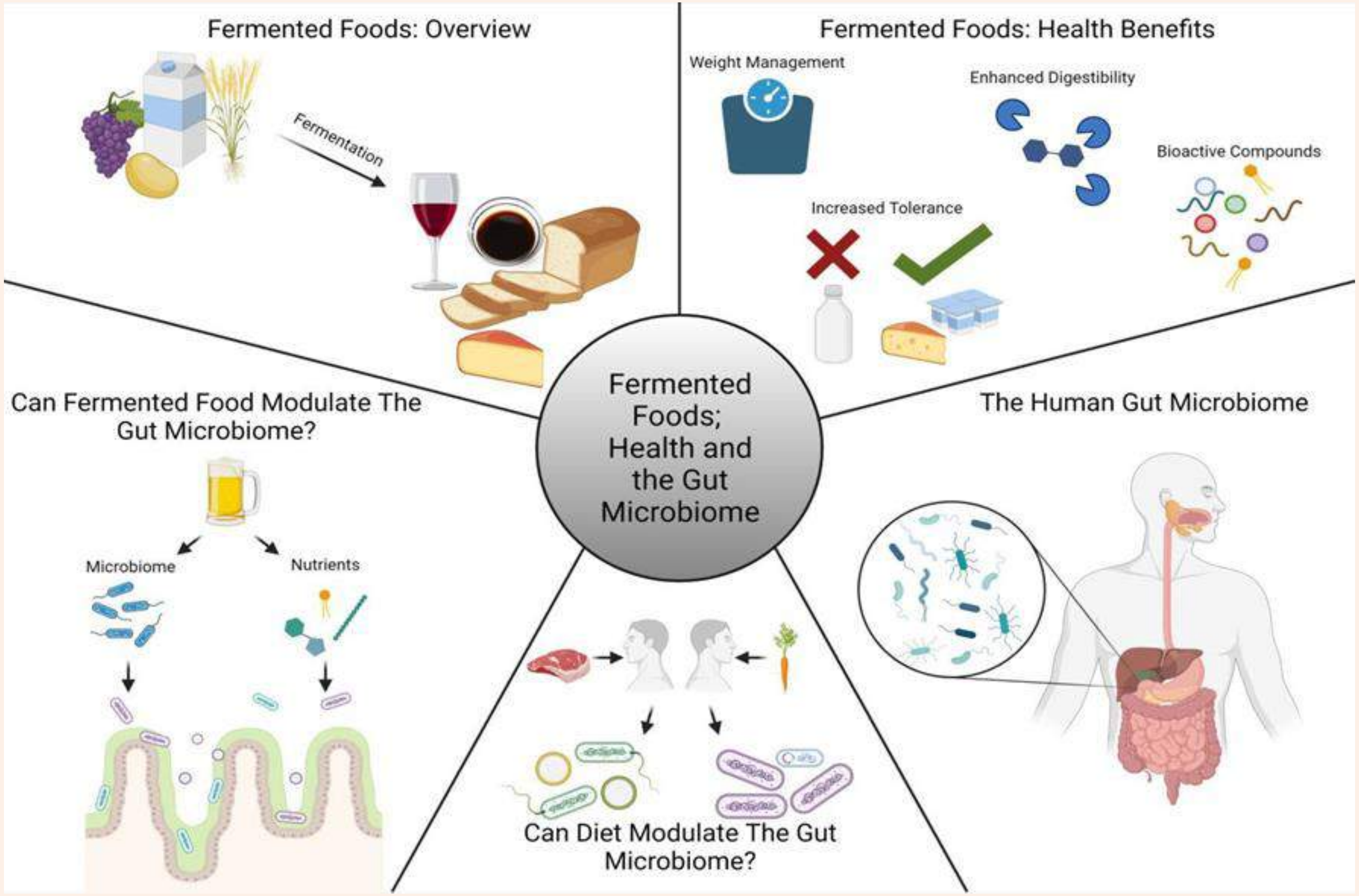
4. FERMENTATION

From a biochemical point of view, **fermentation** is a metabolic process through which organic compounds are converted into energy, without the involvement of an oxidizing agent. As Louis Pasteur succinctly suggested, fermentation is “la vie sans l’air,” or “life without air.” However, fermentation is not one size fits all. There is actually incredible diversity when it comes to fermentation processes, as different microorganisms house different mechanisms for the conversion of glucose into energy.

Short chain fatty acids (SCFA) produced from the diet are important modulators of the immune system and may play a role in weight loss

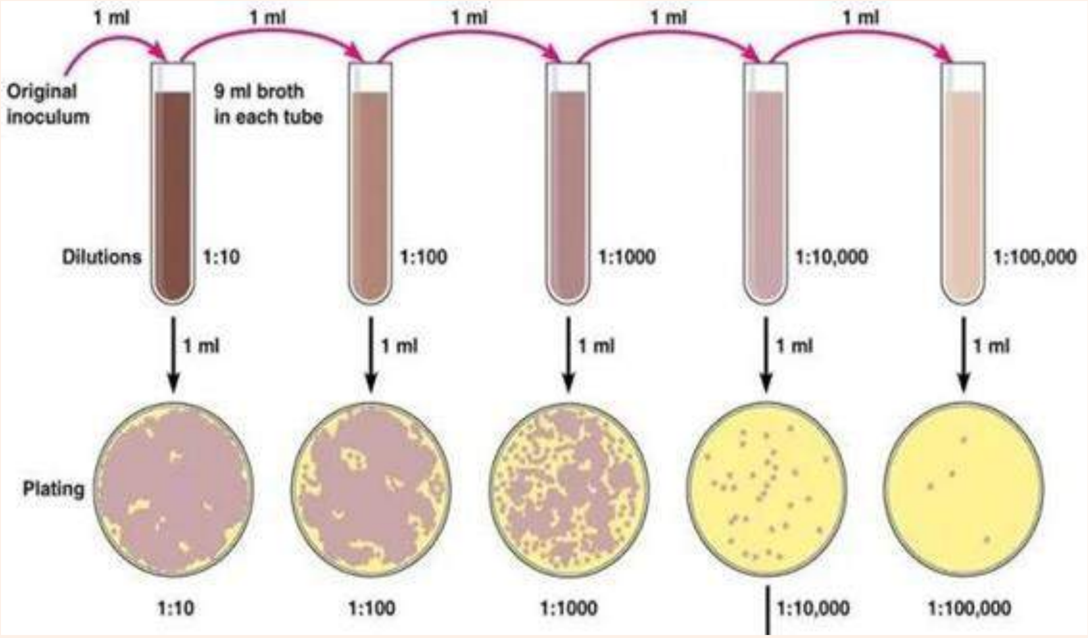


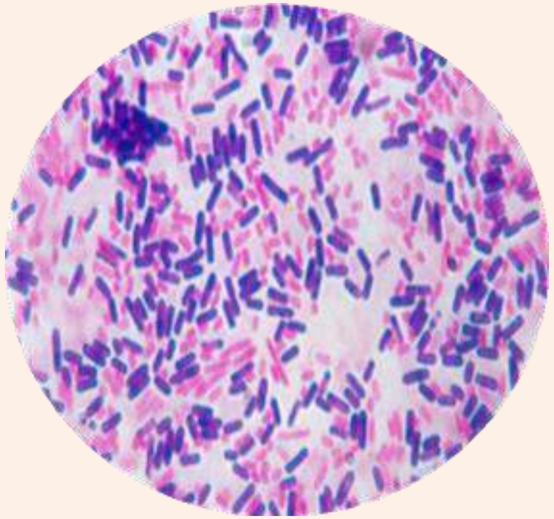
Examples of fermentation products



Leeuwendaal, et al. 2022.
https://doi.org/10.3390/nu14071527

Olive Pomace Paste: Native Microbiota





Total microorganism count was evaluated, through surface spread in adequate culture media and incubation conditions to characterize the type of microorganisms present

Main

- Bacteria – Lactobacilli
- Yeast

Our study evaluated the potential of fermentation of Olive Pomace as a process of valorization as a new food ingredient

Olive oil by-products are rich in **bioactive compounds** that can promote the growth of beneficial intestinal bacteria.

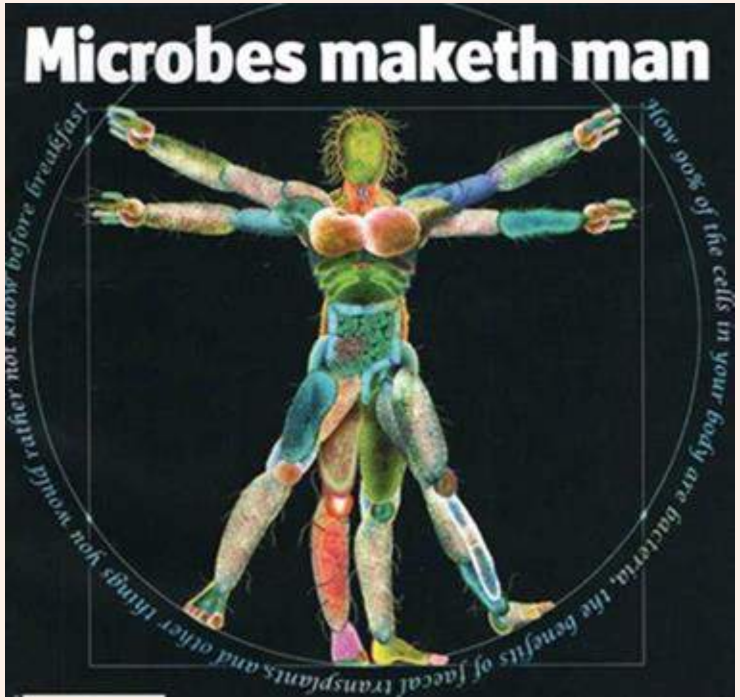
After fermentation, these by-products can produce **symbiotic functional foods** or food ingredients that are relevant for **intestinal health and well-being**, also due to their antioxidant and anti-inflammatory properties associated with the polyphenols present. These compounds help stimulate the growth of **probiotics**, improving intestinal health, producing beneficial enzymes and metabolites that improve the intestinal microbiome. This approach may also be advantageous in obtaining low-alcohol symbiotic functional beverages that are well accepted by consumers.

This approach will allow adding value to by-products, as a sustainable and regenerative practice

Nutrition

Gut microbiome modulation

Healthy Intestinal Microbiota



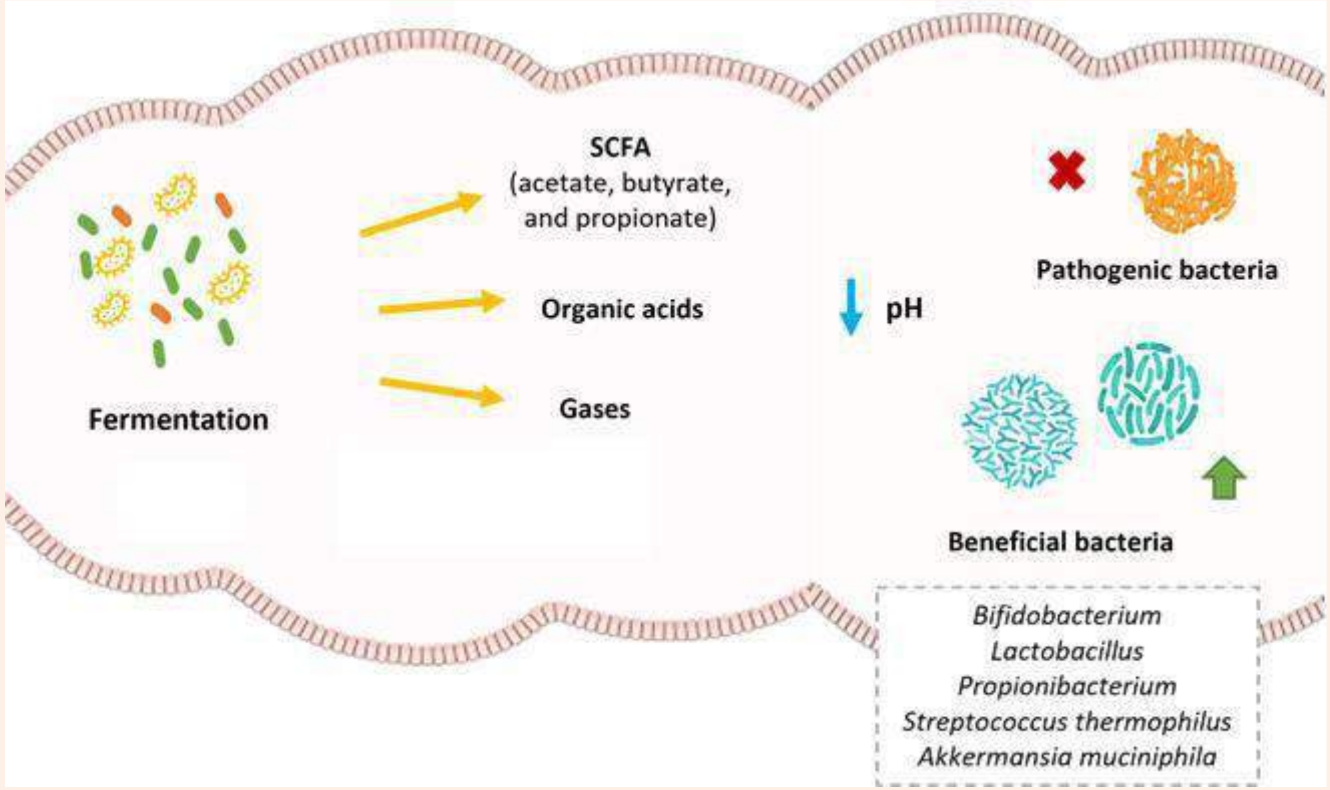
Fermented Coffee by-products

Machado et al., 2023.
https://doi.org/10.1080/10408398.2023.2181761

Prebiotics are substrates selectively used by microorganisms that favor the host's health

Prebiotics must satisfy three requirements:

- **resistant to gastric acid, to the hydrolysis** by mammalian enzymes and **gastrointestinal absorption**;
- **metabolized by the intestinal microbiota** and **selectively stimulate the growth and/or activity of the bacteria** with beneficial health effects;
- **not cause negative effects to the host**, as for example, the growth of pathogenic microorganisms.



Machado, M., Ferreira, H., Oliveira, M. B. P. P., & Alves, R. C. (2023). Coffee by-products: An underexplored source of prebiotic ingredients. Critical Reviews in Food Science and Nutrition, 64(20), 7181–7200
https://doi.org/10.1080/10408398.2023.2181761

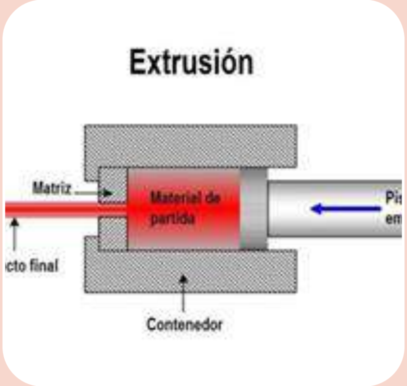
5.Food extrusion processing

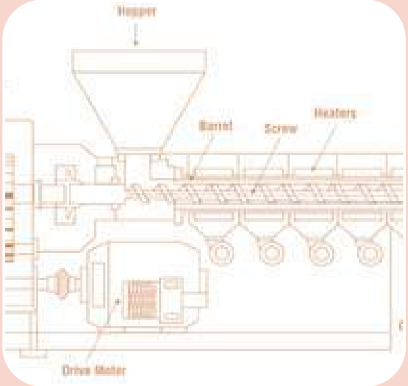
- Temperature processing

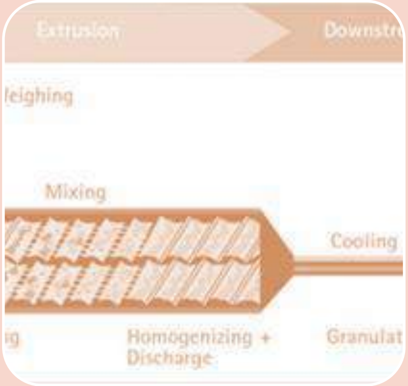
Cold → products with high density and high humidity are obtained, such as cookies, muffins, candies or sausages.

applying heat → products with low density and low humidity are obtained, such as snacks.

Extruders by mechanic system







Piston

- The simples one of the extruders.
- Consist of a single piston that force the material through a hole
- Designed for precise delivery and uses in confectionery and meat industry.

Roller

- Consist of two counter-rotating.
- The gap between the Rolls is controlled.
- A variety of products can be obtained altering gap, rotation speed and the roller Surface.
- For crackers, hard cookies, etc. Also for the production of flakes (after baked).

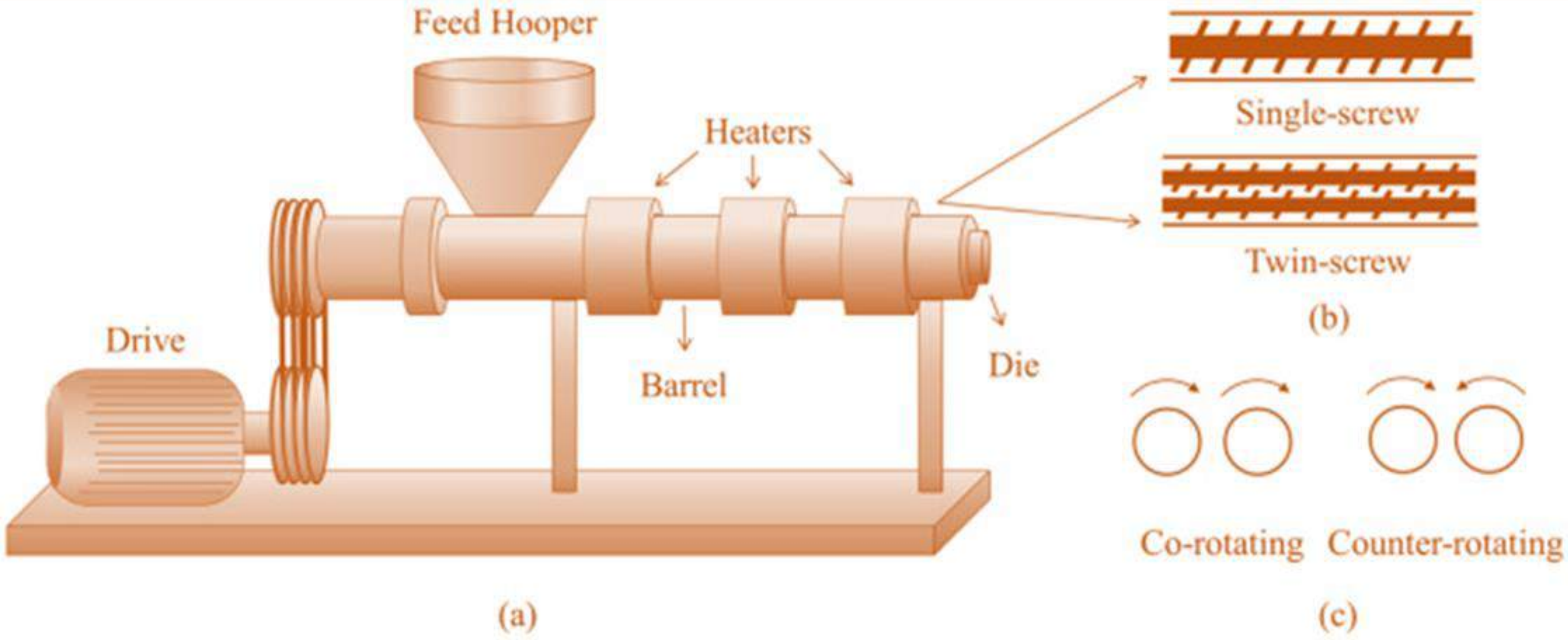
Single-screw

- It means that there is only one screw inside de barrel.
- The length to diameter ratio (L/D) varies between 2:1 until 25:1
- (it is the ratio of the screw diameter to the lenght of the barrel).
- It have three sections inside the barrel, feed section, transition section and metering section.

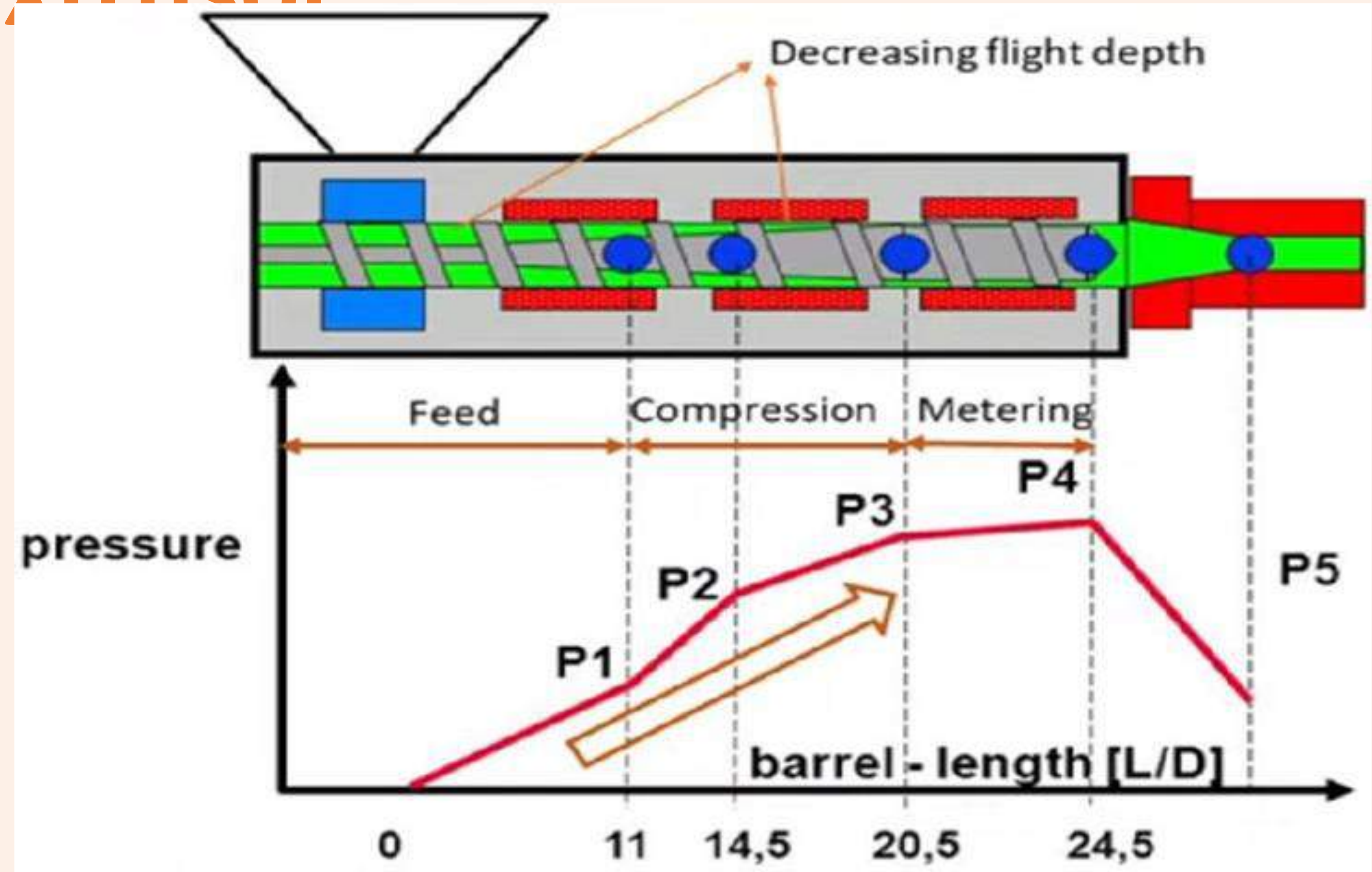
Twin-screw

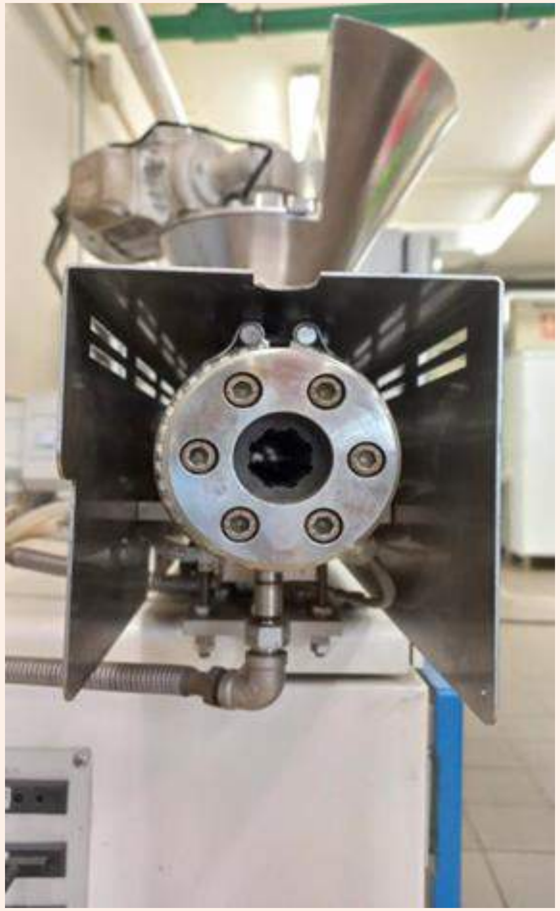
- There are two screws inside the closed barrel.
- Clamshell top opening barrel (easy change).
- Replaceable barrel liners (speed)
- screws parts mounted on a line.
- Screw ejection.
- In one screw (12-17 % fats) vs double screw (18 – 22% fats) and better union with the rest of components.
- Wide range of moisture (more tan 30%).

Screw extruders



Single-screw extrusor



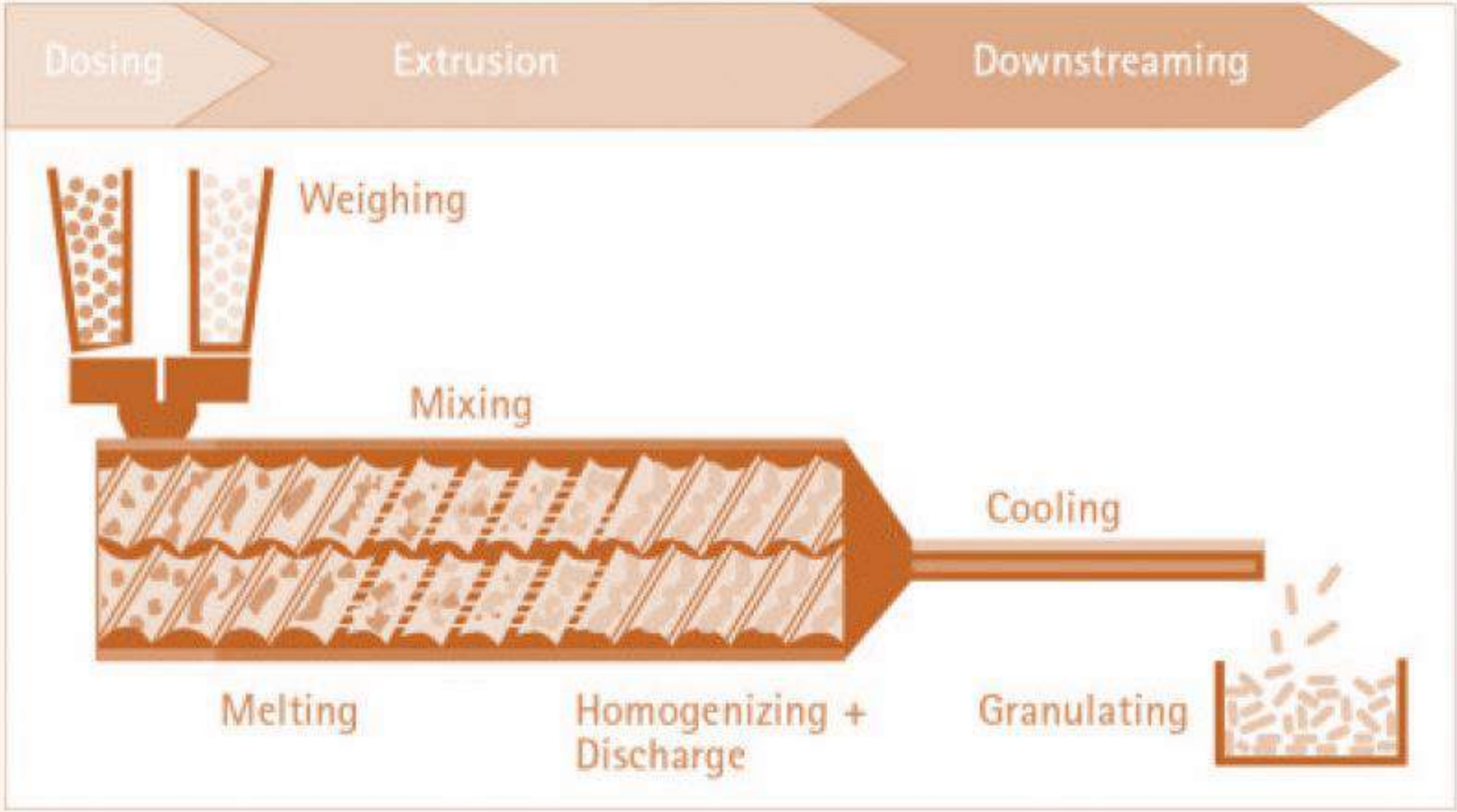


Feed section: has deep flighted screws which aid conveying the material forward

Compression section: The material is partially cooked and subjected to high pressure

Metering section: Receive the compressed material, homogenize it and force it through the die at a constant pressure

Twin screw extrusor



Twin -screw extruder

In the food industry twin- screw systems is more used because of their flexibility.

Multiple operations - one machine

- Extrusion applying heat is a thermo-mechanical processing operation that combines several unit operations:
    - Mixing
    - Kneading
    - Shearing
    - Heating
    - Forming
    - Partial drying
    - Etc.

Advantages

- Extrusion systems reduce the space occupied in the food processing plant, allowing lower operating and energy costs.

Space reduction

- Extrusion has lower processing cost tan other cooking methods. Less raw material, labor, and capital investment.

Low cost

- A variety of products is feasible by changing the minor ingredients and the operation conditions of the extruder.

Adaptability

- The process is continuous and capable of happening in short time (< 1 minute).

Speed

- Extrusion can modify proteins (animal and vegetable), flours, and other food materials to produce a variety of food products.

New food

- Extrusion can be fully automated.

Automatic control

- Due to extrusion is a continuous process in short time, it minimizes degradation of food nutrients while it improves the digestibility of proteins and starches. (also reduce undesirable enzymes, microorganisms, anti nutrients, etc.)

High quality products

- Shapes, textures, colors, different appearances, etc which is not easy produced using other production methods.

Wide range

Ingredien s

More used Extrusion ingredient s

Starch y foods

Cereal flours such wheat, corn, rice, etc.

Protein-rich foods

Soybean, sunflower, vegetable, and cereal protein isolates

Complementary ingredients:

- plant extracts
- functional products
- Salts
- Legumes
- Insects (ants, crickets, etc.)
- By-products

What kind of products we obtain with these ingredients?

- Expanded snacks
- Breakfast cereals
- Sweets
- Cookies
- Pasta
- Precooked flours
- Food for animals (aquaculture, feed, etc.)
- Texturized proteins

Improving functional properties of food

- Extrusion affects the structure and composition of proteins.
  - Denaturation.
  - Bond formation

Changes

- Solubility
- Water retention capability
- Gelation
- Texturing
- emulsification

Meat substitute

Improving functional properties of food

- Denaturation and inactivation of antinutritional factors.
- Some vegetables have high nutritional value, but high concentrations of antinutritional factors.

- The conditions used in extrusion improve the suitability of these plant foods for human consumption.
  - Aflatoxins.
  - Gelation of vegetables proteins.
  - Saponines
  - Lectins,
  - Enzyme inactivation
  - Etc.

better digestibility

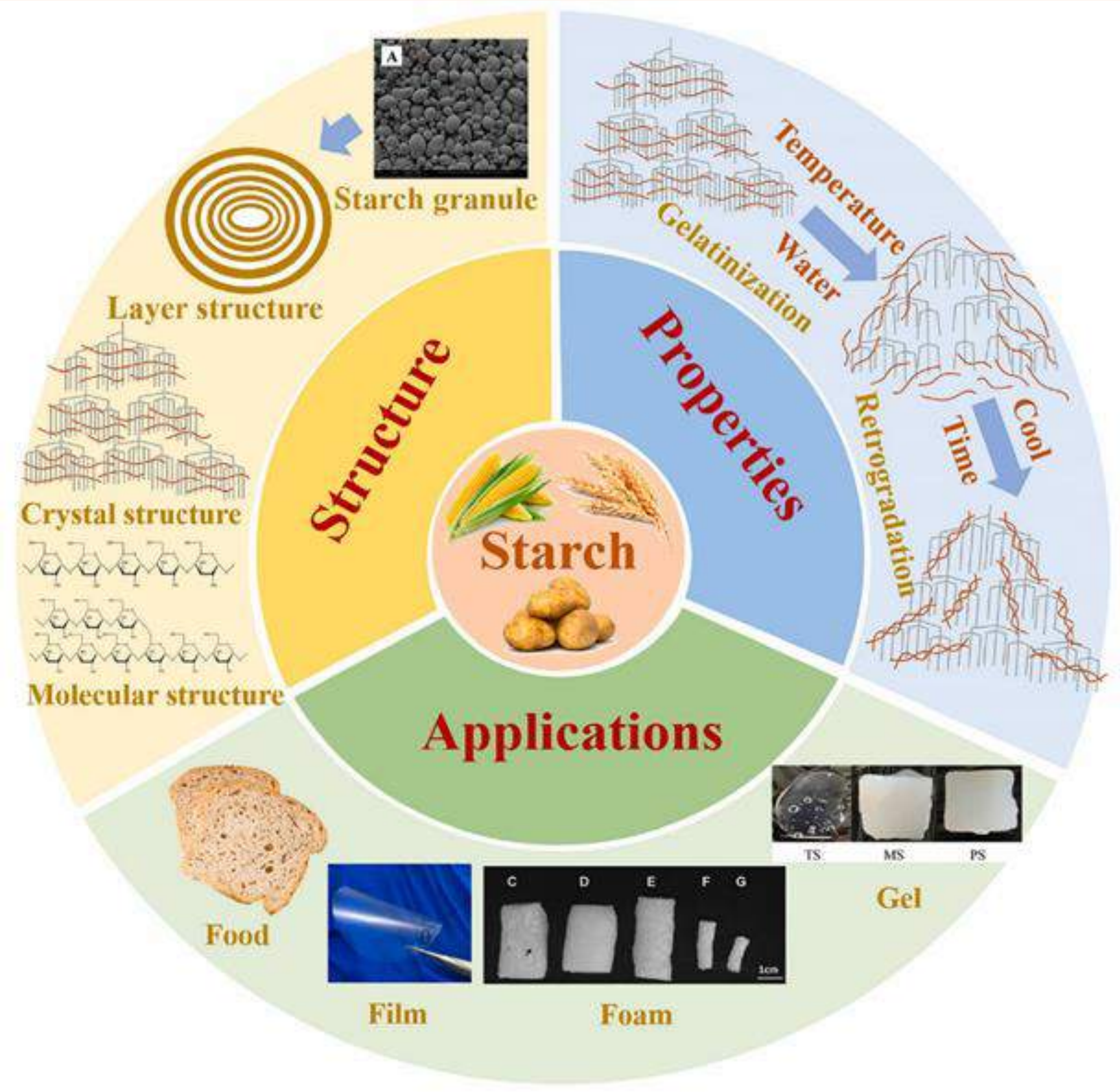
6. FOOD PACKAGING from food by-products

Carvalho,et al., 2025. https://doi.org/10.1016/j.clwas.2025.100275

Cereals for packaging

- Starch is a good source of biodegradable material for food packaging, originating from wheat, corn, rice, and potatoes. It is widely viewed as a sustainable substitute to plastics for food packaging.
- Moreover, various foods, such as fruits, vegetables, snacks, and dry products, can be packaged using starch as a biodegradable film

Kolybaba, et al., 2021. DOI:10.13031/2013.41300



Composition, characteristics, and uses of starch

Cheng, H.; et al., 2021.
https://doi.org/10.1016/j.foodhyd.2022.108364

The process of obtaining corn starch packaging

Harvest the corn, soaking it in water to separate the endosperm from fiber and gluten. The corn kernels are then soaked in hot water and sulfur dioxide solution, which breaks them down into starch, protein and fiber.

The liquid melange is centrifuged to remove the corn oil, leaving behind pure starch.

Enzymes are added to the cornstarch, converting it into simple sugars.

Bacterial cultures are introduced into the sugars, fermenting it into lactic acid. The lactide molecules in the acid bond together to form polymer chains, resulting in polylactic acid.

Pellets of PLA plastic are produced from this mixture. They are then melted down and molded into specific shapes for various applications.

Once set and cooled, the finished packaging is removed from its mold and ready for transport and sale.

https://www.greencompostables.com/blog/cornstarch-packaging

Types of cornstarch packaging

Cornstarch can be shaped into different forms and types of packaging to serve various practical purposes:

Clamshell containers

Meat trays

Resealable food bags

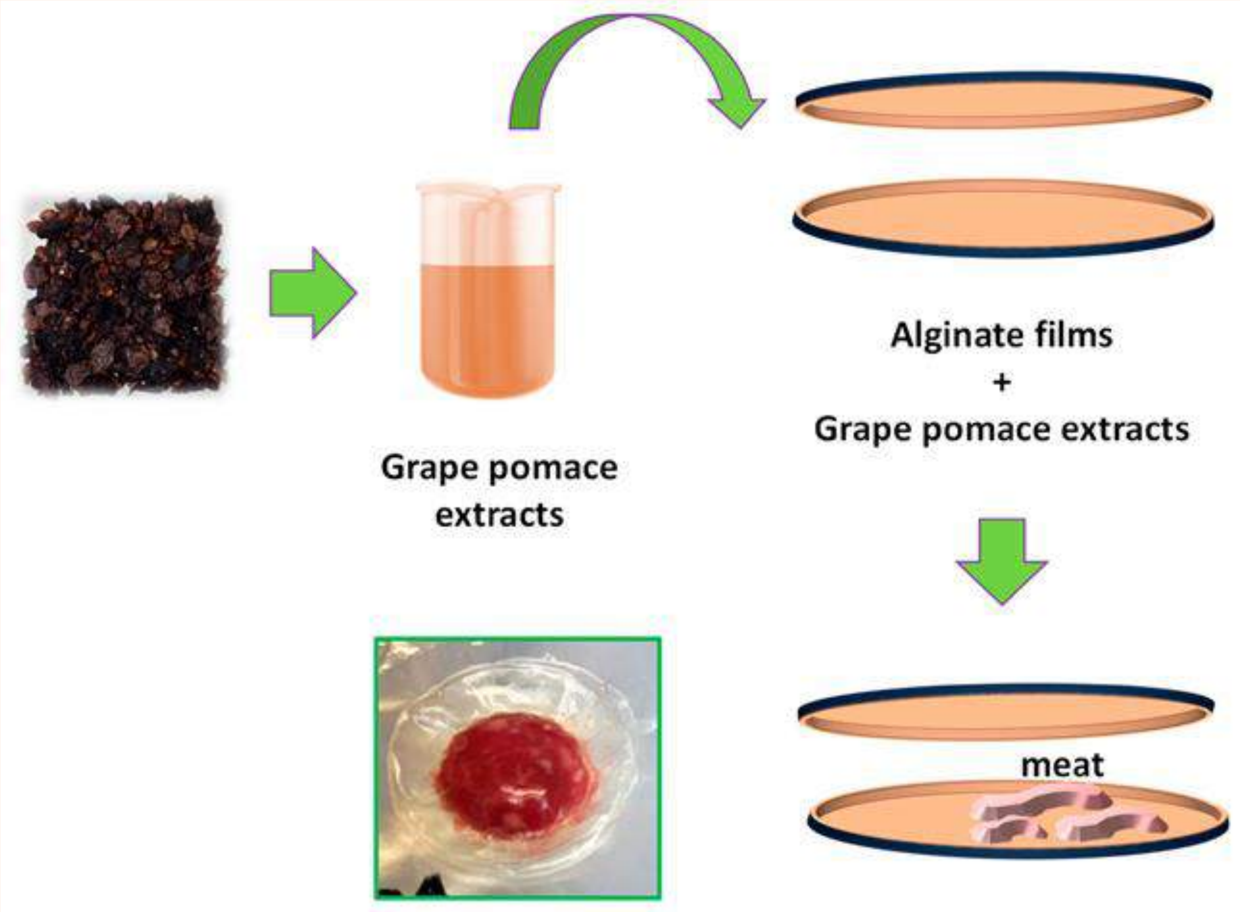
Beverage cartons

Cup lids

Fruits and vegetables for packaging

The fruit and vegetable are valuable sources of cellulose, pectin and other biopolymers with potential in packaging applications.

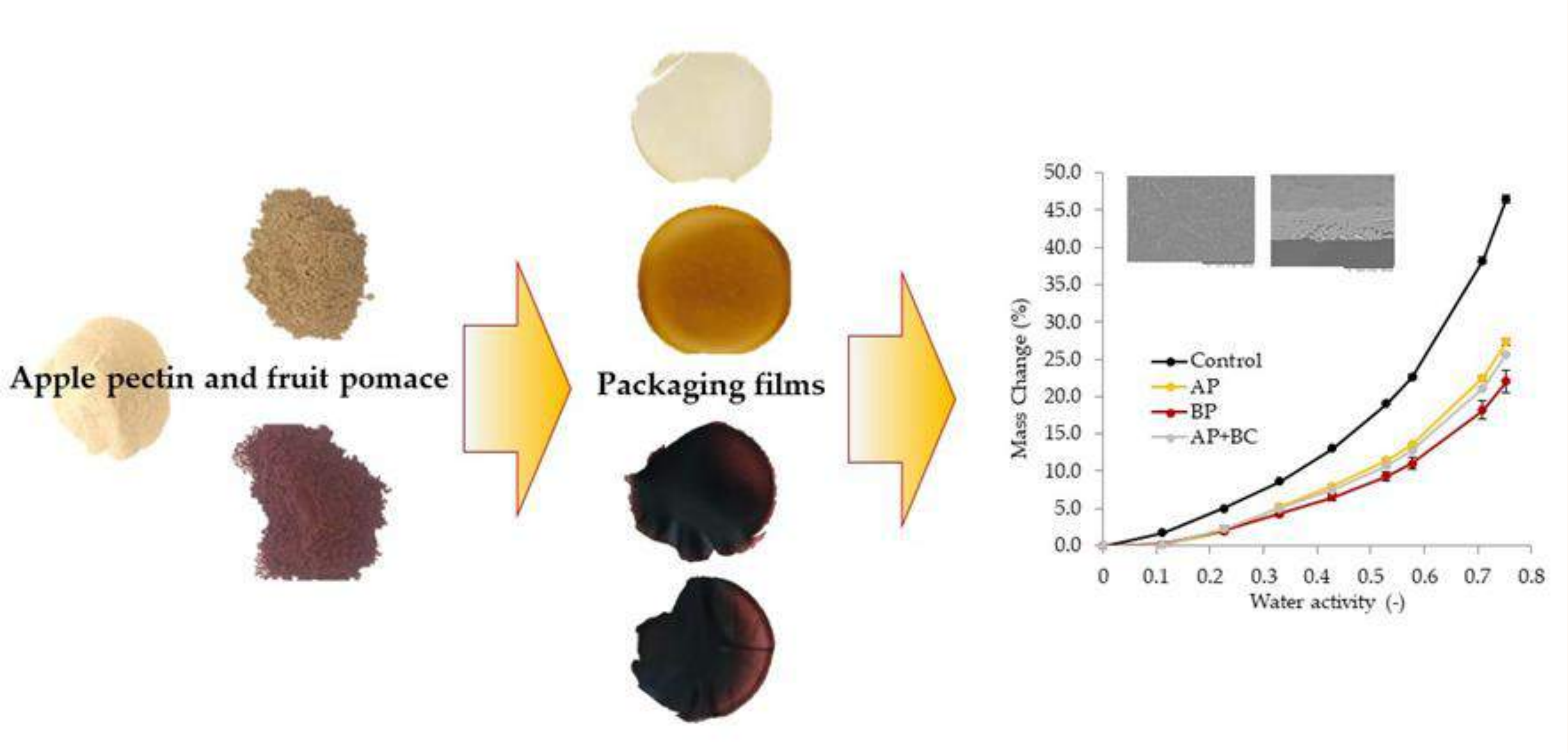
Eco-friendly packaging material based on alginic acid and grape pomace extract from *Vitis vinifera* L. (winemaking by-products) for storing red meat in refrigerator. Specifically, biogenic amines are considered “sentinels” of the putrefactive processes.



Aresta et al.,. 2023.
https://doi.org/10.3390/ijms242115958

Apple and Blackcurrant Pomace Powders as the Components of Pectin Packaging Films

The addition of fruit pomace significantly increase the thickness and the mechanical strength of pectin films, while water adsorption is reduced. All the films analyzed showed very good solubility in water, indicating the potential for good degradation of materials in aqueous conditions.



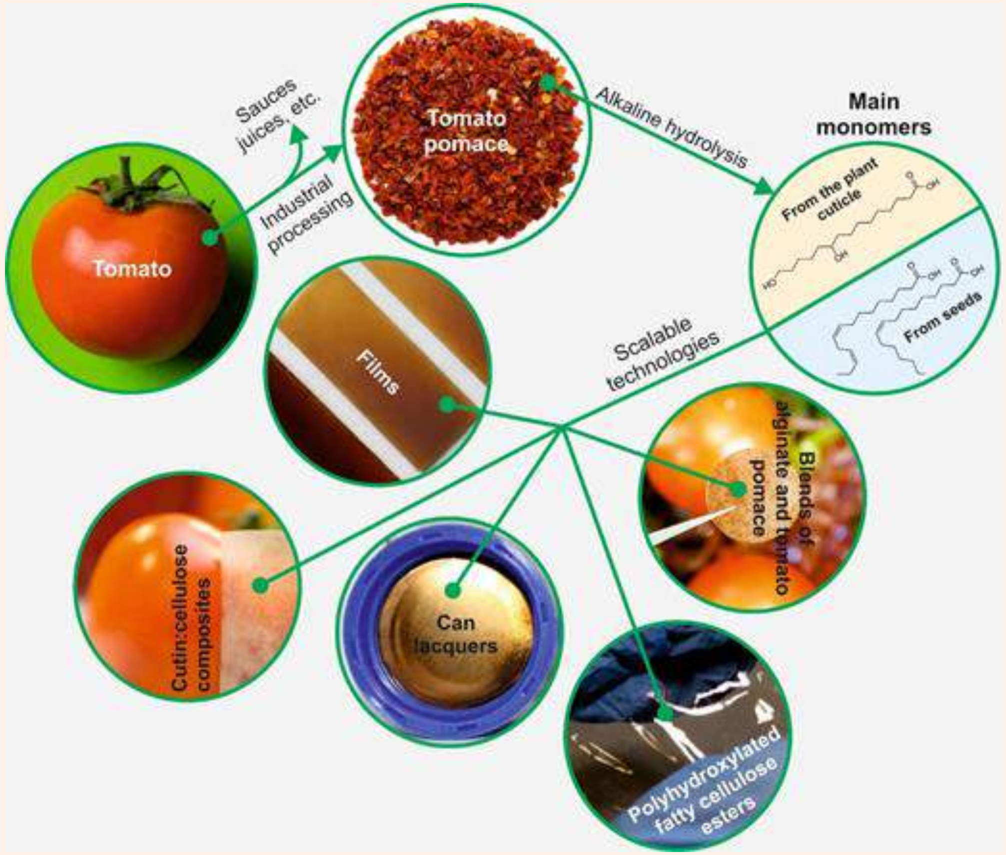
Pakulska,et al., 2023. https://doi.org/10.3390/coatings13081409

Tomato pomace as a renewable resource for bioplastic production

Tomato pomace is the resulting by-product after tomato fruit processing to prepare sauces, ketchups, juices, gazpachos, purees, concentrates, etc.

It is composed of peels (almost half), seeds (approx 40%), and a residual fibrous material

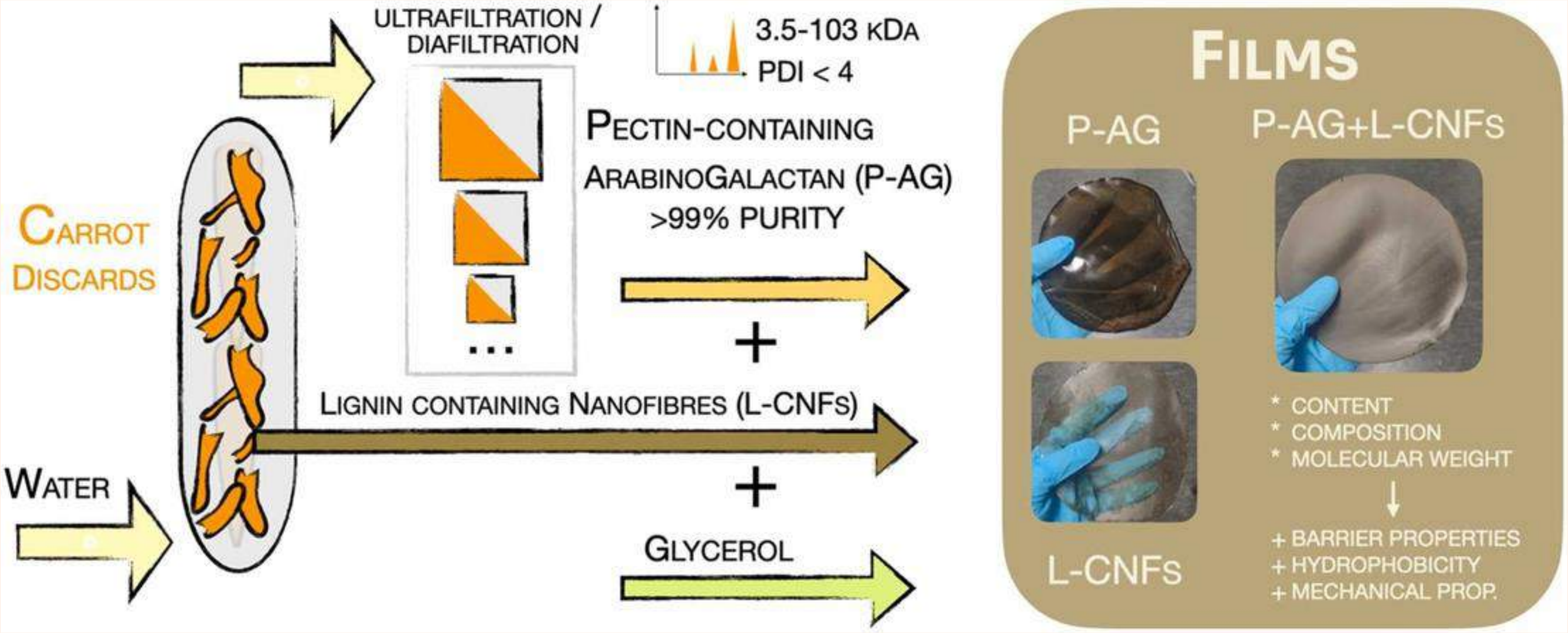
Extracting cellulose from the skins of tomatoes discarded by the canning industry after producing tomato paste, sauce, or ketchup. From the cellulose obtained from these byproducts, a material has been developed that can be modified with bioactive antibacterial substances and antioxidants. This material possesses properties suitable for food packaging and, in addition, degrades more quickly than conventional plastic containers



https://www.tomatonews.com/en/tomato-pomace-as-a-renewable-resource-for-bioplastic-production_2_1518.html

Carrot waste used for film production

Discarded carrots were successfully valorized through subcritical hydrolysis, yielding biopolymeric fractions to produce bio-based films. Pectin-containing arabinogalactan (P-AG) extracted via hydrothermal treatment was purified through multiple cycles of UF and DF, resulting in solid fractions.

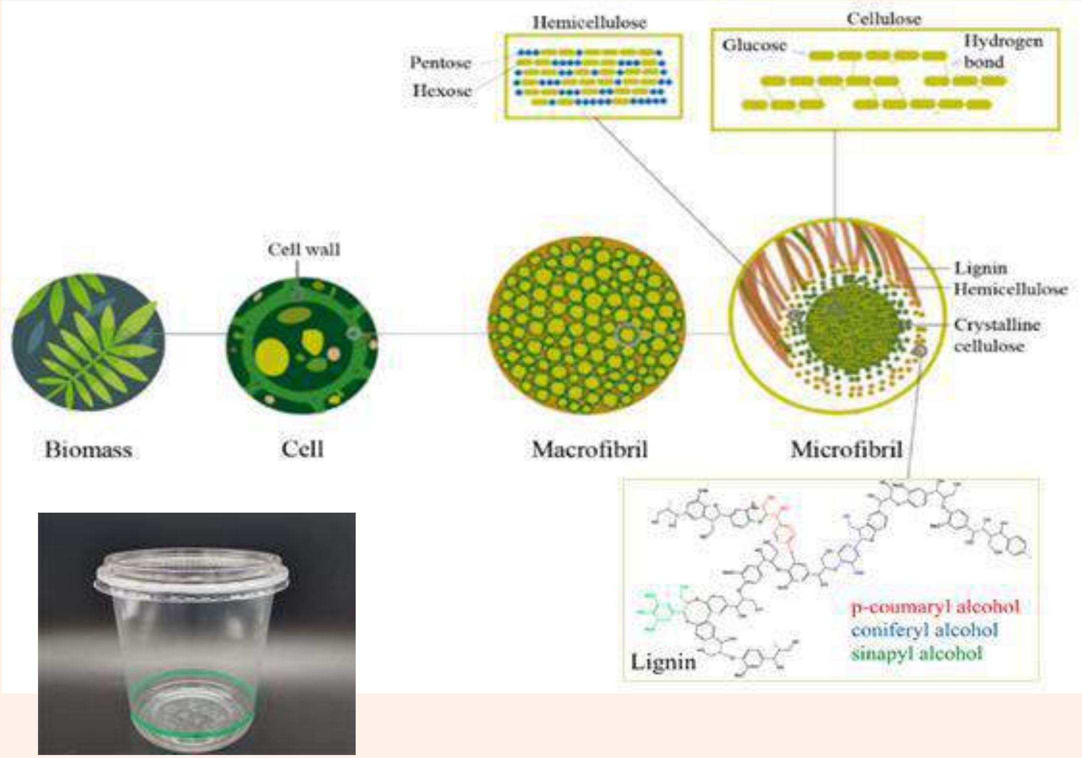


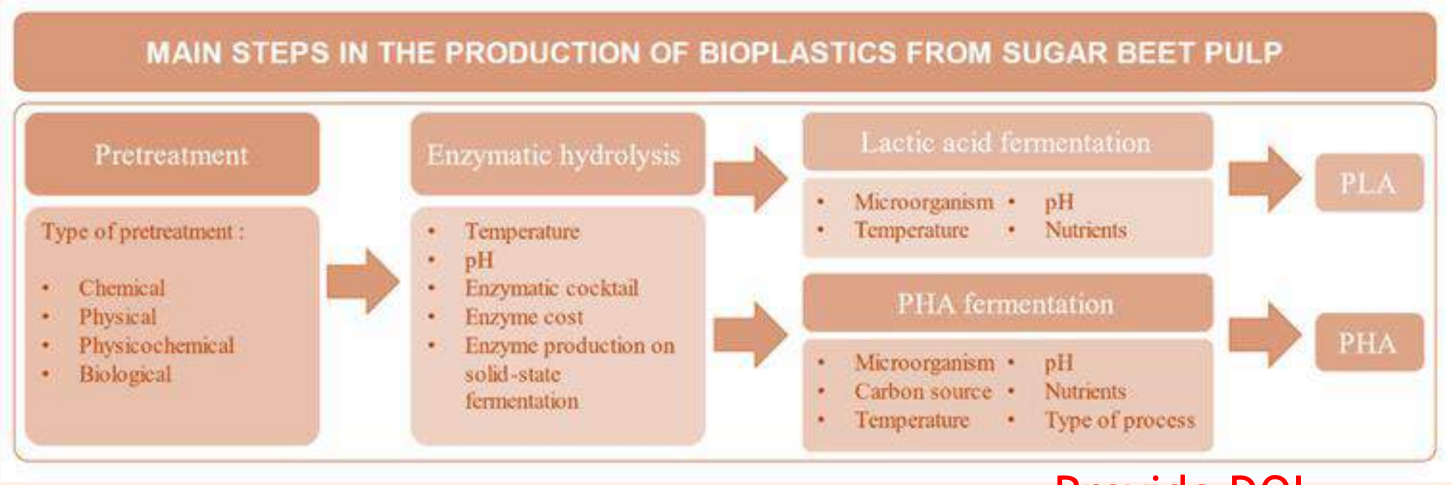
Sugar beet pulp for packaging

Polylactic acid (PLA) and PHAs, are biobased and biodegradable bioplastics. PLA is a polymer composed of lactic acid (LA) monomers and qualifies as a linear aliphatic thermoplastic polyester. PLA can be used in different areas such as food packaging.

Sugar beet pulp is a lignocellulosic by-product of the sugar industry that has traditionally been used for animal feed. However, it has also been used as raw material to produce a wide range of value-added products, such as LA or PHAs, through biotechnological processes.

Polylactic acid (PLA) is the most widely used biopolymer in the food packaging industry, with an annual production of around 140,000 tons. PLA is classified as Generally Recognized As Safe (GRAS) by the U.S. FDA, making it suitable for all food contact applications.

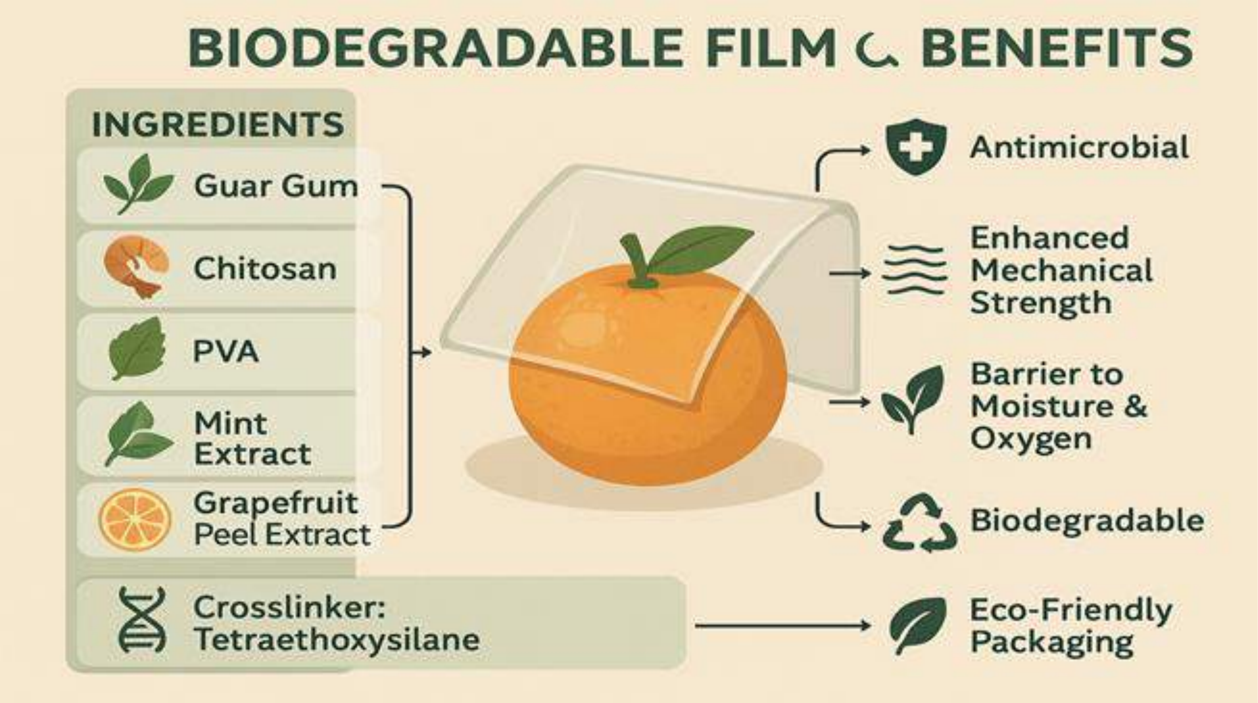




Provide DOI

Marzo-Gago et al. **2023**.

Biodegradable Antimicrobial Films



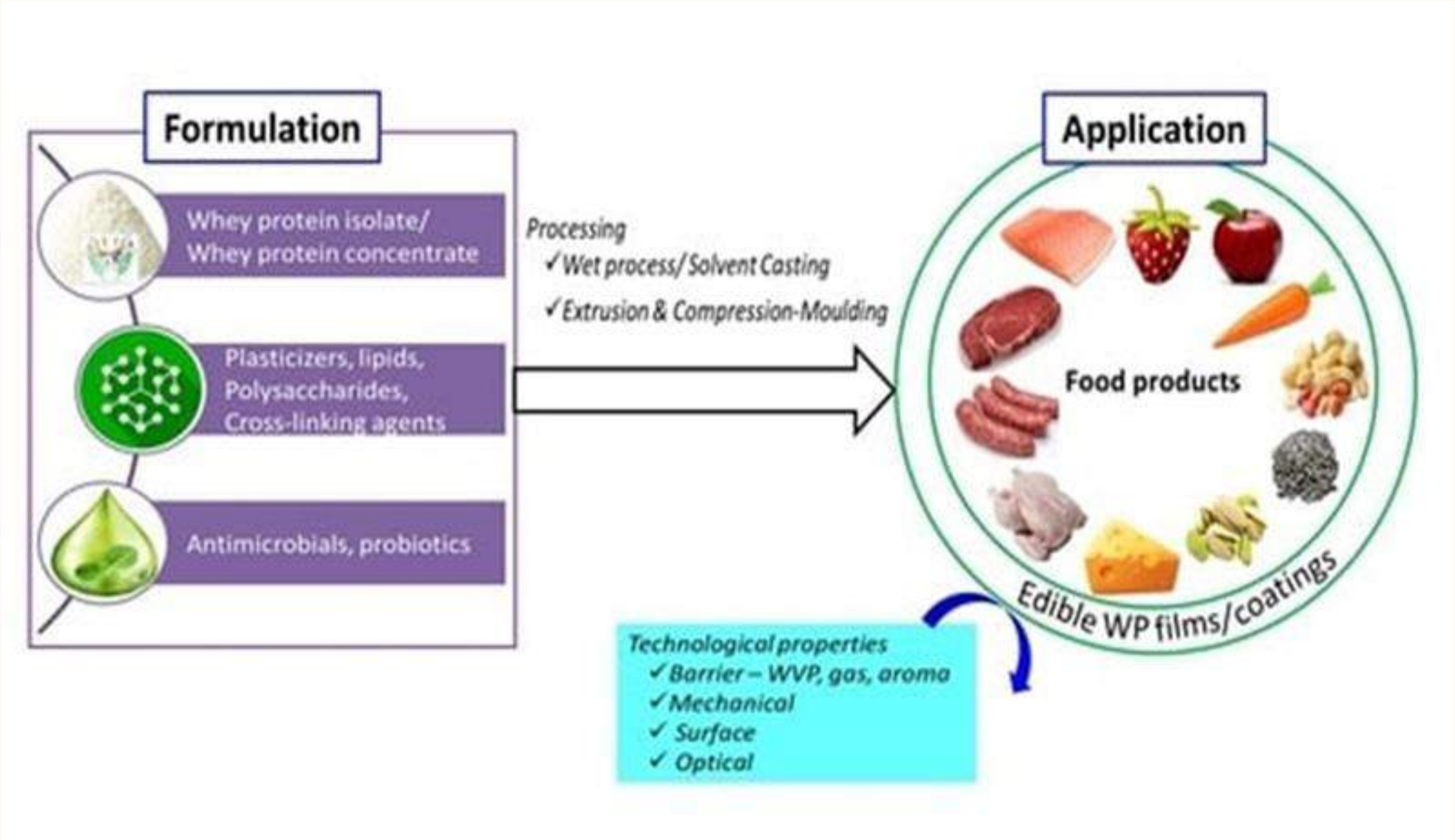
Bashir et al. developed a innovative biodegradable films by blending *guar gum*, *chitosan*, and *polyvinyl alcohol (PVA)*.

These films were further enhanced by incorporating *mint* and *grapefruit peel extracts*, both known for their natural antimicrobial and antioxidant properties. To improve mechanical strength and stability, the films were crosslinked using non-toxic *tetraethoxysilane (TEOS)*.

The resulting films showed improved **barrier**, **mechanical**, and **biological properties**, making them suitable for **food packaging applications**.

The use of plant-based materials and biodegradable polymers supports the development of sustainable and eco-friendly alternatives to synthetic plastic packaging.

Whey Biodegradable films and coatings

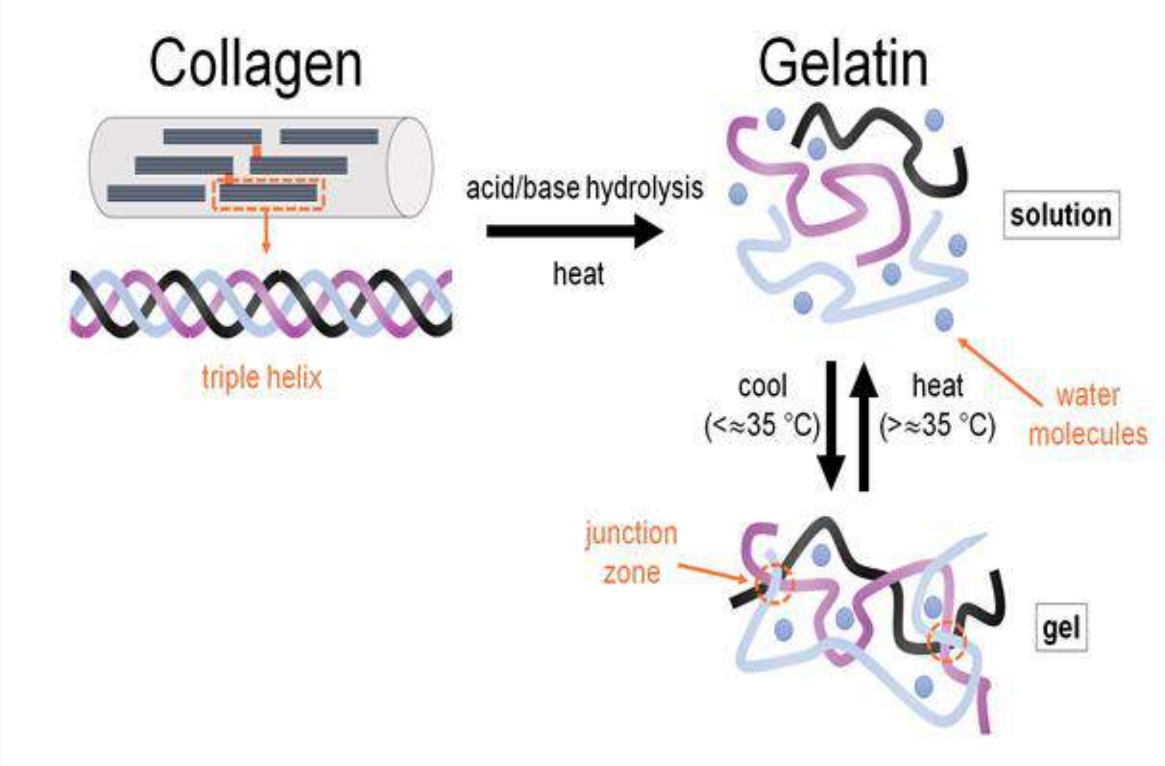


The dairy industry generates large volumes of liquid waste as a by-product during the casein coagulation process. This liquid, termed as dairy whey (DW) is a yellowish green colored, water-soluble protein by-product derived after casein extraction in cheese processing.

Yadav, et al., 2015. DOI:10.1016/j.biotechadv.2015.07.002

Meat industry

In the meat sector, slaughterhouses generate various animal by-products, such as organs, blood, bones, and fats. These materials can be processed into gelatin for coatings or used in composites. Derived from collagen in animal skin and bones (e.g., bovine and pork) and in fish by-products gelatine consists of a pool of protein segments carrying different molecular weights (100 to 300 kDa), along with high-molecular-weight aggregates and peptide fractions (<100 kDa).



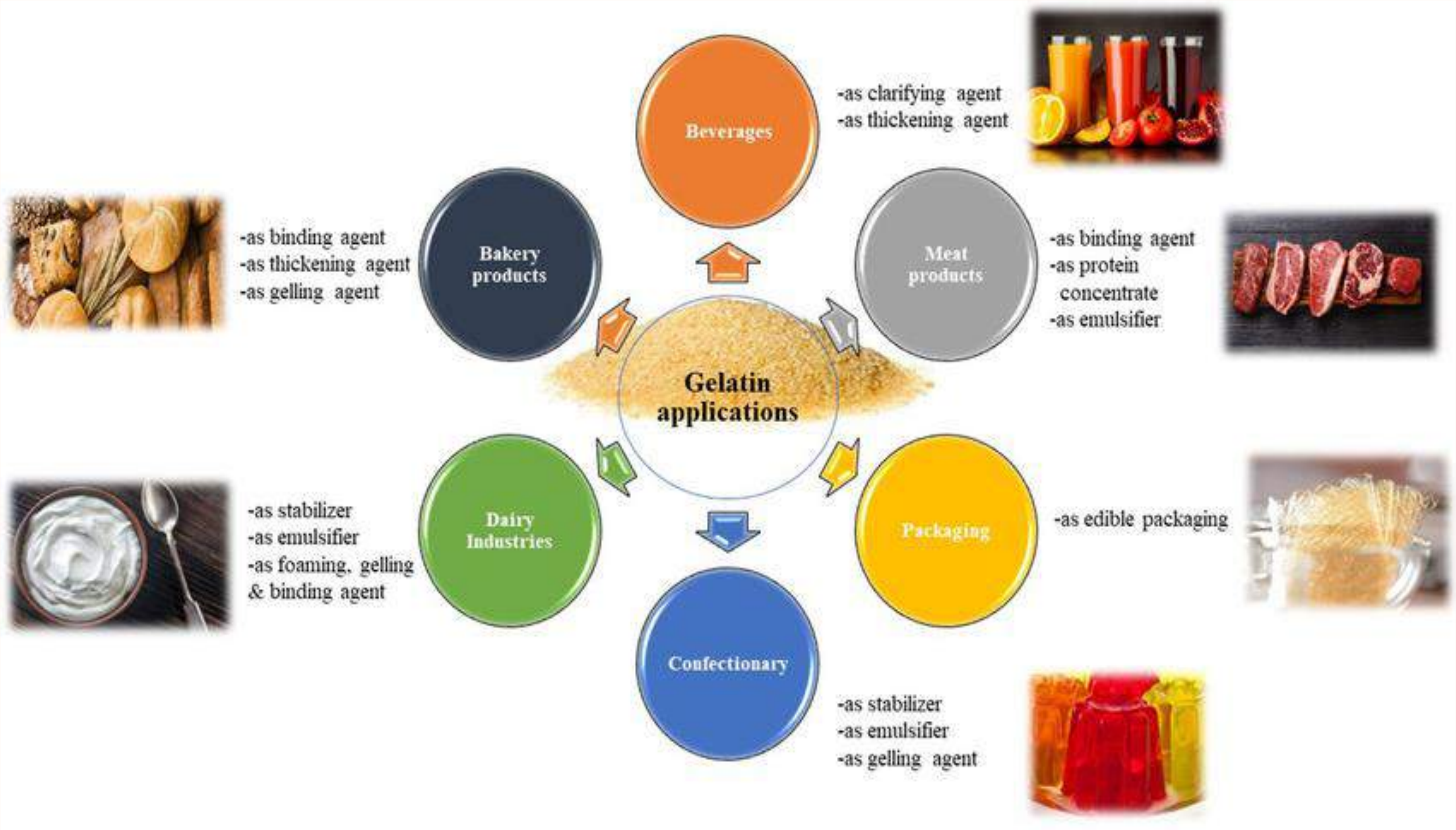
The gelatins extracted from porcine, poultry, and fish skins and untanned bovine hide wastes, or by-products can be used for the production of packaging films or edible coatings

Gelatin is an animal-based protein obtained by hydrolysis of collagen and is accepted as one of the most versatile biopolymers that are extensively utilized in the food, pharmaceutical, and biomedical industries.

The skins of pigs and cow are the main sources of gelatin as they are easily available. The commonly used gelatin sources reported are pigs' skin and cartilage (46%), and bovine hides (29.4%), bones (23.1%), and other sources (1.5%)

Nilsen-Nygaard et al. 2021
Li, et al., 2021 https://doi.org/10.1111/1541-4337.12715

Gelatin applications

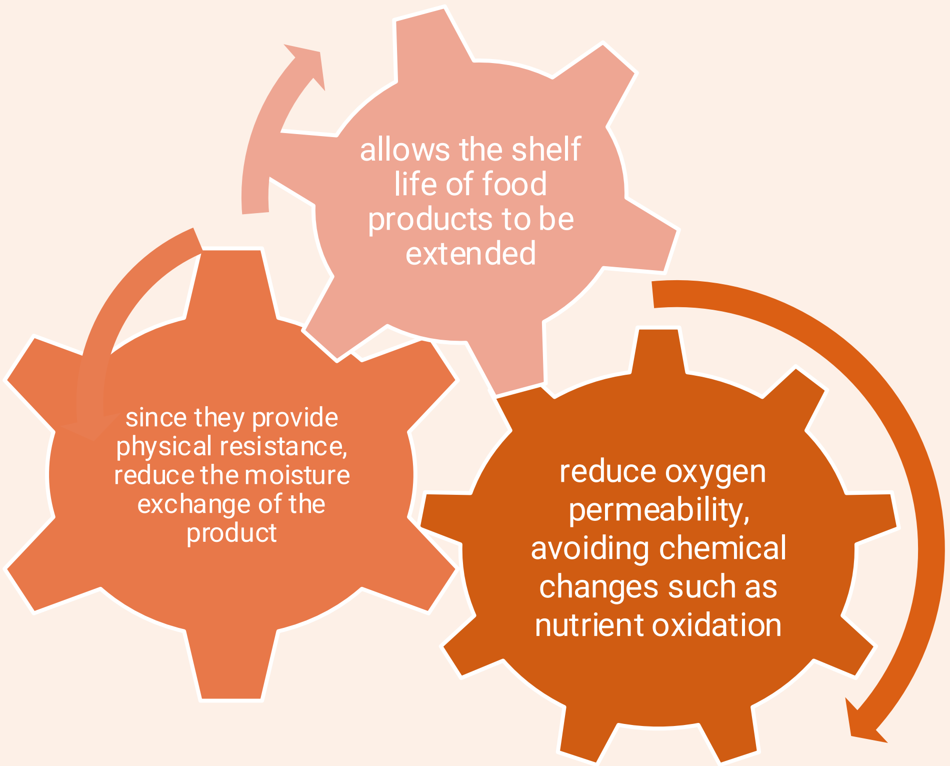


Usman et al. 2023. 10.1007/s13399-023-04547-5.

The vegetable oil industry

The vegetable oil industry, which includes the processing of sunflower, rapeseed and soybean seeds, produces groats and other residues rich in protein and fiber.

Properties of edible coatings obtained from groats:



Oilscakes

Oilcakes are the principal by-products obtained after the extraction of oil from the seeds. Then they are air-dried to remove the water before storage.

Generally, the meal is used in animal diet as feeds because it is an excellent source of protein and thus produces an increase in biomass. It can be also used for human consumption (Serrapica, F.; et al., 2019)

The essential amino acids present in sunflower press-cakes are cysteine, methionine, leucine, valine, isoleucine, tryptophan, alanine and phenylalanine [Petraru, A.; et al., 2021].

Edible films are suitable for packaging if they possess strong structural, biological, optical, and barrier properties. They should effectively block scents, vapor, oil, water, oxygen, and light to prevent lipid oxidation, moisture loss, and discoloration, thereby preserving product quality and appearance.

Edible films must offer good solubility, antimicrobial activity, and favorable sensory properties. Ultimately, their commercial viability depends on their edibility.

Serrapica et al., **2019.** doi:https://doi.org/10.3390/ani9110918
Petraru et al., **2021**. DOI: http://dx.doi.org/10.4316/fens.2022.035

Sunflower cake is a by-product that remains after the extraction of oil from oilseeds by the process of pressing, primarily in the production of edible nonrefined or cold pressed oils. Cakes are rich in proteins and fibers, making them excellent sources for biopolymer production.

Protein-Based Biopolymers

Soybean Cake: Contains soy protein, used to produce biodegradable films with good mechanical and barrier properties.

Sunflower Cake: Rich in sunflower protein, suitable for film formation with moderate water resistance.

Rapeseed (Canola) Cake: Contains rapeseed protein, utilized in creating edible films with antioxidant and antimicrobial activity.

Peanut Cake: High in protein, used for making biodegradable films with good flexibility.

Composite Biopolymers

Mixed Oilseed Cakes (e.g., blends of soybean and sunflower): Used to formulate composite biopolymer films by combining proteins and fibers for improved mechanical and barrier performance.

Cakes of sunflower seeds obtained from the production of cold pressed

Popović et al. 2020. ISBN 9780128181881.

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

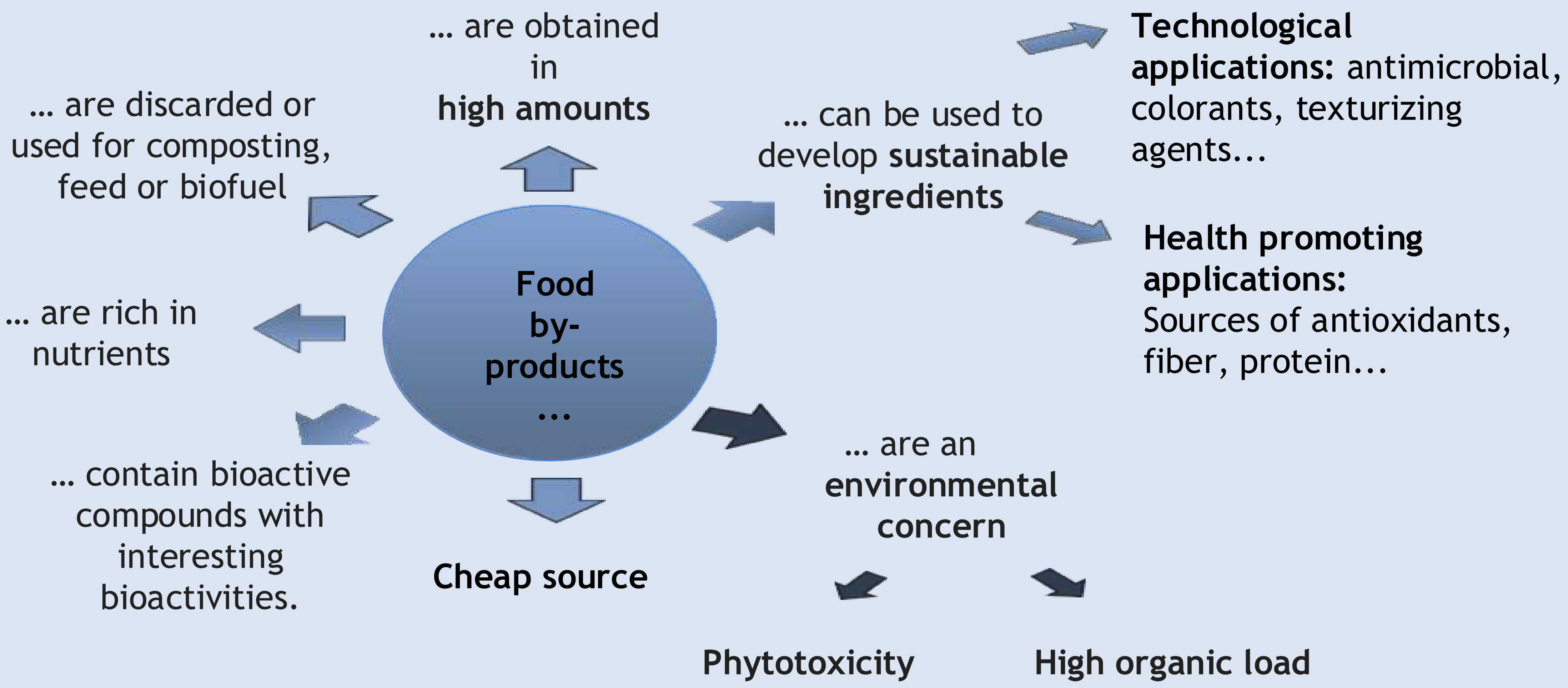
U.PORTO FACULDADE DE FARMÁCIA UNIVERSIDADE DO PORTO

Project code: 2024-1-RO01-KA220-HED-000246776

Chapter 4: New Food by-Products Enhance Nutritional and Functional Potential

Co-funded by the European Union

Why food by-products?



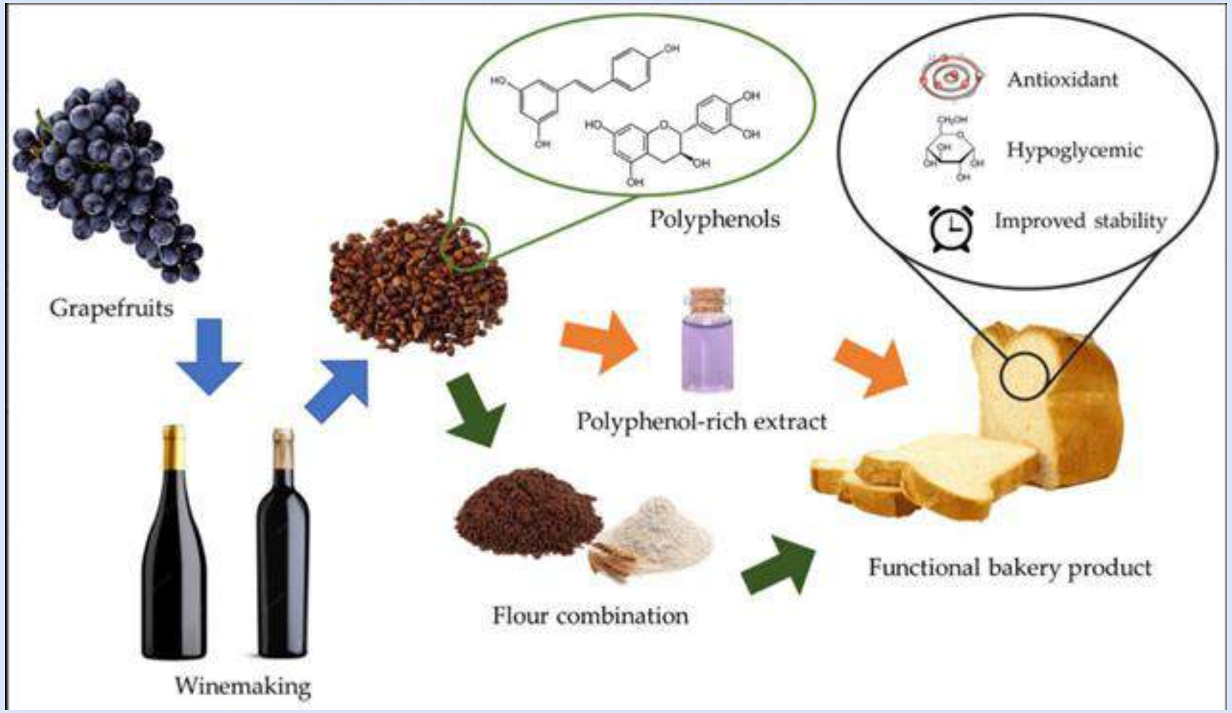
Wine by-products Industry: Grape pomace case study

The recovery of wine waste, such as grape pomace, can be easily and beneficially reintegrated into the bakery industry.

These wastes represent natural sources of antioxidants, the reuse of which allows the reduction of synthetic analogues linked to negative side effects.

Incorporating these antioxidants as preservatives maintains the stability of the final product, while also adding potential health benefits.

This reuse of grape pomace can be an effective strategy for creating value-added products, while reducing the volumes of this biomass destined for landfill, thus promoting a circular economy model.



Echave, J.; et al., **2023**, https://doi.org/10.3390/ECP2023-14676

Biscuits enriched with red grape pomace

Biscuits are a staple food in the diet of most populations around the world.

In general, biscuits are consumed daily, being suitable for many meal occasions, from breakfast to an after-dinner snack.

Biscuits are generally characterized by a optimal nutritional profile, being a source of carbohydrates with a high glycemic index, sugar, and saturated and/or trans fatty acids.

Grape pomace flour

Grape skins, seeds and stalks are obtained from the wine or grape juice production industry immediately after pressing.

Fresh grape pomace is dried at 50°C for 24 hours and subjected to the grinding process to obtain flour.

Grape pomace flour was sifted and included in the preparation of biscuits as a partial replacement for wheat flour.

Wine making

Grape pomace

Grape pomace flour

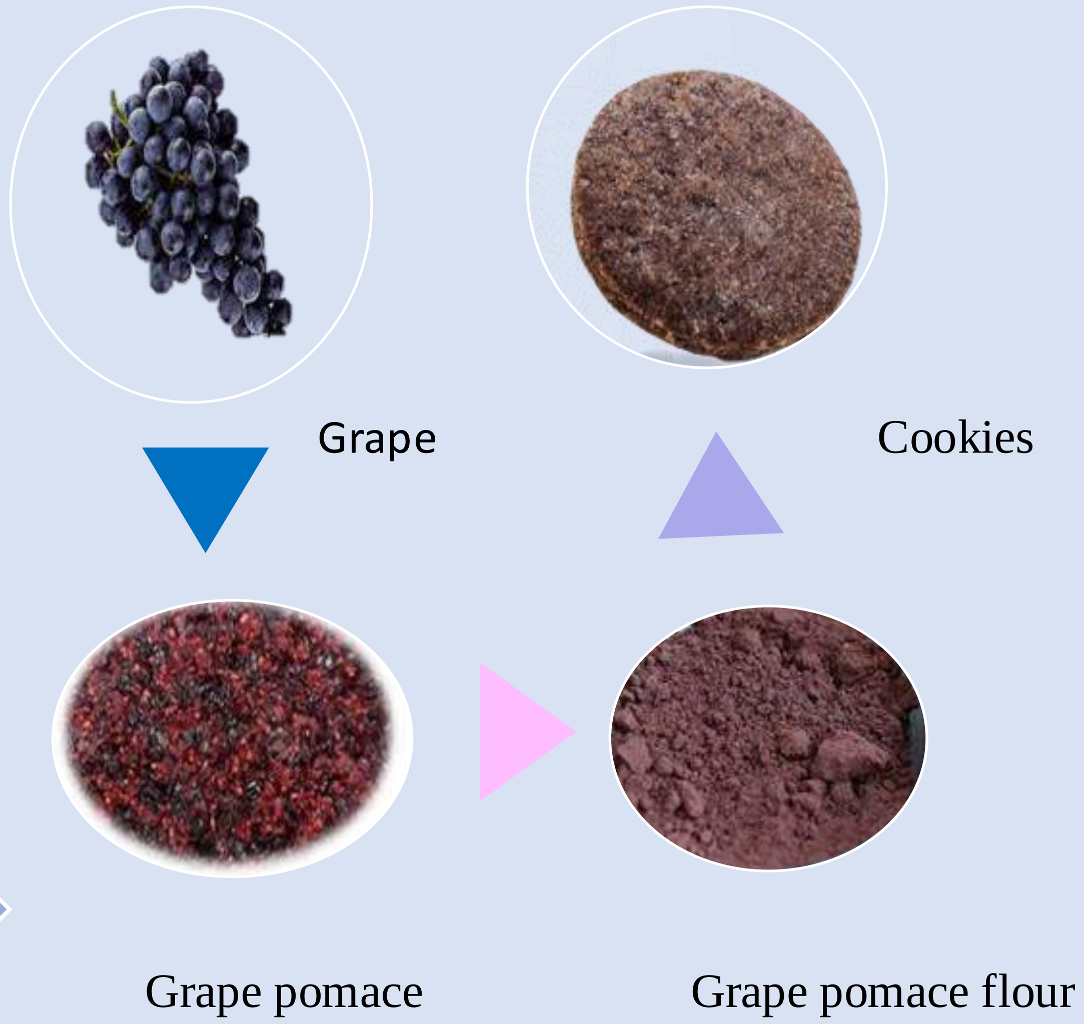
Biscuits

Biscuits enriched with red grape pomace

The biscuits can be produced from a basic formula containing wheat flour, white sugar, olive oil, milk and baking powder.

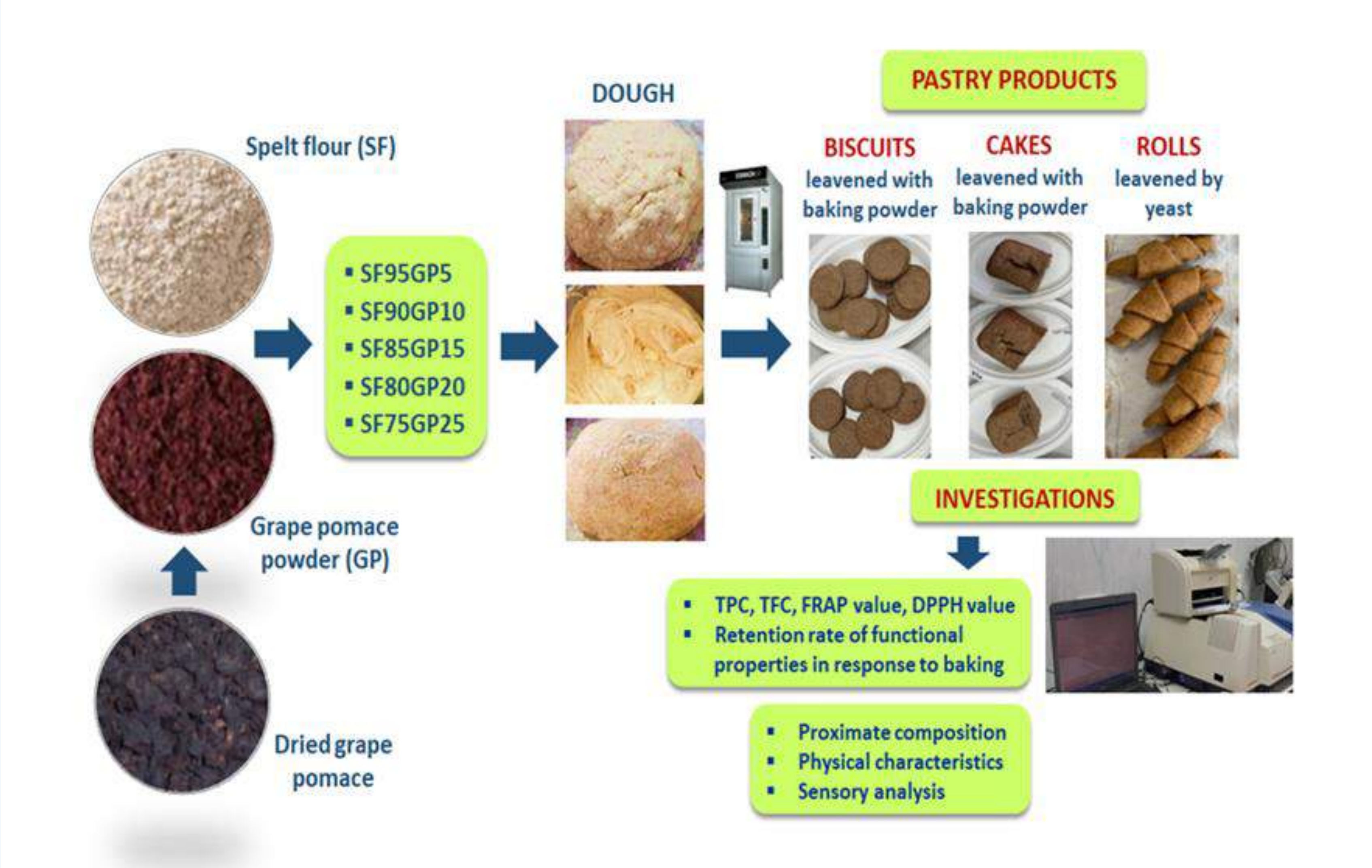
The amount of grape pomace flour replaced 20%-30% of the amount of wheat flour.

The percentage of grape pomace flour was selected as a compromise to maximize potential health benefits while ensuring dough workability.



Pastry with Grape Pomace Powder

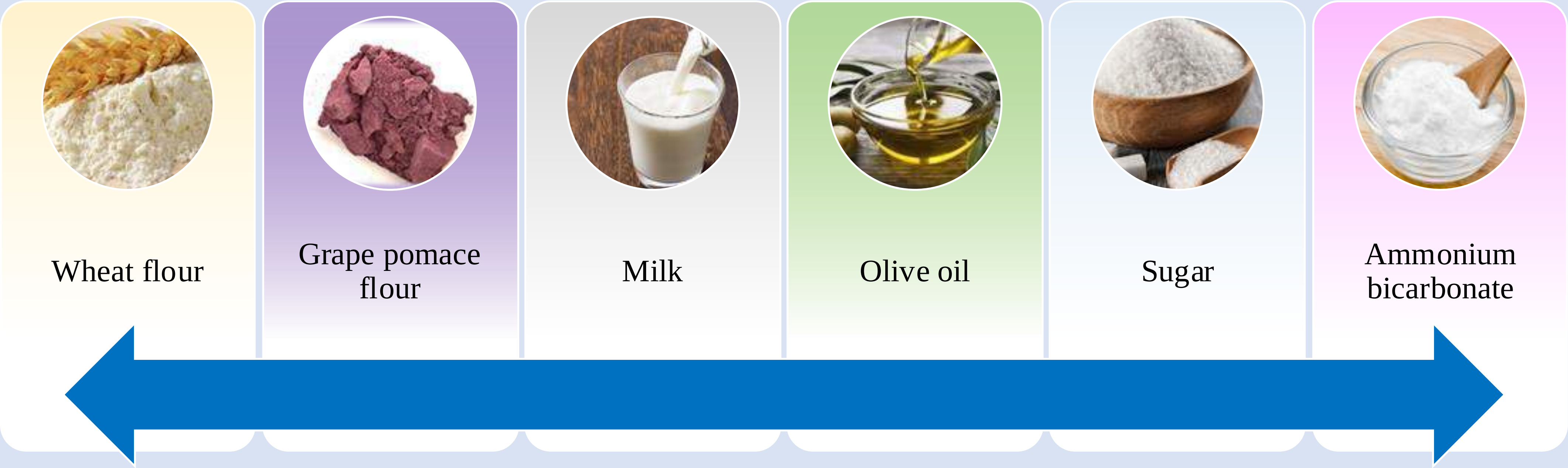
Biscuits, cakes, and rolls—were developed using spelt wheat flour and varying percentages of grape pomace (GP).



Incorporating grape pomace flour into the recipes improved the nutritional profile by increasing the amount of fiber and polyphenols and reducing lipid and energy content.

Poiana et al., 2023; https://doi.org/10.3390/foods12173239

Biscuits enriched with red grape pomace



Ingredients for biscuits

Biscuits enriched with red grape pomace

Mixing the wheat flour, grape pomace flour, sugar and oil with a mechanical whisk for 5 minutes.

Adding milk and ammonium bicarbonate and kneading mechanically for 12 minutes.

Manually shaping the dough with a diameter of 6 cm and a thickness of 0.3 cm.

The cookies were baked in an electric oven for 16 minutes at 160 ◦C.

The process of making biscuits

GRAPE POMACE BISCUITS

Physical-chemical properties (according to the technical specifications)

Proprieties	Value
Humidity (%)	16.8
Proteins (%)	8.46
Lipids (%)	22.17
Fatty acids (%)	12.36
Carbohydrates (%)	46.16
Energy value, kJ/100g	1770.21
Sugar (%)	16.69
Fiber (%)	6.42
Salts (%)	0.25

Sensory properties (according to the technical specifications)

Proprieties	Admissibility conditions
Aspect	Round flat pieces, whole, with semiclusive surface, smooth, without basics, Diameter 8 cm
Colour	Light to reddish brown characteristic of the grape pomace. Whitish or burnt coloration is not allowed
Taste	Pleasant, characteristic, suitable for sweet, without sour or bitter taste
Flavour	Pleasant, characteristic of the sea buckthorn
Smell	Without foreign smell (moulds, rancid, etc.)

Other uses of grape pomace

Grape pomace and its constituents have been added to a variety of foods, including bread, pastries, cookies, pasta, expanded cereals, and others.

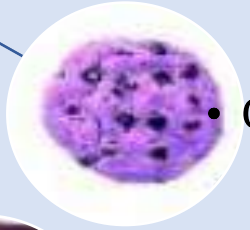
Grape pomace

Food products

Bread

Extruded cereals

Muffins



Cookies

Noodles

In addition to anthocyanins, grape pomace contains flavonoids and procyanidins from grape seeds, contributing to the food products remarkable antioxidant capacity.

GRAPE POMACE PASTA

Ingredients

Spelta wheat flour, grape pomace premix, eggs, salt, water

Physical-chemical properties (according to the technical specifications)

Proprieties	Value
Humidity (%)	12.4
Proteins (%)	13.6
Lipids (%)	5.7
Carbohydrates (%)	60
Energy values, kcal/100g	262
Sugar (%)	0.8
Fatty acids (%)	1.2
Salts (%)	0.8
Fiber (%)	8.4

Sensory properties (according to the technical specifications)

Proprieties	Admission conditions
Aspect	smooth surface without traces of unfermented flour, in the break of glassy appearance, punctate particles of brown porosity of Spelta flour are allowed
Colour	reddish-brown specific to grape pomace
Taste	Pleasant, characteristic, suitable for sweet, without sour or bitter taste
Foreign corps	absent

GRAPE POMACE MUFFINS

Ingredients

Spelta wheat flour, grape pomace premix, Eggs, butter, sugar, vegetal oil, salt, baking power, flavours

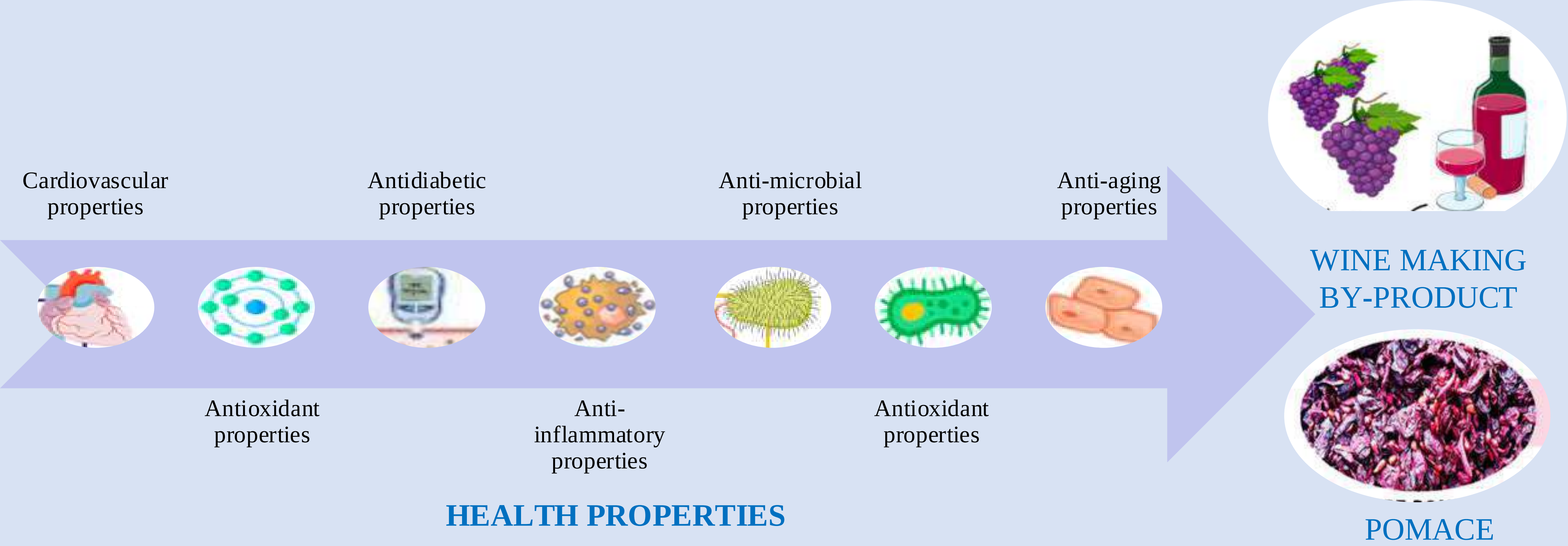
Physical-chemical properties (according to the technical specifications)

Proprieties	Value
Humidity (%)	21.7
Proteins (%)	6.7
Lipids (%)	27.9
Carbohydrates (%)	40.4
Energy value, kcal/100g	443.83
Fatty acids (%)	3.3
Sugars (%)	25
Salt (%)	0.3
Fibres (%)	3.3

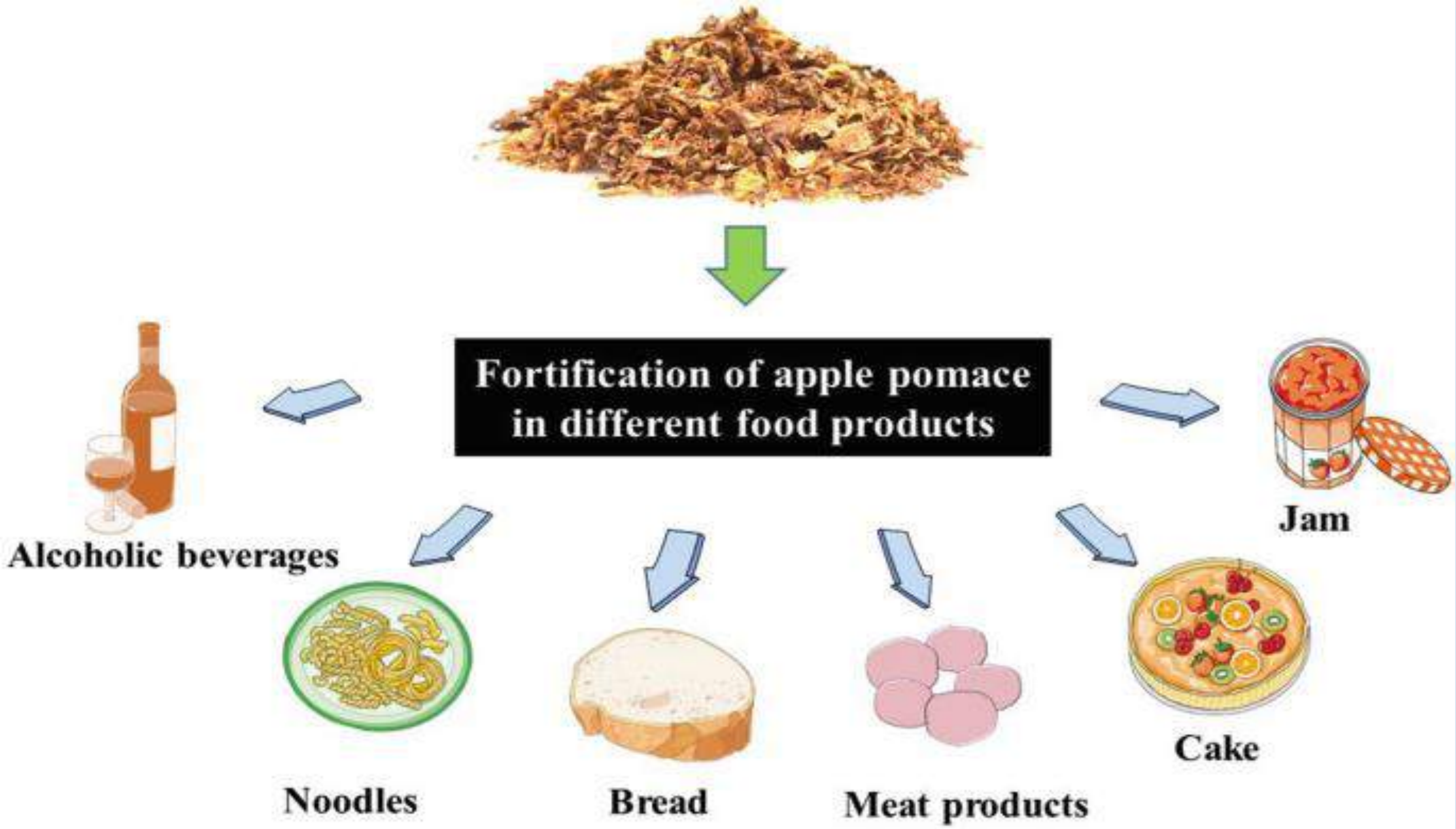
Sensory properties (according to the technical specifications)

Proprieties	Admissibility conditions
Shape	Characteristic for Muffins product
Appearance	matte surface, unburned, slightly cracked
Colour	brown, uniform
Core	homogeneous mass, characteristic of a well-baked product, in section without lumps or traces of unfrozen flour
Taste	Pleasant, characteristic for grape pomace, suitable for sweet, without sour or bitter taste
Smell	Pleasant, fruity, characteristic, without a foreign smell (of mold, rancid, stale, etc.)
Consistency	dense core, slightly wet to touch, slightly crumbly with voids

Effects of polyphenols isolated from grape pomace on human health



APPLE PROCESSING BY-PRODUCTS AS A POTENTIAL SOURCE OF BIOACTIVE MOLECULES



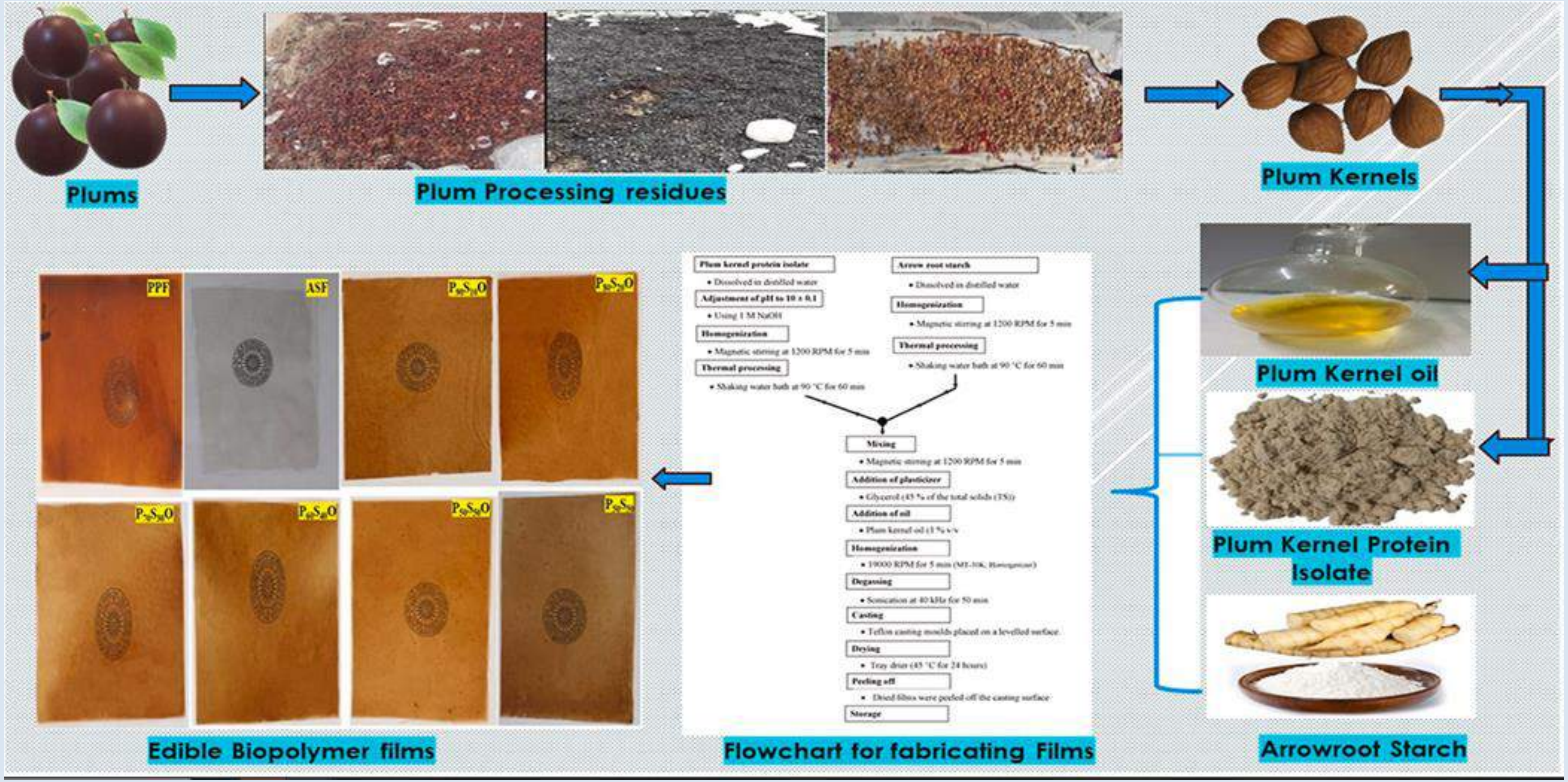
please Anamaria add source, authors and doi

APPLE PROCESSING BY-PRODUCTS AS A POTENTIAL SOURCE OF BIOACTIVE MOLECULES

Fig By-products and final baked biscuits. BJS: biscuits with JS; JS: Jonathan skin; BJP: biscuits with JP; JP: Jonathan pomace; BGS: biscuits with GS; GS: Golden skin; BGP: biscuits with GP; BCS: biscuits with WF; GP: Golden pomace; BCS: biscuits control sample; WF: wheat flour.

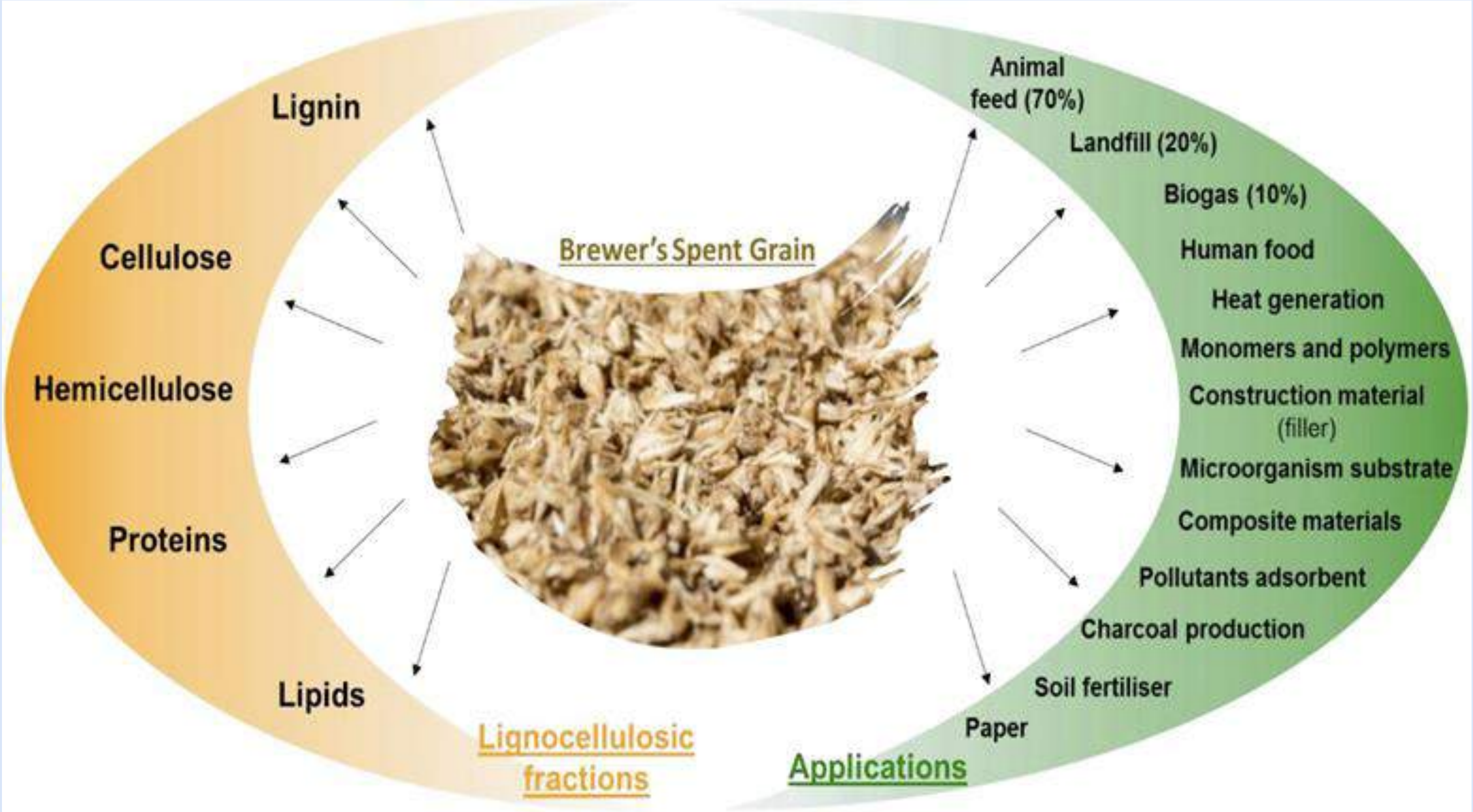
Fărcaș, A.C.; Socaci, S.A.; Chiș, M.S.; Dulf, F.V.; Podea, P.; Tofană, M. Analysis of Fatty Acids, Amino Acids and VolatileProfile of Apple By-Products by Gas Chromatography-Mass Spectrometry. *Molecules* **2022**, *27*, 1987.

PLUM PROCESSING BY-PRODUCTS AS A POTENTIAL SOURCE OF BIOACTIVE MOLECULES

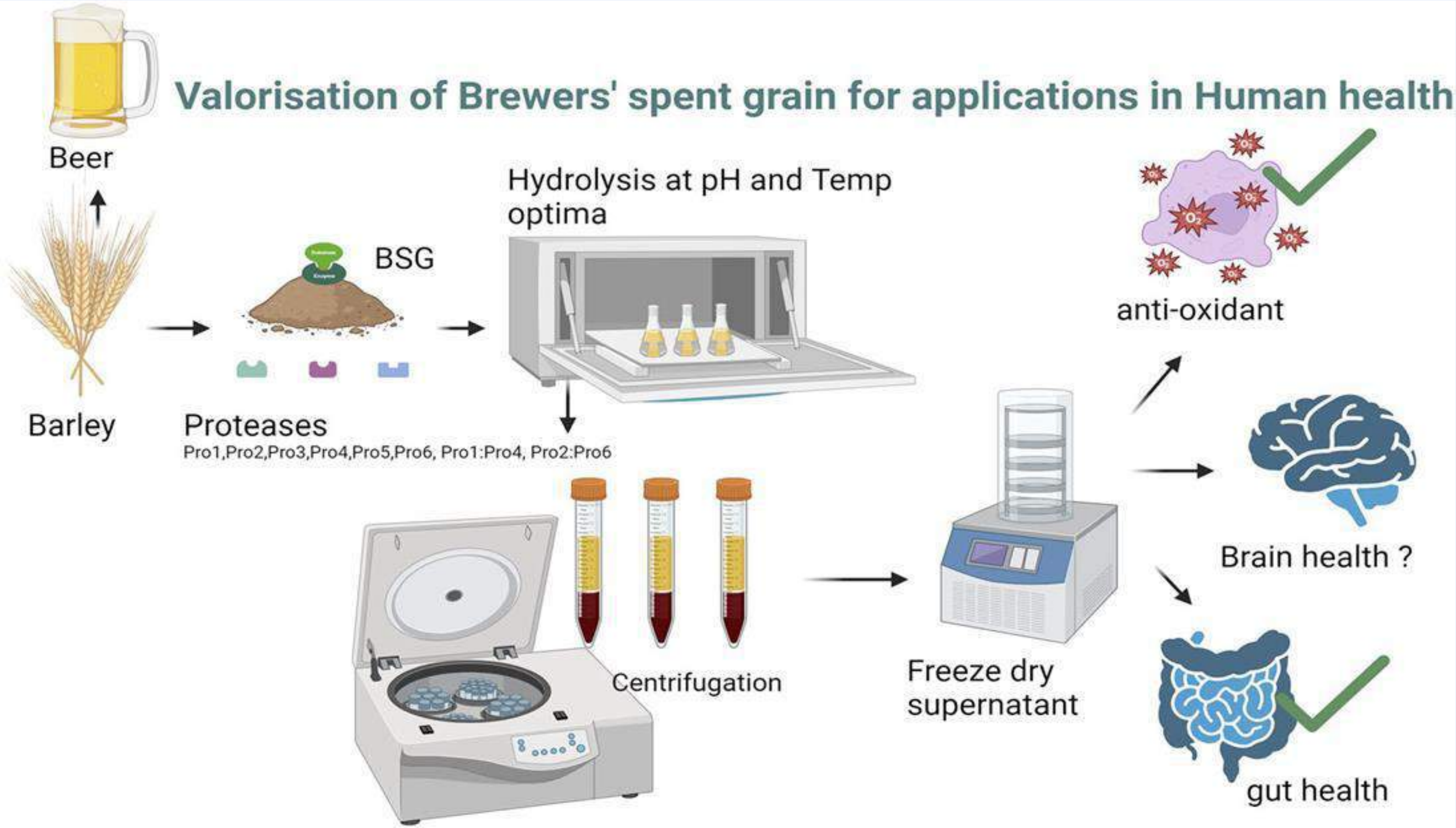


Sheikh et al., 2023, https://doi.org/10.1016/j.foodhyd.2023.108790

Beer by-products valorization



Fractions present in BSG's lignocellulosic biomass and their potential applications,
Arnaud 2024, https://hal.science/hal-04437457v1



Naik et al., 2024

https://doi.org/10.1007/s43393-024-00241-3

Direct integration of BSG in food composition – cases study

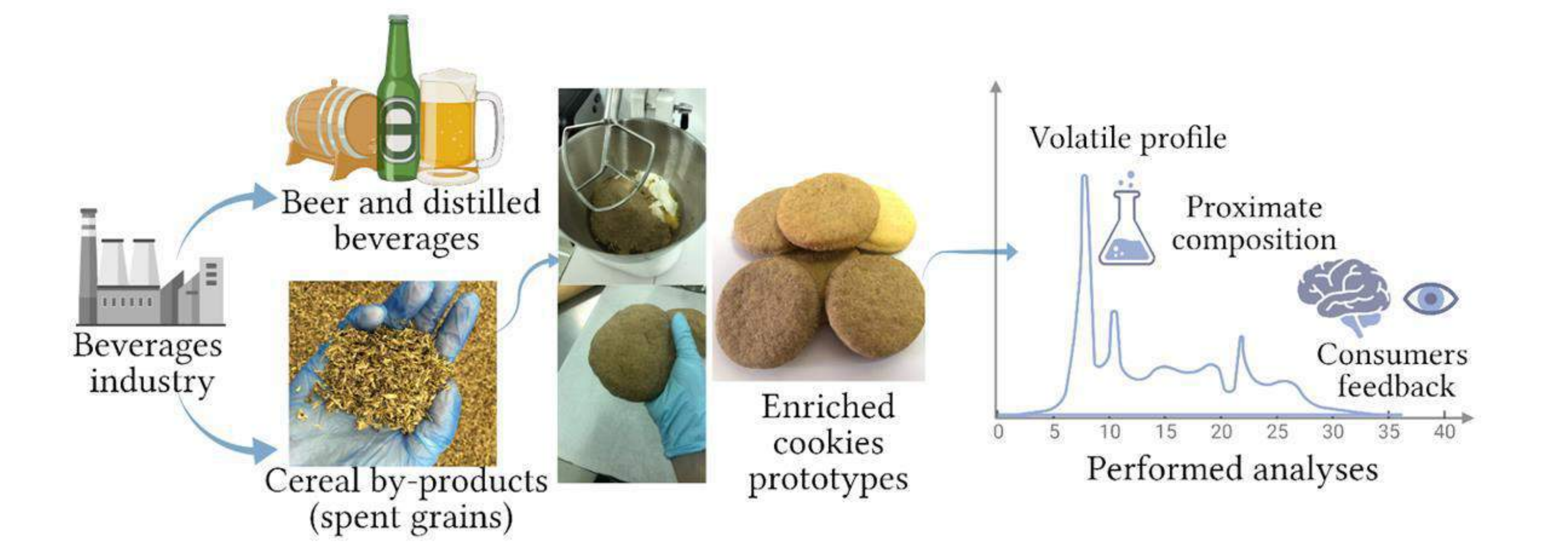


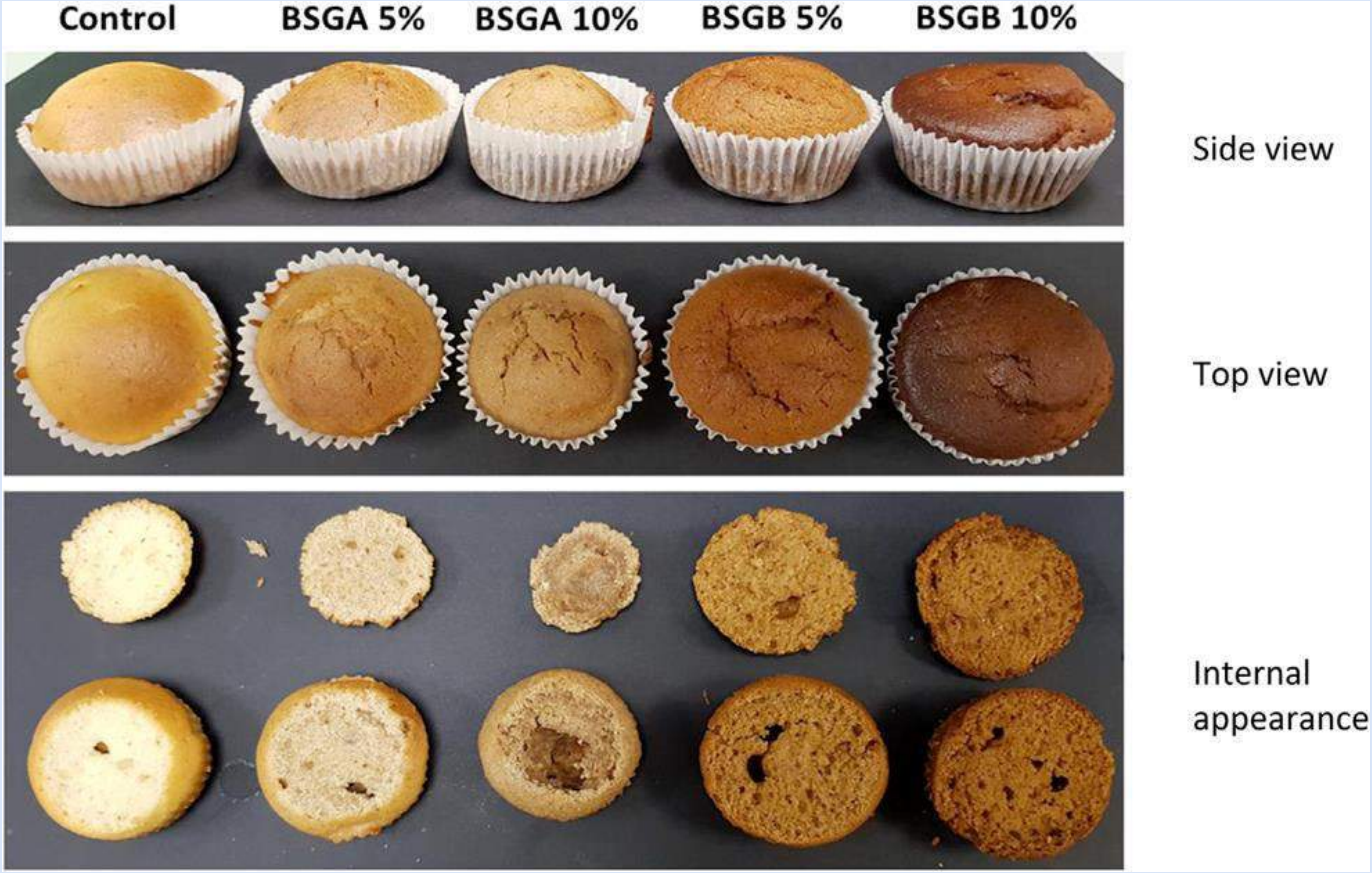
Figure – Graphic abstract of the experimental design

Source: Farcas, A.C.; Socaci, S.A.; Chiș, M.S.; Pop, O.L.; Fogarasi, M.; Păucean, A.; Igual, M.; Michiu, D. Reintegration of Brewers Spent Grains in the Food Chain: Nutritional, Functional and Sensorial Aspects. *Plants* **2021**

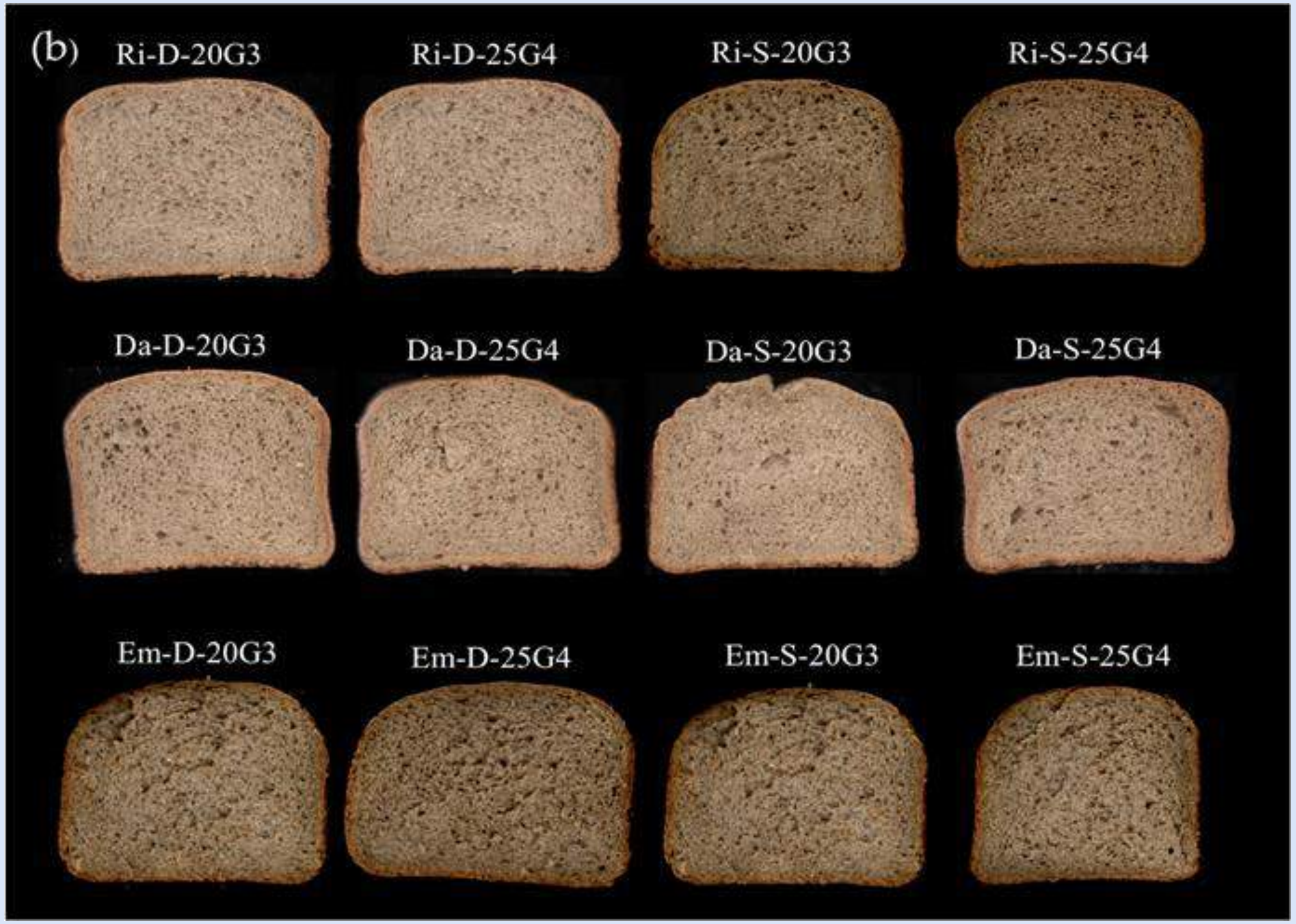
Direct integration of BSG in food composition – cases study

Figure – Crackers graphic abstract of the experimental design

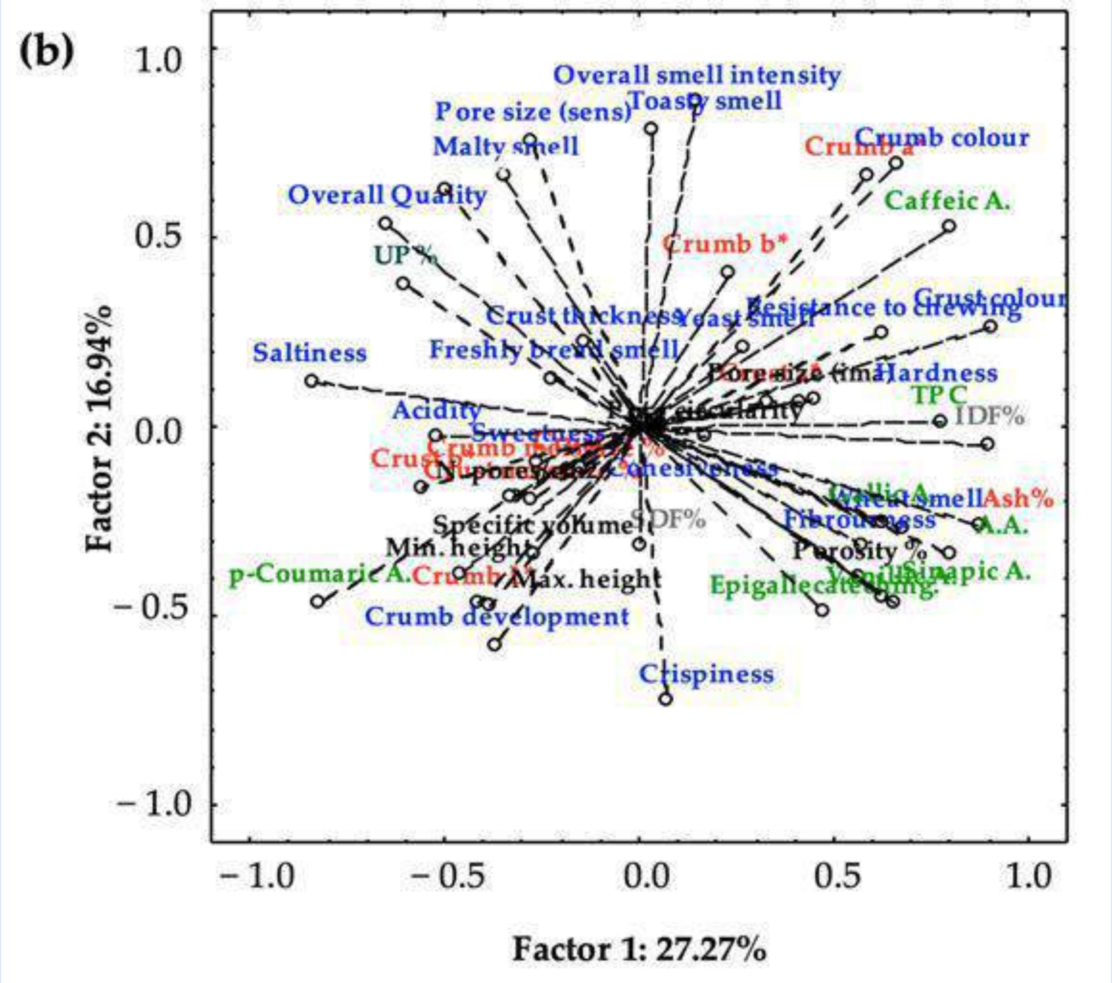
Source: Farcas, A.C.; Socaci, S.A.; Chiș, M.S.; Pop, O.L.; Fogarasi, M.; Păucean - disertation thesis



Visual appearance of muffins produced for the sensory study with different levels (0–10%) of supplementation of brewers' spent grain (BSG) sample A (BSGA) and enzymatically hydrolysed BSG sample B (BSGB), Cermeño et al., 2021



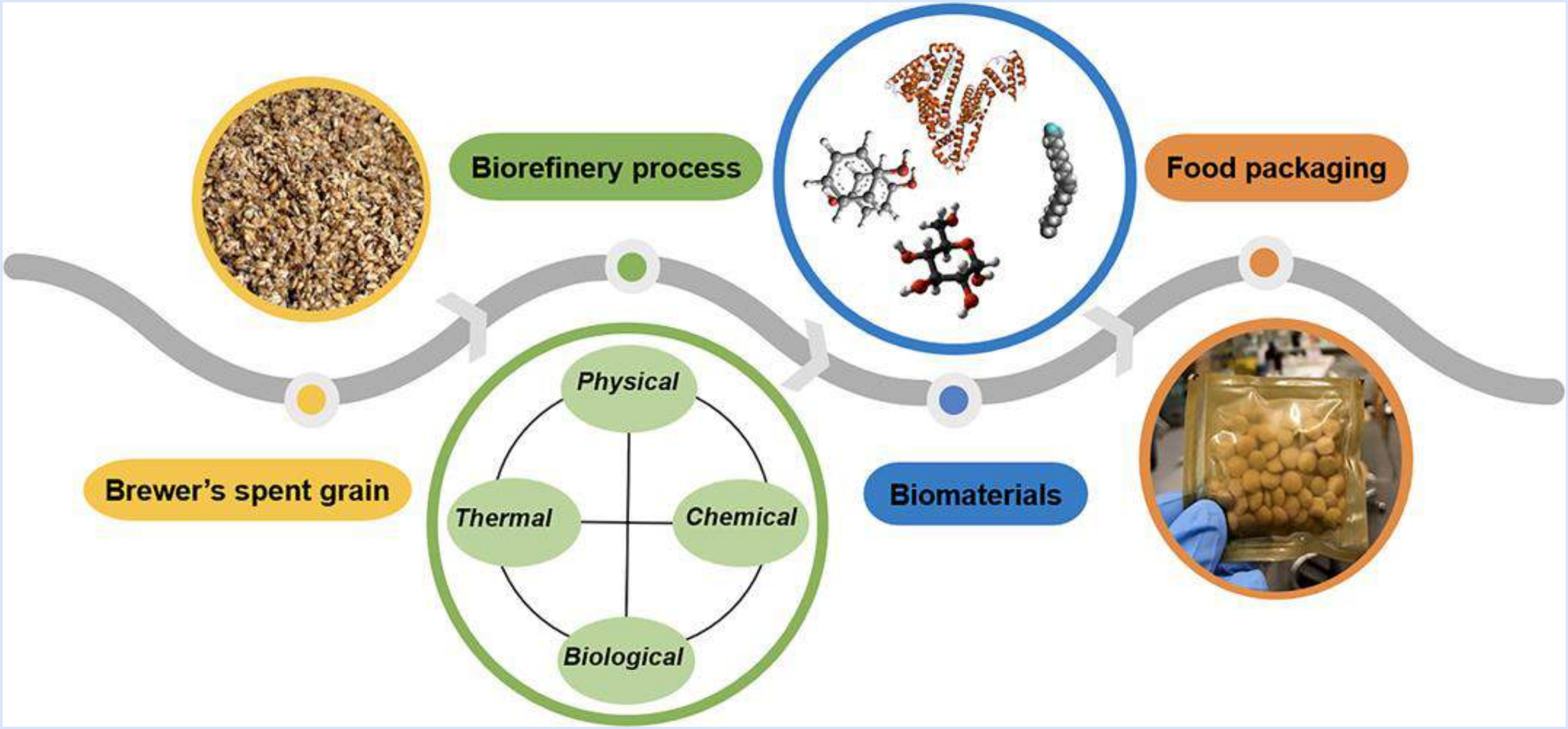
(b)



(a)

Slices of control bread (a) and (b) the 12 functional breads produced with brewer spent grain addition; **(b)** projections of functional obtained breads Phenolics are in green font; Insoluble and Soluble Dietary Fibres are in purple; UP% is in dark green; Moisture %, Ash %, and colorimetric indices are in red; structural parameters are in black (Baiano et al., 2022).

Schematic of biorefinery process to transform BSG into biodegradable food packaging



Ghazanfar Zadeh et al., 2023
https://doi.org/10.1016/j.jclepro.2022.135726

Olive by-products

Valorization strategies

Sprelive — **Fresh olive pomace**

Extracted olive pomace — **Soilife**

Patent PCT/IB2018/060111

Foodstuff composition, process and uses thereof

This functional ingredient is a mixture of bioactive compounds, in particular hydroxytyrosol, tyrosol, sterols, tocopherols, triterpenes, coenzyme Q10, K, Mg and Ca, among others, obtained from olive pomace by mechanical pressing.

Patent PCT/IB2017/053422

Olive pomace products, method of production and their uses

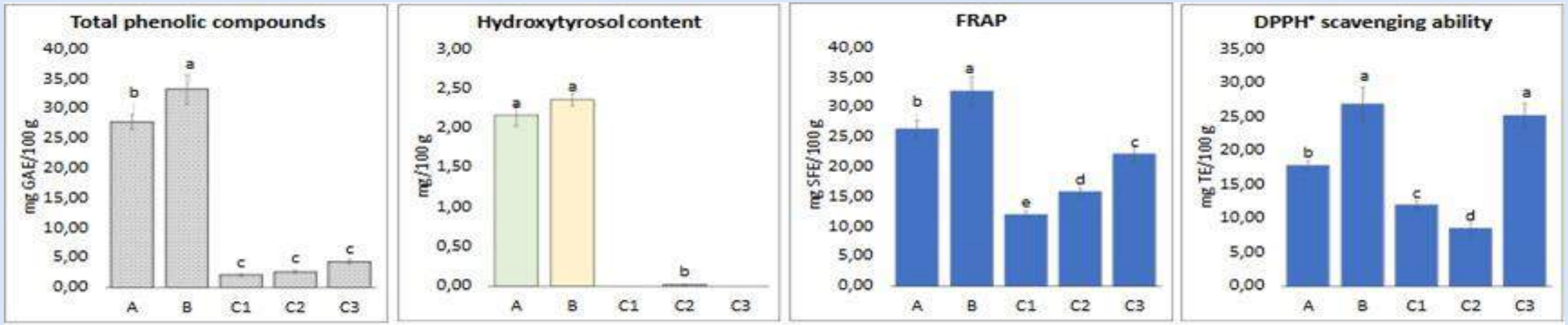
The present disclosure relates to olive pomace and a green methodology to obtain derivative products for it valorization.

The obtained products may be used as a solid substrate, nutraceuticals, cosmetics or food supplements.

Olive oil-based spreadable cream with olive pomace extract

70% olive oil
Water
Technological agents
Extract

70% olive oil
Coconut oil
Water
Technological agents
Extract



GAE, gallic acid equivalents; FSE, ferrous sulfate equivalents; TE, trolox equivalents; FRAP, ferric reducing antioxidant power; DPPH•, 2,2-diphenyl-1-picrylhydrazyl radical scavenging ability. Data expressed as mean ± standard deviation. Different lower-case letters mean significant differences between samples.

Patent: PCT/IB2018/060111 – Foodstuff composition, process and uses thereof

Olive pomace pasta

Pasta Incorporating Olive Pomace: Impact on Nutritional Composition and Consumer Acceptance of a Prototype

by Diana Melo Ferreira [1,†], Bárbara C. C. Oliveira [1,†], Carla Barbosa [1,2], Anabela S. G. Costa [1], Maria Antónia Nunes [1], Maria Beatriz P. P. Oliveira [1,*] and Rita C. Alves [1]

[1] LAQV/REQUIMTE, Department of Chemical Sciences, Faculty of Pharmacy, University of Porto, Street of Jorge Viterbo Ferreira, 4050-313 Porto, Portugal

[2] CISAS/IPVC, Polytechnic Institute of Viana do Castelo, Avenue of Atlantic, 4900-348 Viana do Castelo, Portugal

[*] Author to whom correspondence should be addressed.

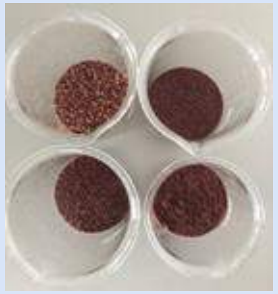
[†] These authors contributed equally to this work.

Foods **2024**, *13*(18), 2933; https://doi.org/10.3390/foods13182933

Olive pomace

Freeze-dried and milled

- Dried 40 ˚C 48h
- Dried 70 ˚C 24h



Sieved for stone fragments removal

After chemical analysis results, olive pomace dried at 70 °C 24 h was selected for pasta incorporation

Benefits of incorporation of olive pomace in foods:

- Circular economy
- Upcycling of OPP
- Development of new food products
- Valorization of the olive oil sector

Olive pomace pasta

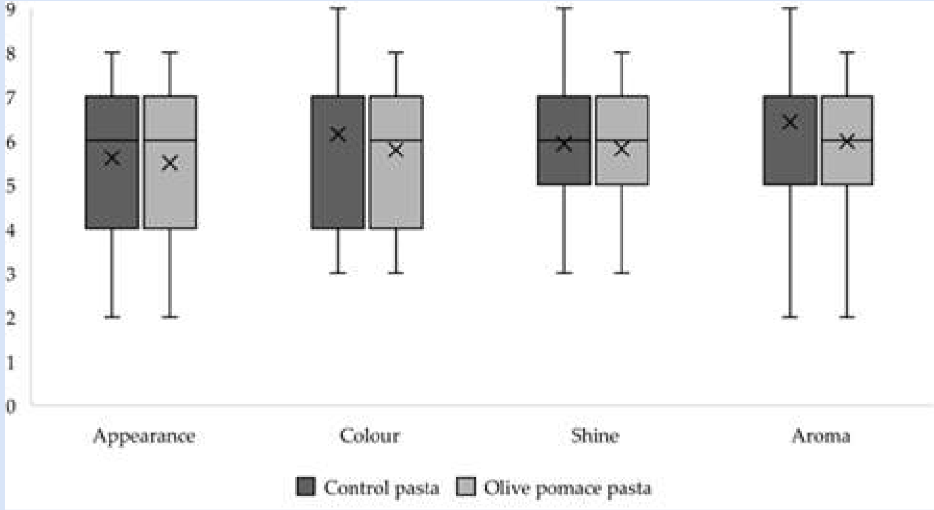
- Pasta dried at 50 ˚C 5 h
- Cooked at 100 ˚C 10 min

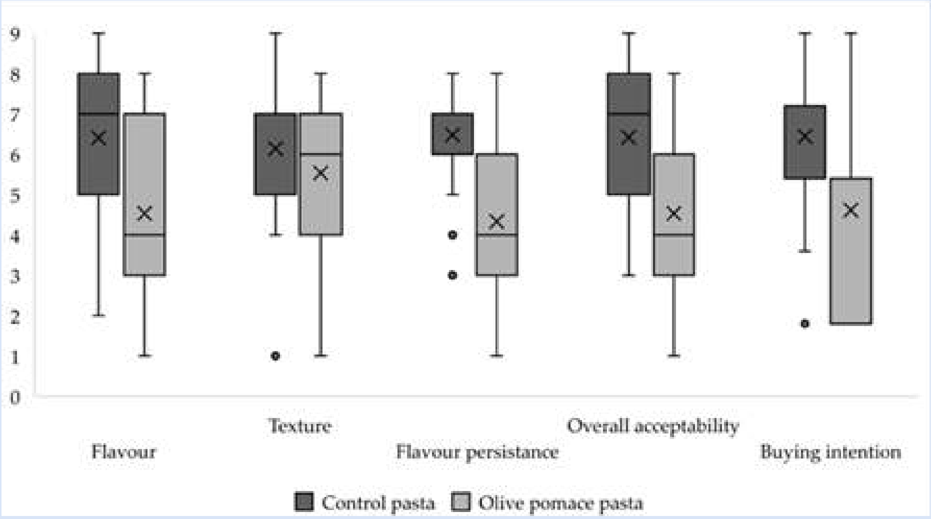
Enriched pasta had increased macronutrients, vitamin E, and antioxidant activity

200 g wheat flour + 110 mL water

185 g wheat flour + 15 g olive pomace + 110 mL water

Sensory analysis

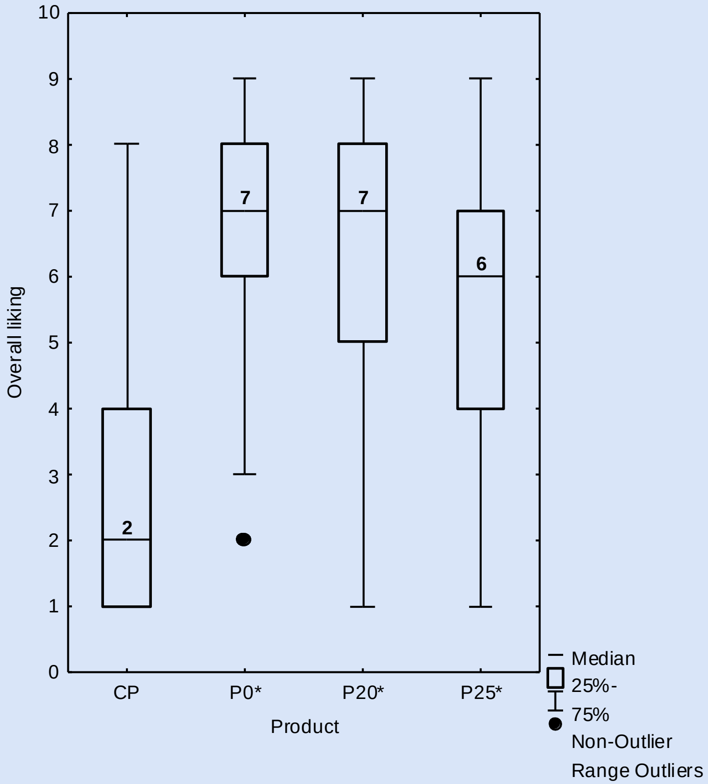




Olive pomace pâtés

Olive pâté	Ingredients
Olive pâté (P0)	75% depicted black oxidized olives, 10% vinegar, 10% EVOO, 3% aromatic herbs, 1% garlic powder, and 1% salt.
Olive pâté with 20% HT-OPP (P20)	55% depicted black oxidized olives, 20% HT-OPP, 10% vinegar, 10% EVOO, 3% aromatic herbs, 1% garlic powder, and 1% salt.
Olive pâté with 25% HT-OPP (P25)	50% depicted black oxidized olives, 25% HT-OPP, 10% vinegar, 10% EVOO, 3% aromatic herbs, 1% garlic powder, and 1% salt.

High Pressure Processing (HPP)



source: original

Olive pomace and cosmetic application

Chemical and Rheological Characterization of a Facial Mask Containing an Olive Pomace Fraction

by Raquel Rodrigues [1,†], Joana C. Lobo [1,†], Diana M. Ferreira [1], Ewa Senderowicz [1], M. Antónia Nunes [1], M. Helena Amaral [2,3,*], Rita C. Alves [1,*] and M. Beatriz P. P. Oliveira [1]

[1] REQUIMTE/LAQV, Department of Chemical Sciences, Faculty of Pharmacy, University of Porto, R. J. Viterbo Ferreira, 228, 4050-313 Porto, Portugal

[2] Associate Laboratory i4HB—Institute for Health and Bioeconomy, Faculty of Pharmacy, University of Porto, 4050-313 Porto, Portugal

[3] UCIBIO—Applied Molecular Biosciences Unit, MEDTECH, Laboratory of Pharmaceutical Technology, Department of Drug Sciences, Faculty of Pharmacy, University of Porto, 4050-313 Porto, Portugal

[*] Authors to whom correspondence should be addressed.

[†] These authors contributed equally to this work.

Cosmetics **2023**, *10*(2), 64; https://doi.org/10.3390/cosmetics10020064

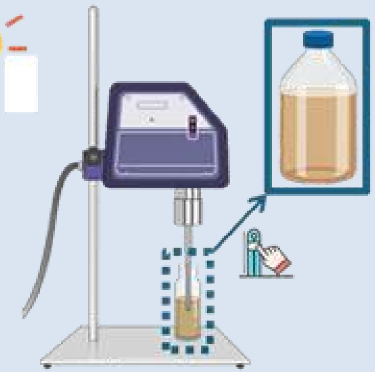
The incorporation of 5% olive pomace paste into facial masks resulted in:

- A 17-fold increase in total phenolic content, enhancing antioxidant capacity.
- Masks with good texture, no odor, and an appealing appearance.
- Improved viscosity and firmness of the mask, while maintaining desirable spreadability and ease of application.

Coffee by-produts: Food Applications

source: original

Coffee by-produts: Food Applications



UAE: An effective and viable option to be applied by industries to recover bioactive compounds from silverskin

Good source of bioactive compounds (CGA and caffeine)

- Easily extracted using "green" solvents and methods
- Several anti-MetS effects (e.g., antidiabetic, antiadipogenic, and anti-inflammatory) found in different cell lines

Possibility to develop a functional product

Cookies enriched with CS well accepted by consumers

SUSTAINABLE DEVELOPMENT GOALS

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Silverskin valorization
(Sustainability and Circular economy in coffee industries)

Prevention/ management of MetS
(Major concern in developed countries)

Sustainable alternative

- Promote health and well-being
- Promote sustainability and circular economy of coffee value chain
- Innovate and increase the availability and diversity of food

source: original

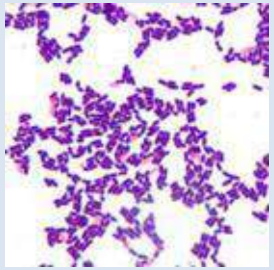
Impact of husks and silverskin on prebiotic properties

Silverskin

Husks

In vitro GID

- ✓ carbohydrate profile
- ✓ chlorogenic acid profile
- ✓ caffeine content



Incubation with *Lactobacilli*

- ✓ Lactobacilli strains growth
- ✓ organic acid production
- ✓ pH variation

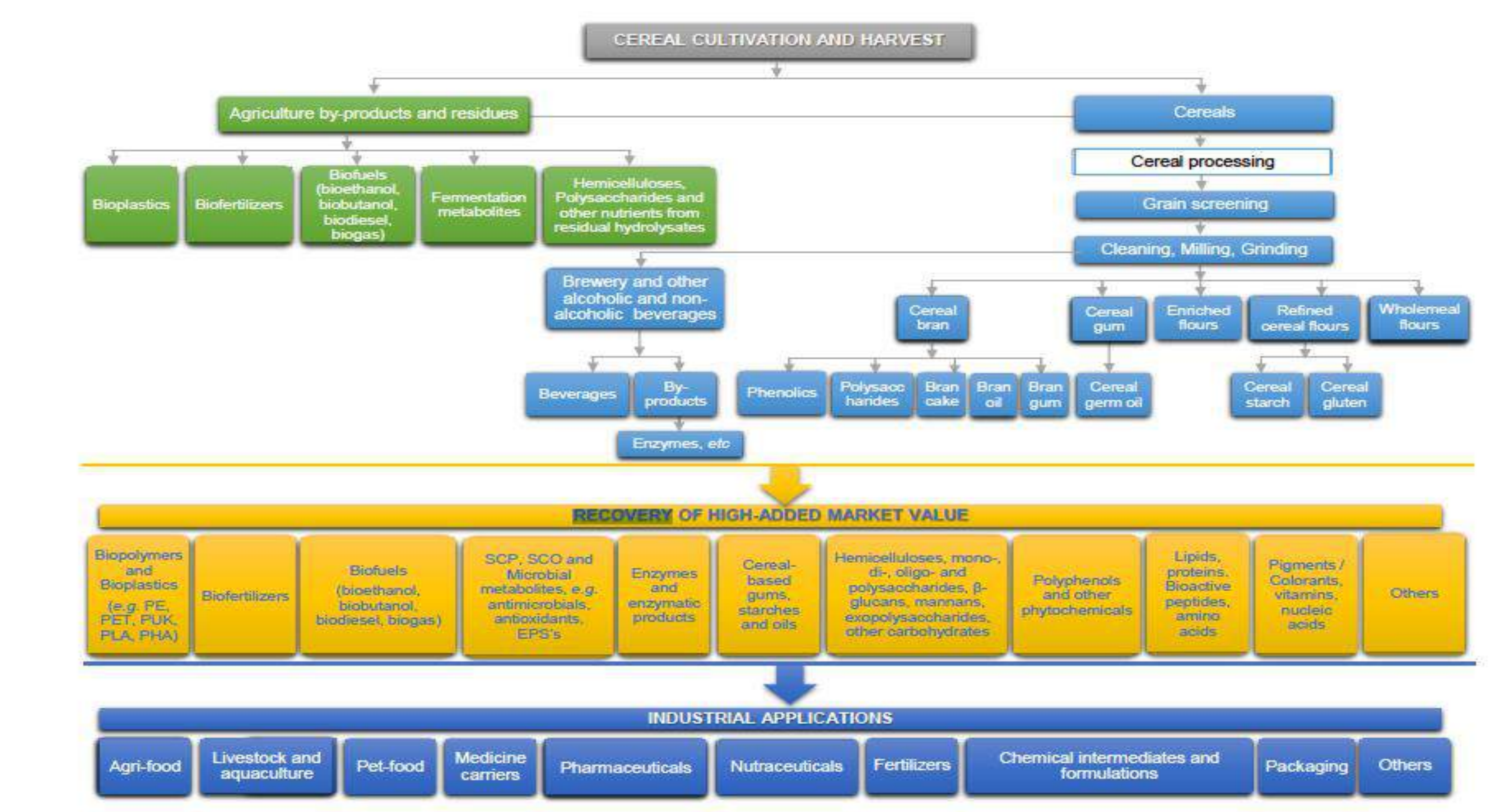
The polysaccharide fraction showed resistance to digestion, with a predominance of pectic polysaccharides. **Chlorogenic acids and caffeine showed moderate stability**, suggesting that a significant fraction of these compounds may reach the colon and act as a substrate for the local microbiota.

Both the control and the digested samples promoted the growth and metabolism of probiotic strains, evidenced by increased cell density, decreased pH, and production of organic acids.

However, limitations remain that justify future studies, namely **evaluation in more realistic *in vitro* colonic fermentation models** and *in vivo* tests to confirm the observed benefits. The use of **coffee by-products in their whole form** as a **prebiotic ingredient** could be a way to contribute to **food waste reduction** and **decrease environmental impact**.

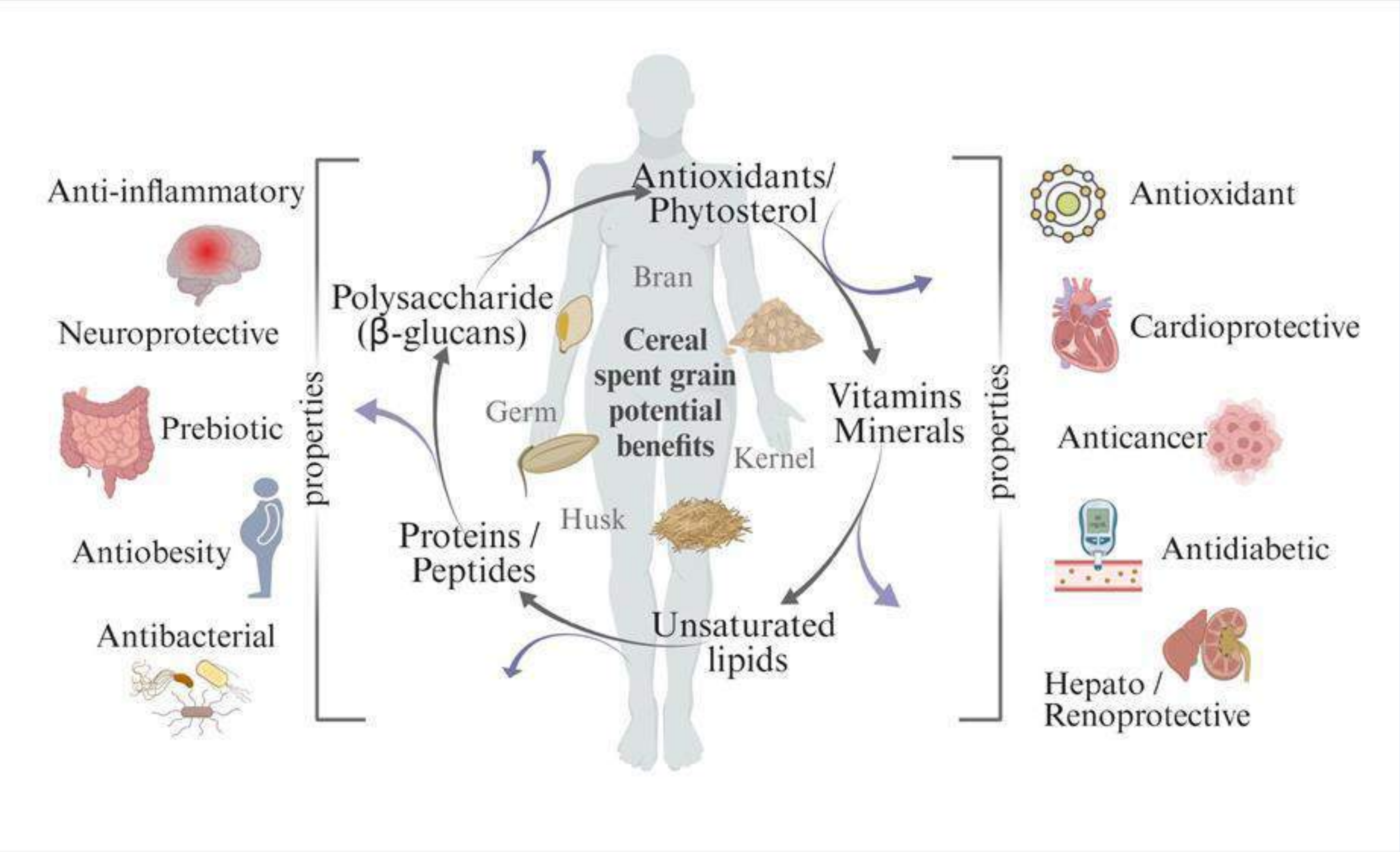
Ongoing study: *in vitro* simulation of human colonic fermentation of husks and silverskin

Cereal by-products valorization



Valorisation of by-products and wastes from cereal-based processing industry, Skendi et al., 2020, doi:10.3390/foods9091243

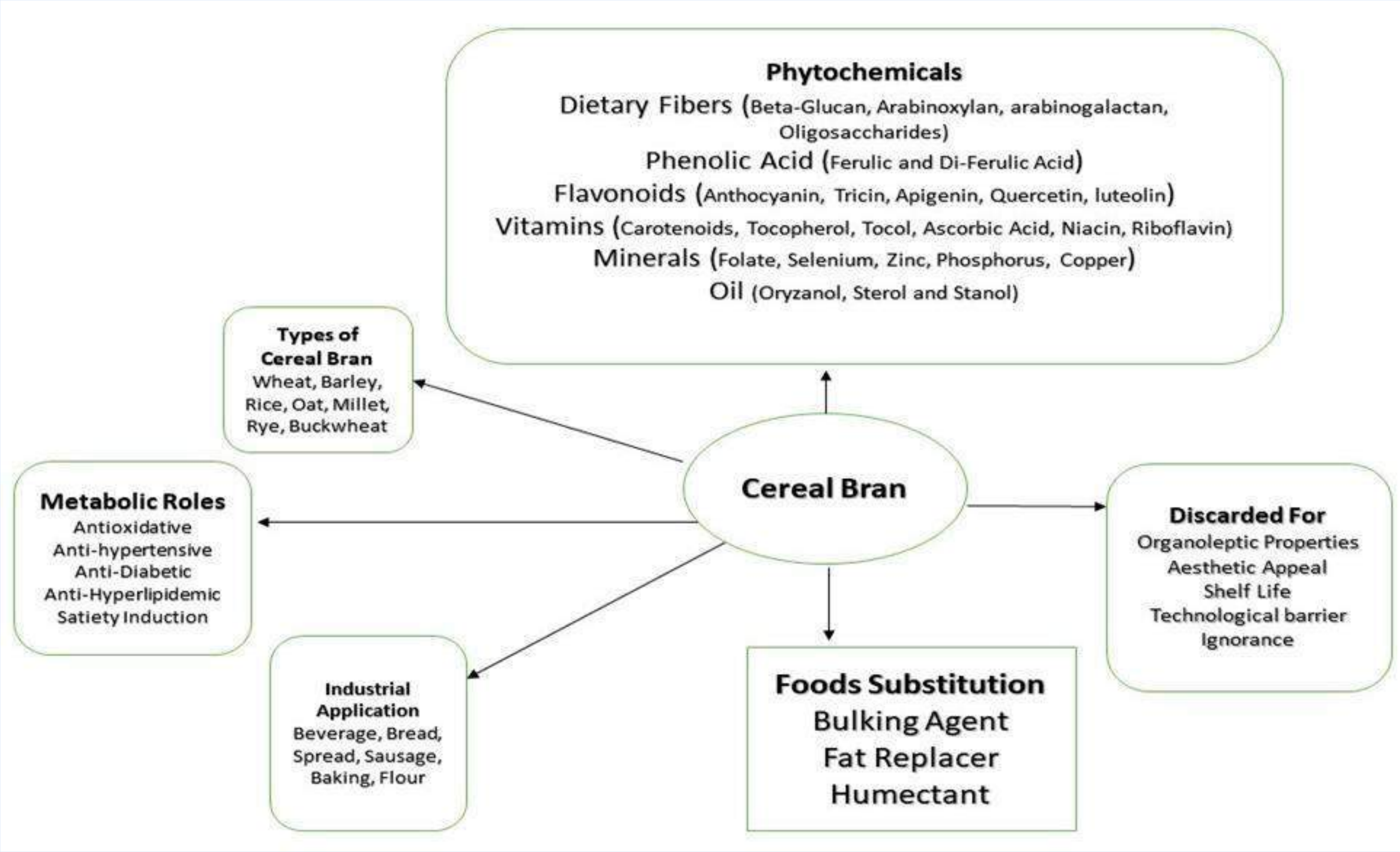
The most relevant potential effects of bioactive compounds identified in cereal by-products



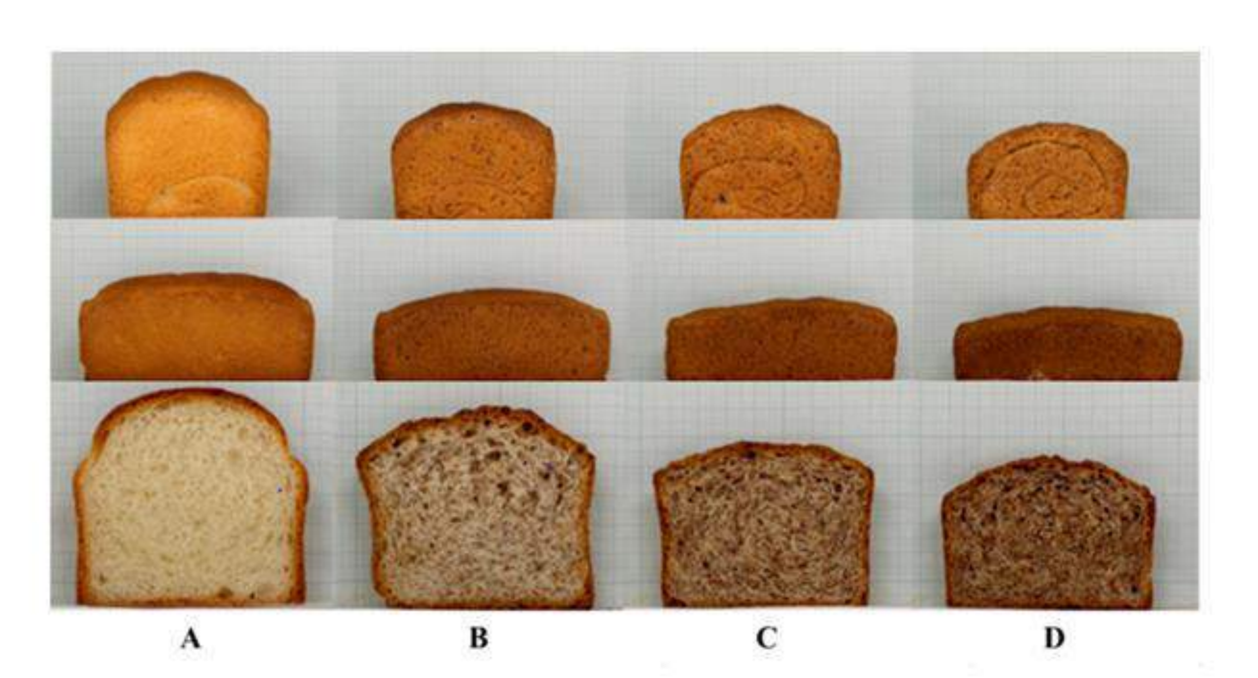
Source: Chis and Farcas Intech Open 2024

DOI: 10.5772/intechopen.1004865

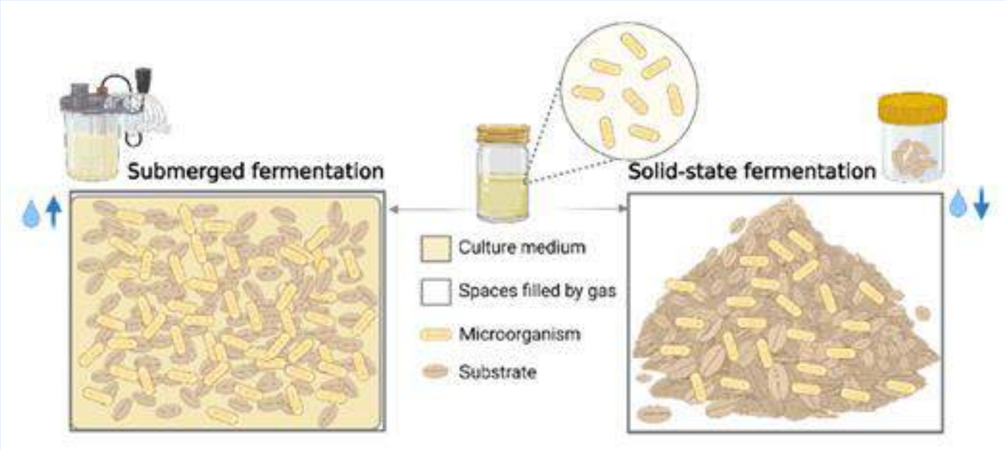
Cereal bran as functional products in different industries



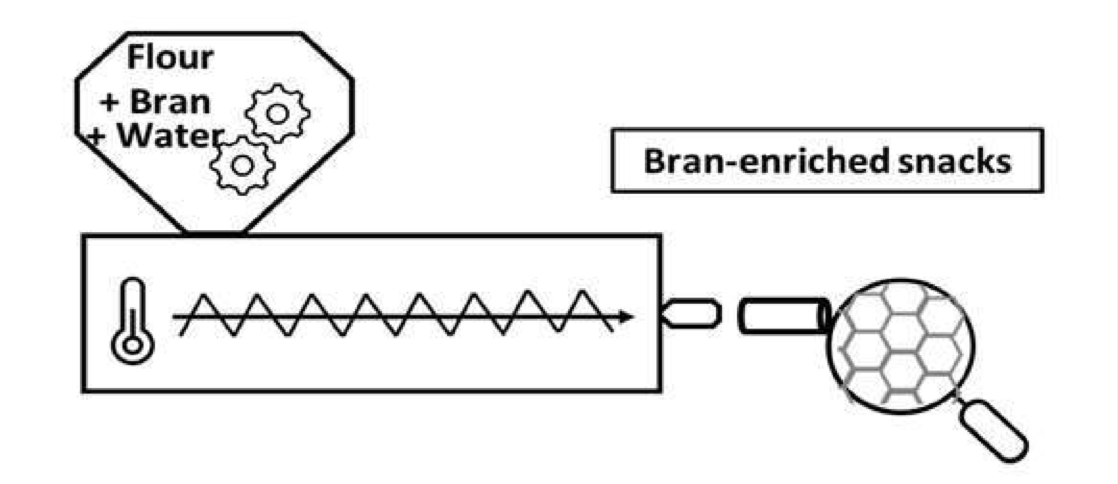
Tufail et al., 2022,
https://doi.org/10.3390/su142114597



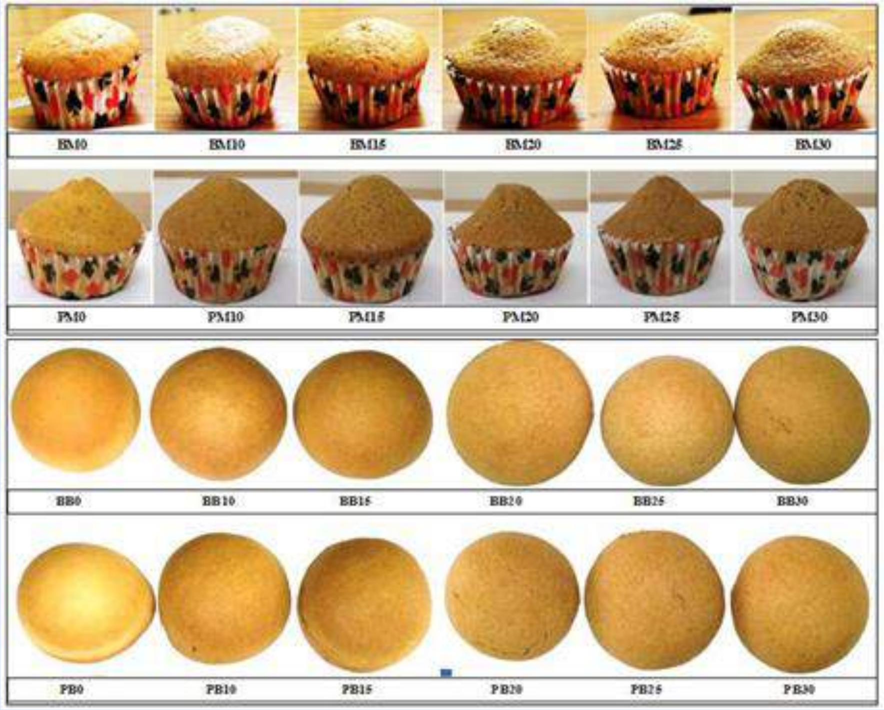
Side view and cross-sections of the breads formulated with the flour–bran blends at different ratios: (A) F100/B0; (B) F90/B10; (C) F80/B20; (D) F70/B30 (Seo et al., 2021, https://doi.org/10.3390/app11094034).



Solid-state fermentation and submerged fermentation of cereal bran (Nemeș et al., 2022, https://doi.org/10.3390/antiox11112159)

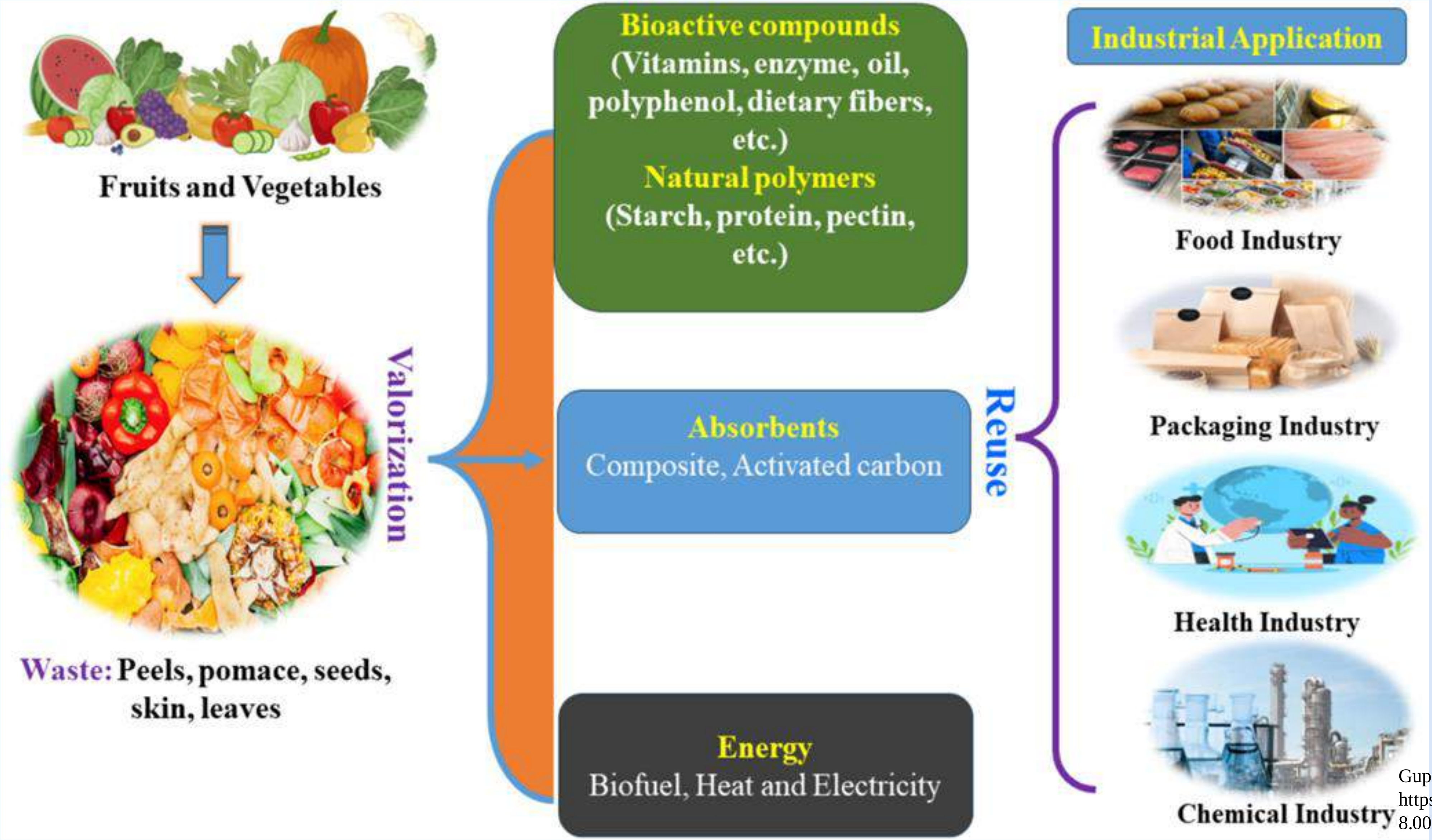


Bran-enriched snacks, Tyl et al., 2021, **https://doi.org/10.3390/foods10092024**



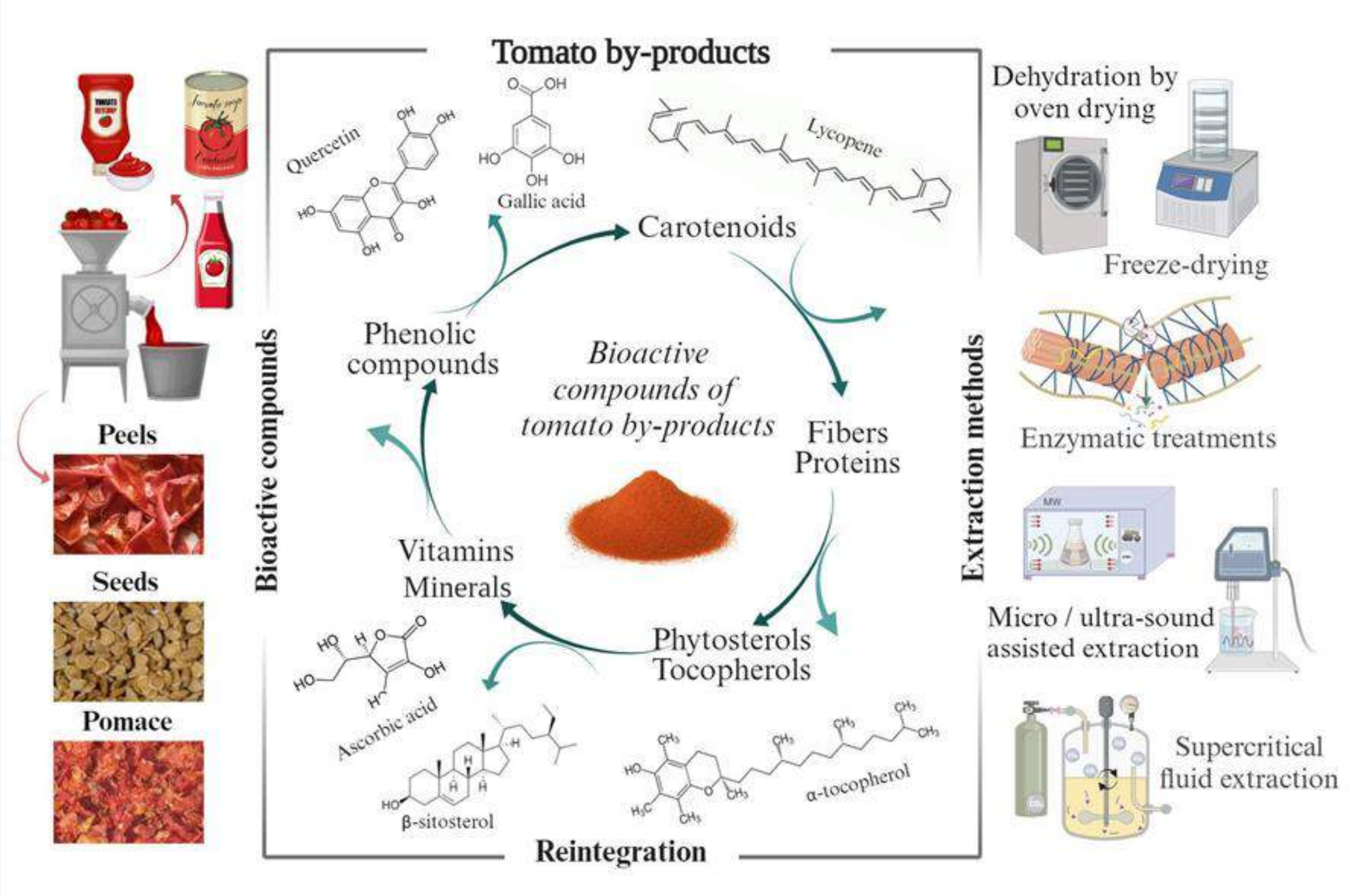
Nutri-cereal bran enriched muffins and buns, Mrunal et al., 2020, 10.9734/IRJPAC/2020/v21i2030282

Fruit and vegetables by-products

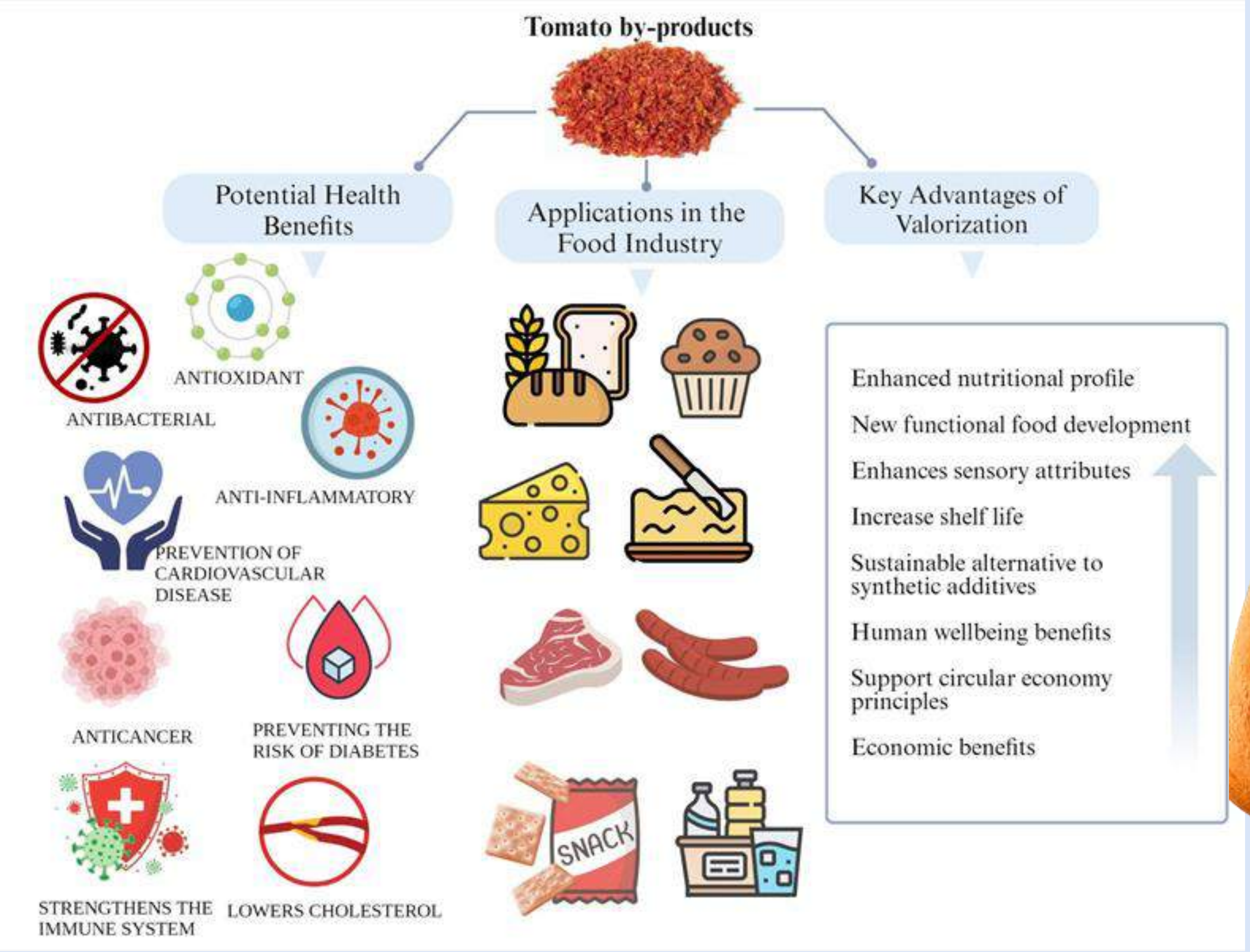


Gupta et al., 2024
https://doi.org/10.1016/j.wmb.2024.08.005

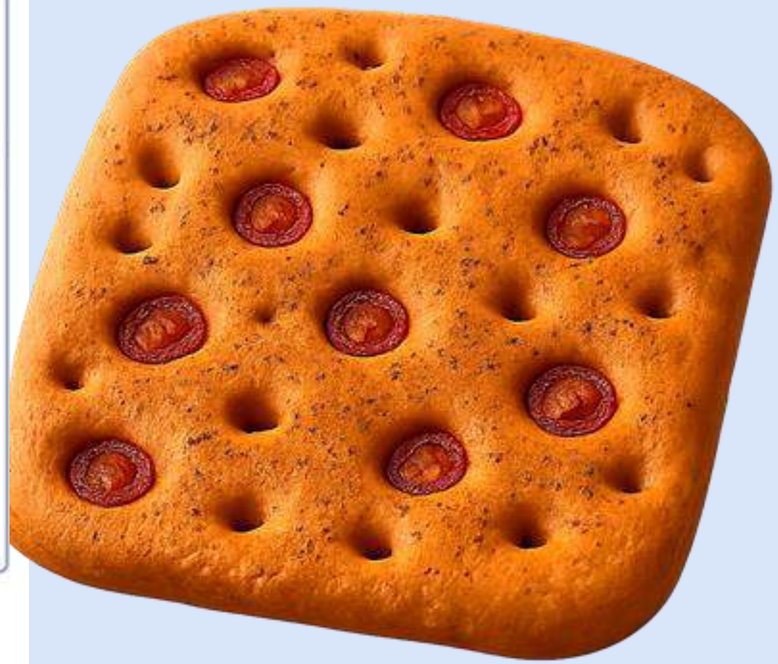
Tomato processing by-products in food industry



Source: Liana Salanță and Anca Fărcaș, 2024,https://doi.org/10.1016/j.fbio.2024.105567



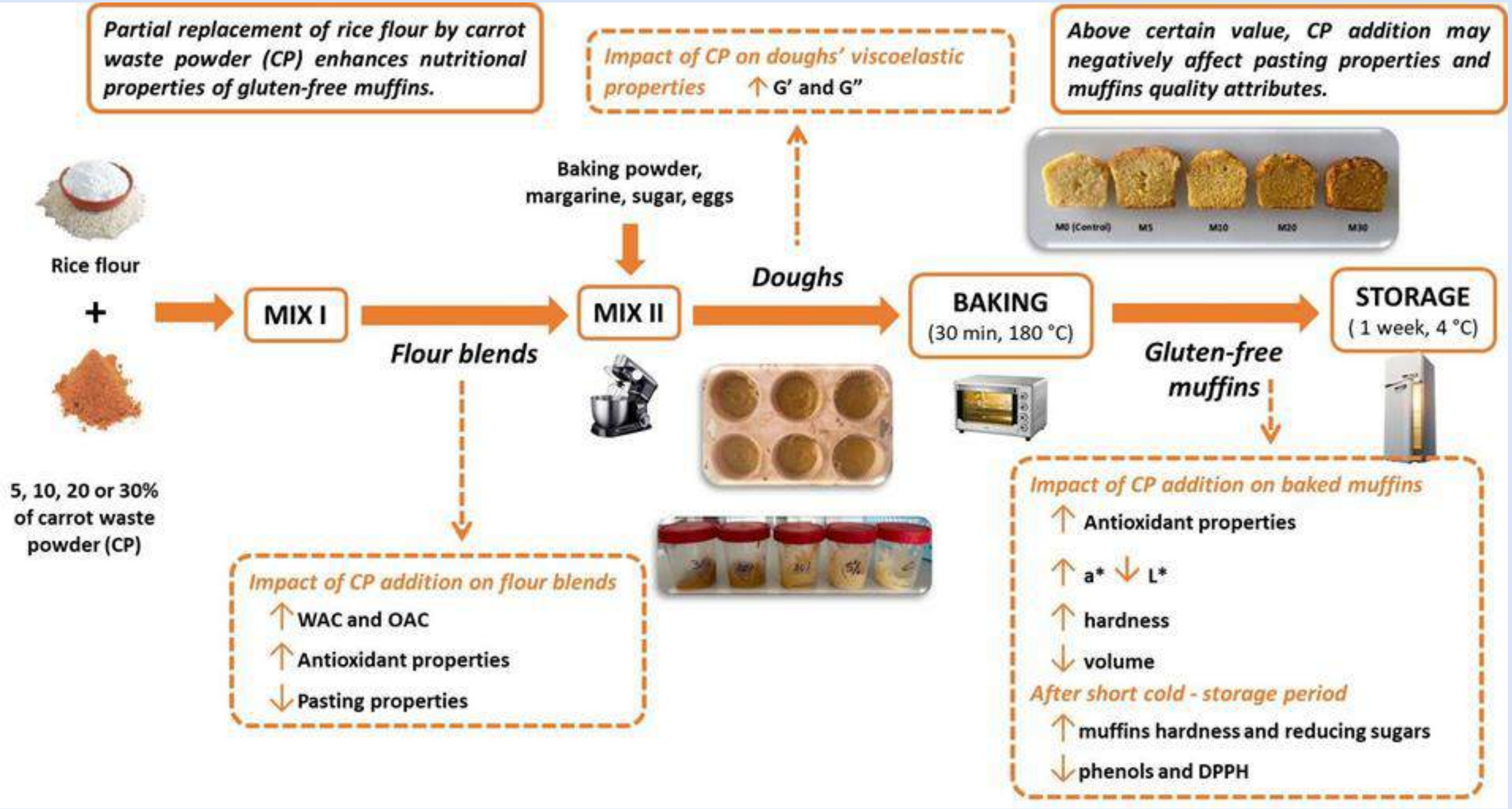
Today we will make focaccia with tomato by-product powder



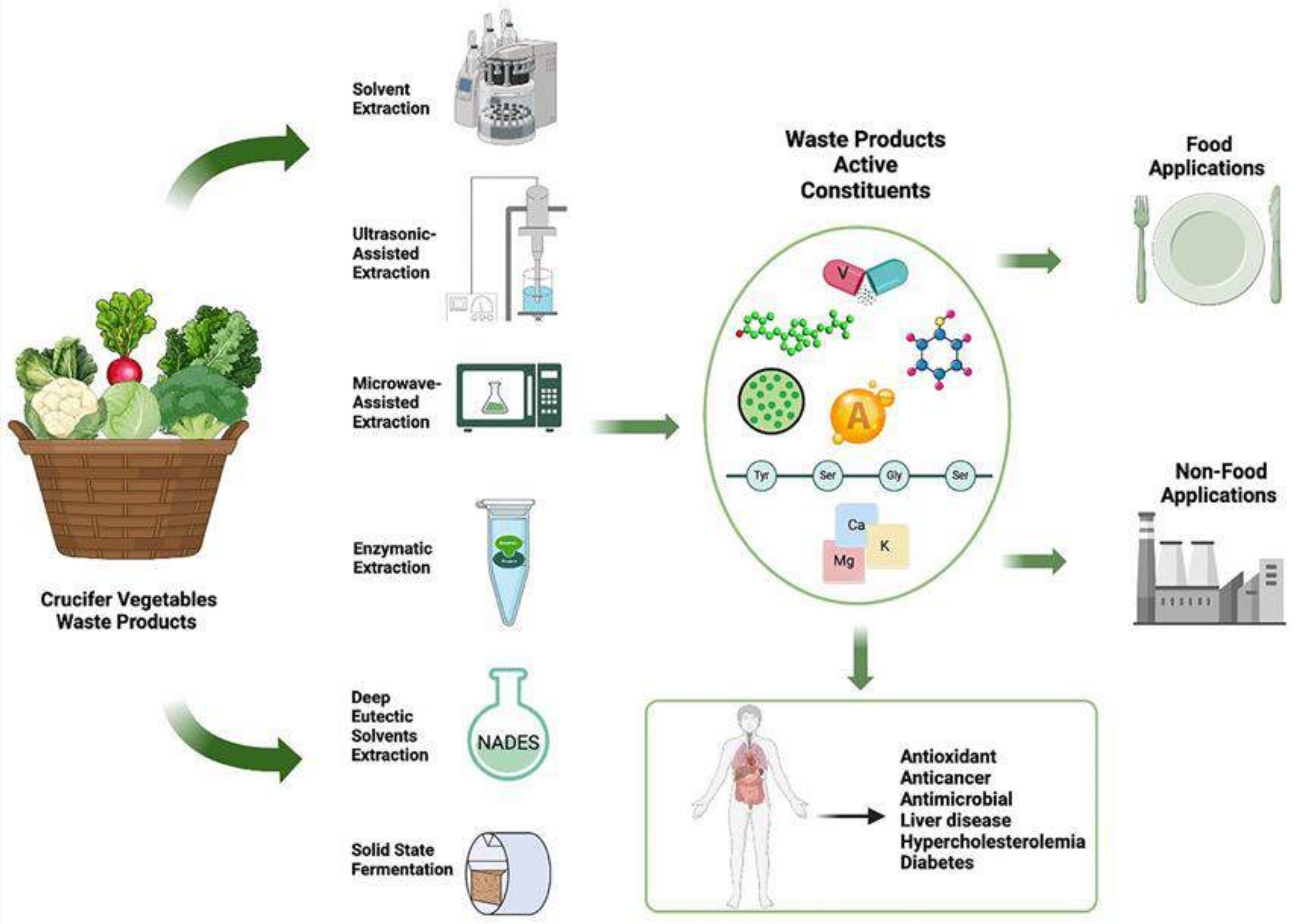
Source: Source: Liana Salanță and Anca Fărcaş, 2024,https://doi.org/10.1016/j.fbio.2024.105567

Valorization of Carrot Waste Flour in bakery products

In this study, carrot waste powder (CP) from a carrot processing line was added in different proportions to gluten-free rice-based muffin recipes to evaluate the effect on the physicochemical and antioxidant properties of the mixtures, doughs, and final products. The ultimate goal was to valorise carrot waste as a functional ingredient for healthier and more sustainable muffins.



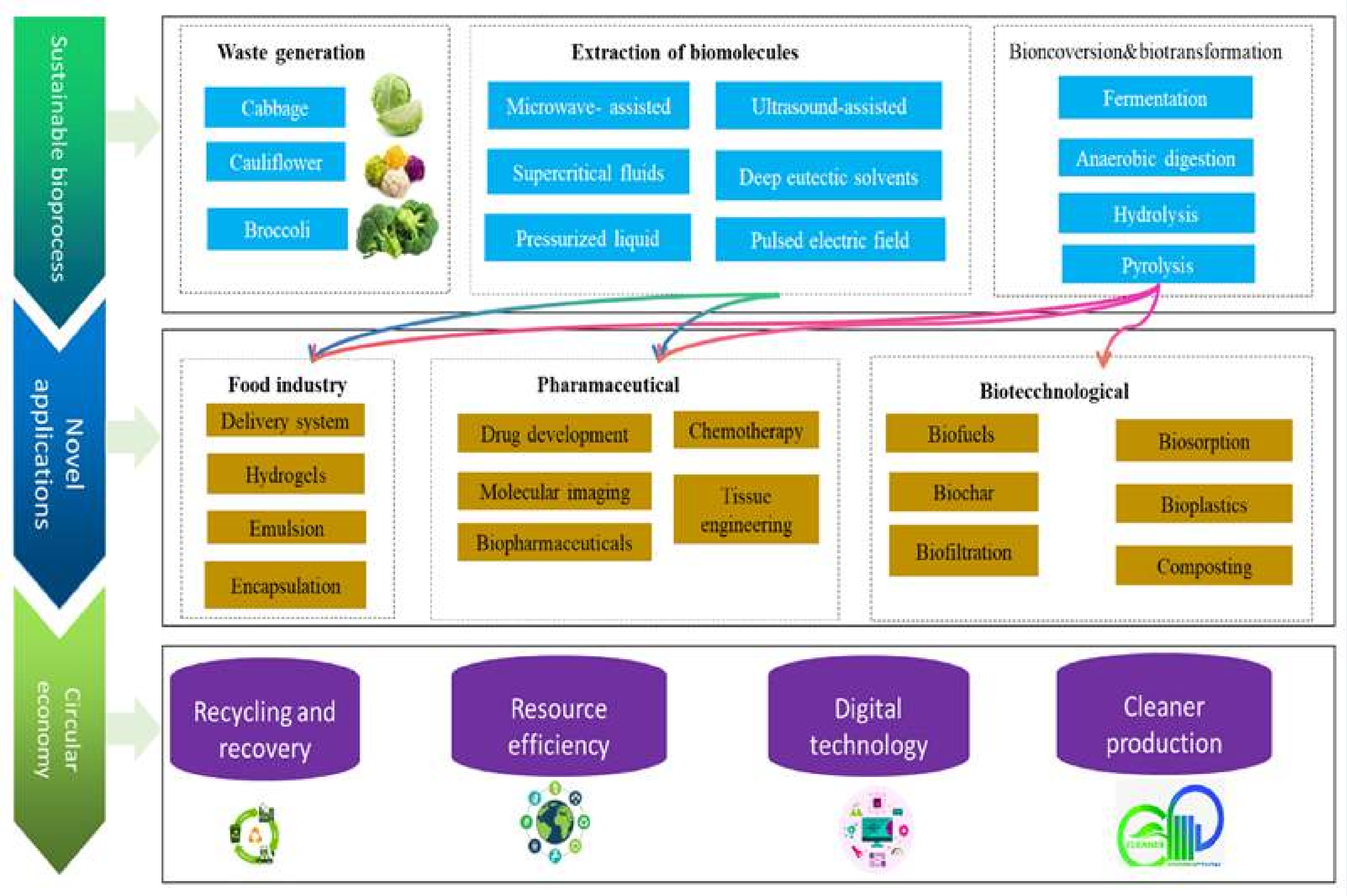
Bas-Bellver, C.; Barrera, C.; Betoret, N.; Seguí, L.; Harasym, J. IV-Range Carrot Waste Flour Enhances Nutritional and Functional Properties of Rice-Based Gluten-Free Muffins. *Foods* **2024**, *13*, 1312.



Valorization of agri-food crucifer vegetables waste for food, functional food and nutraceuticals applications, Kaled et al., 2025, https://doi.org/10.1186/s40643-025-00895-4

Potential applications of cabbage, broccoli, and cauliflower by-products

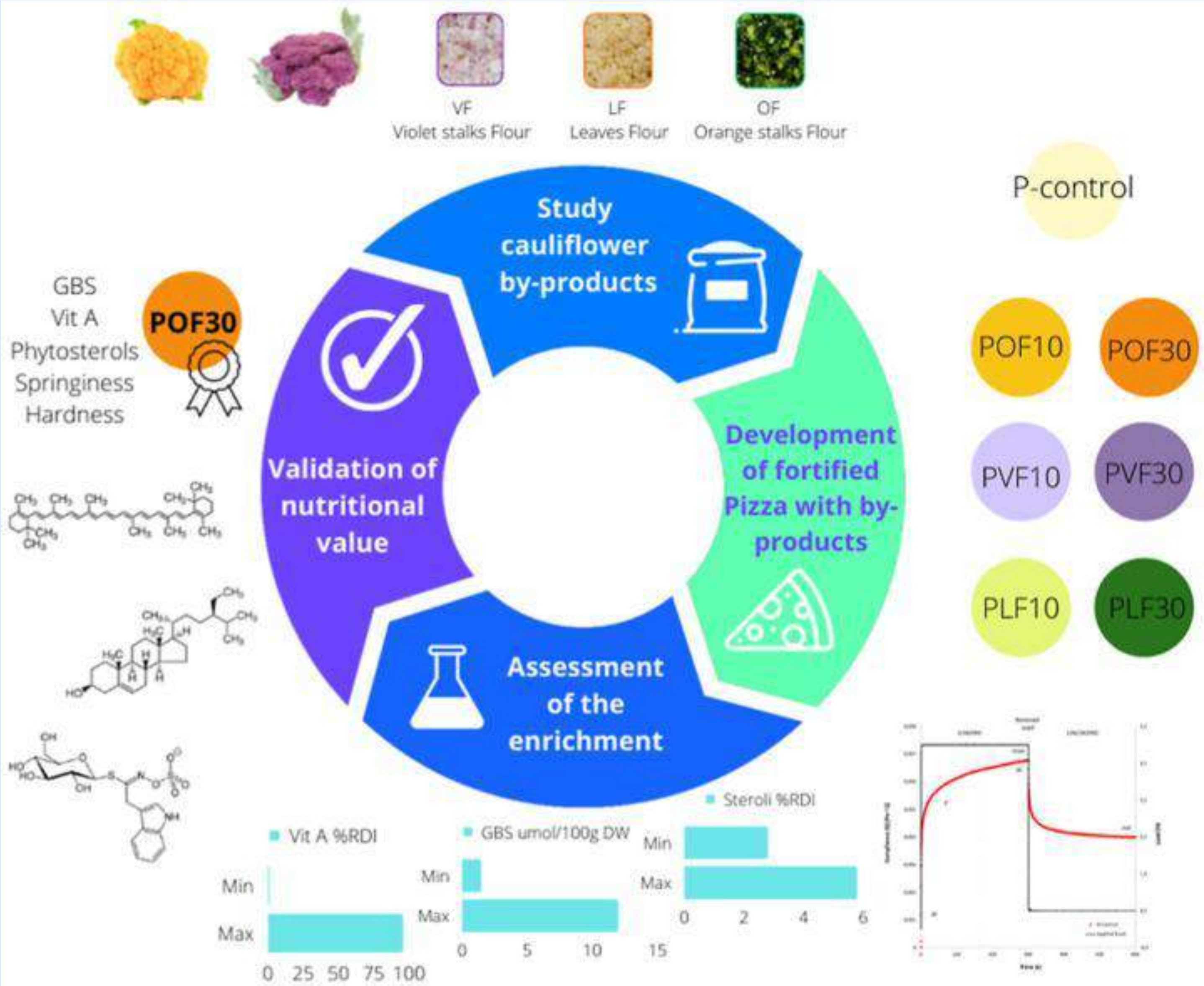
There is growing interest in the use of cruciferous vegetable waste/by-products, including cabbage, broccoli, and cauliflower, in food, because they are still rich in beneficial nutrients and phytochemical profiles.



Shinali, et al. **2024**. https://doi.org/10.3390/foods13081163

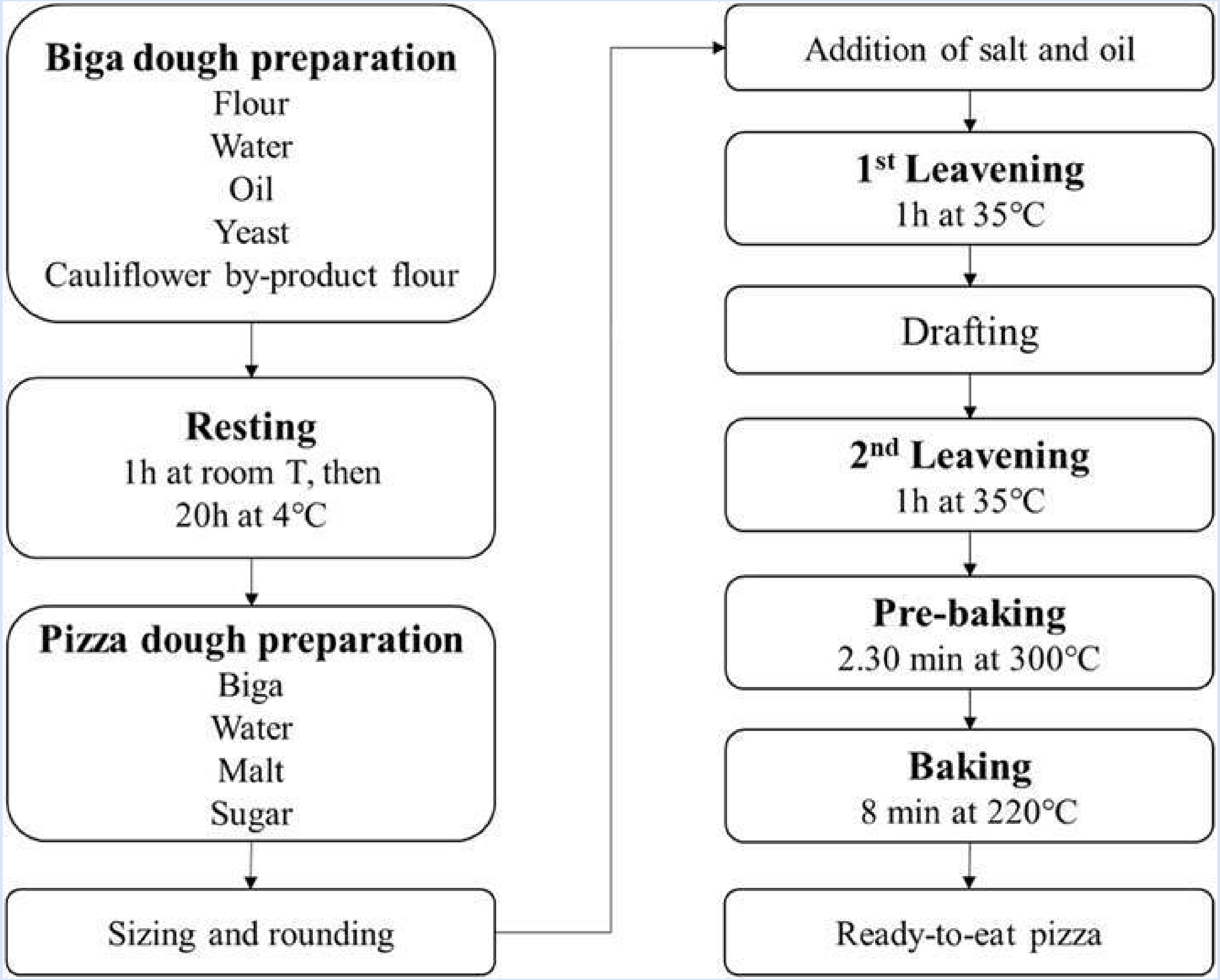
Cauliflower by-products valorized in bakery products

Cauliflower by-products, including leaves and stems, can be used as valuable food ingredients. These by-products are rich in bioactive compounds such as glucosinolates, carotenoids, and phytosterols, as well as dietary fiber, protein, and antioxidants. This recovery can be achieved by incorporating special flours obtained from these by-products into food products such as bread and pizza.



Nartea et al., 2023. https://doi.org/10.1016/j.crfs.2023.100437

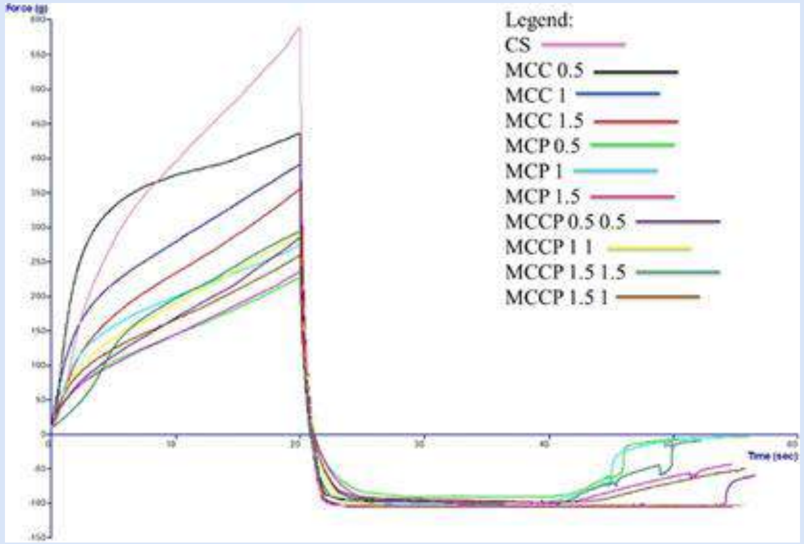
Flow chart of professional pizza preparation

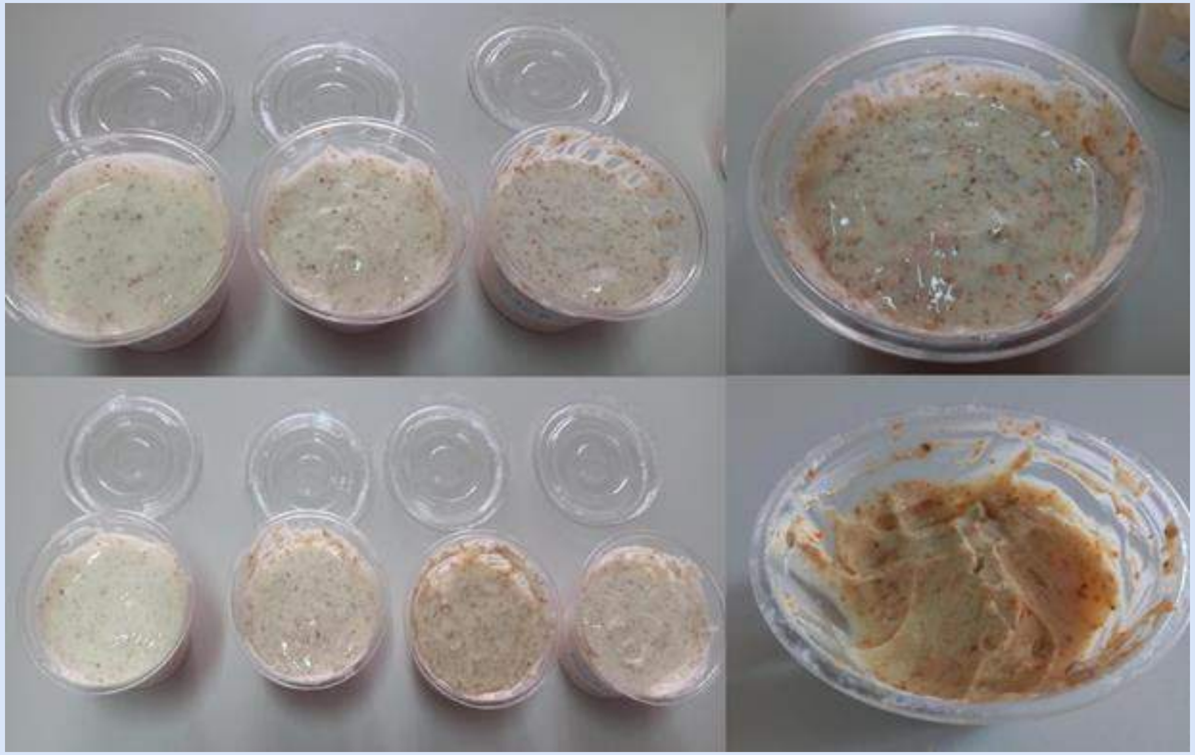


Nartea et al., 2023. https://doi.org/10.1016/j.crfs.2023.100437

Potato and carrot by-products in processed cheese

In this study processed cheese samples were prepared with the addition of potato and carrot peels. These additions altered the physicochemical properties by increasing acidity, water activity, and dry matter content, while decreasing pH and salt levels. Additionally, the L-lactic acid content increased, while glucose, lactose, and galactose levels decreased.





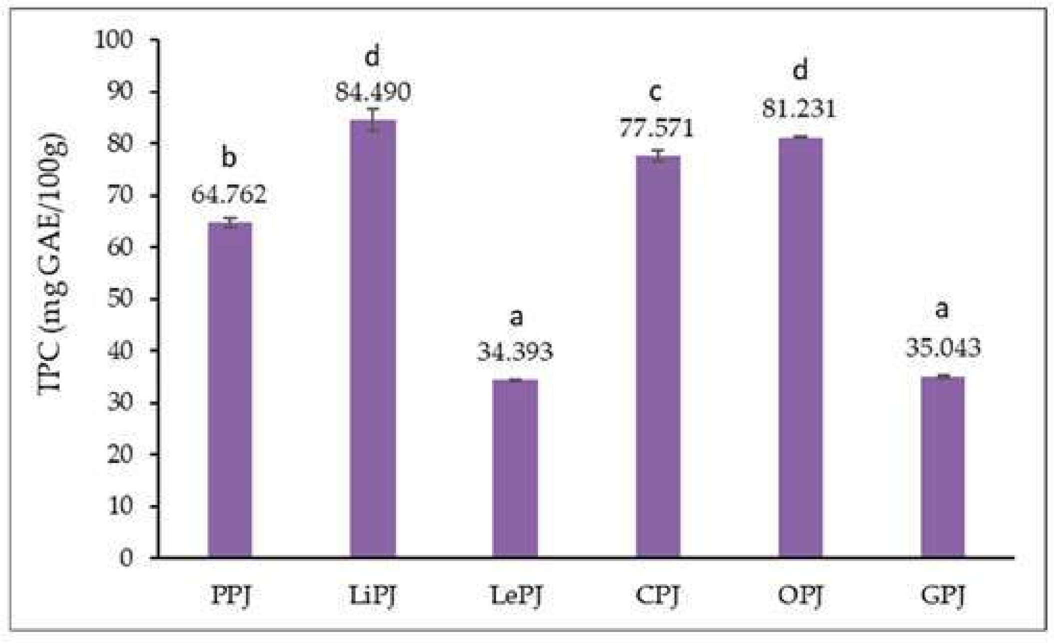
Melted cheese samples with carrot and potato peels

Tiţa, et al., 2024. https://doi.org/10.3389/fnut.2023.1260076.

Valorization of Citrus Peel Byproducts - Jams

PPJ—pomelo peel jam; LiPJ—lime peel jam; LePJ—lemon peel jam; CPJ—clementine peel jam; OPJ—orange peel jam; GPJ—grapefruit peel jam)

OPJ—orange peel jam



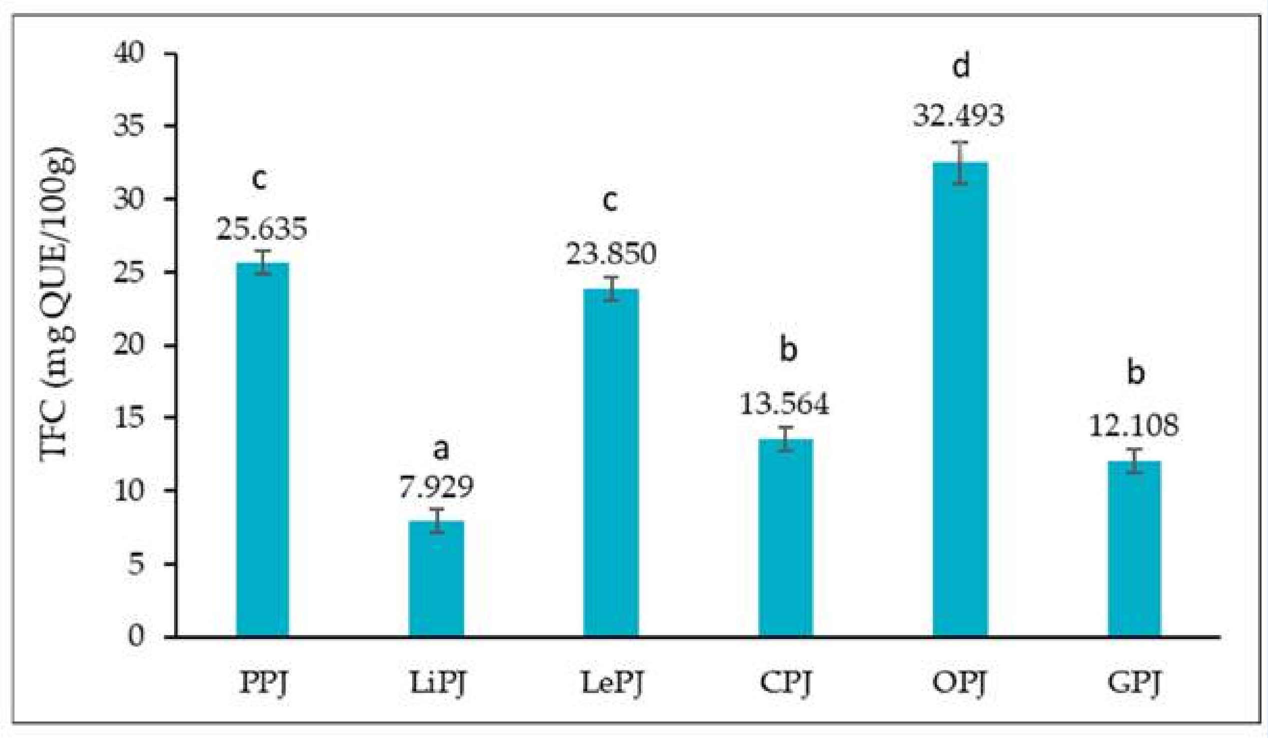
Total polyphenolic content (TPC) of jam samples. The results for the TPC are presented as the mean value of three determinations ± standard deviation (SD).

Negrea et al., **2025.** https://doi.org/10.3390/foods14081339

LePJ—lemon peel jam; LiPJ—lime peel jam

Negrea et al., **2025.** https://doi.org/10.3390/foods14081339

GPJ—grapefruit peel jam



Total flavonoid content (TFC) of jam samples. The results for the TFC are presented as the mean value of three determinations ± standard deviation (SD).

Negrea et al., **2025.** https://doi.org/10.3390/foods14081339

Valorization of diary byproducts - whey

Functional Jelly based on whey

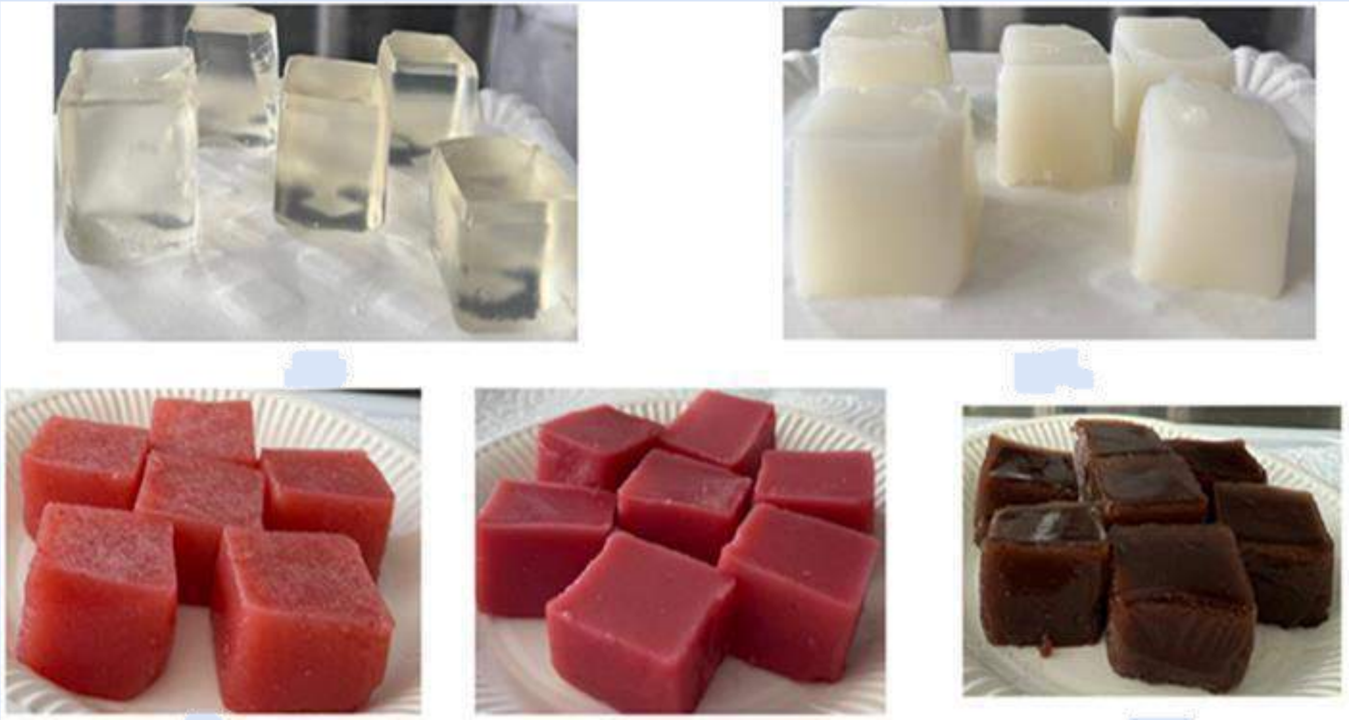


Table 1. Recipes for jellies.

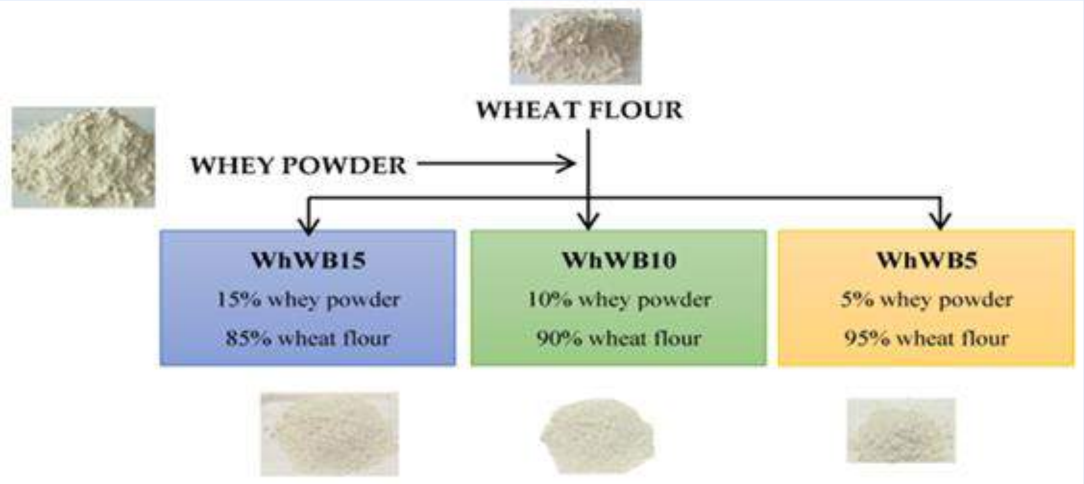
Sample	Abbreviation	Berry Juice (mL)	Whey (mL)	Gelatin (g)	Sugar (g)	Water (mL)
Control	CJ	-	-	10	80	550
Whey jelly	WhJ	-	200	10	80	350
Whey strawberry jelly	WhSJ	300	200	10	80	50
Whey raspberry jelly	WhRJ	300	200	10	80	50
Whey blueberry jelly	WhBJ	300	200	10	80	50

Valorization of whey for jelly production is an innovative approach to creating functional foods enriched with essential nutrients and bioactive compounds.

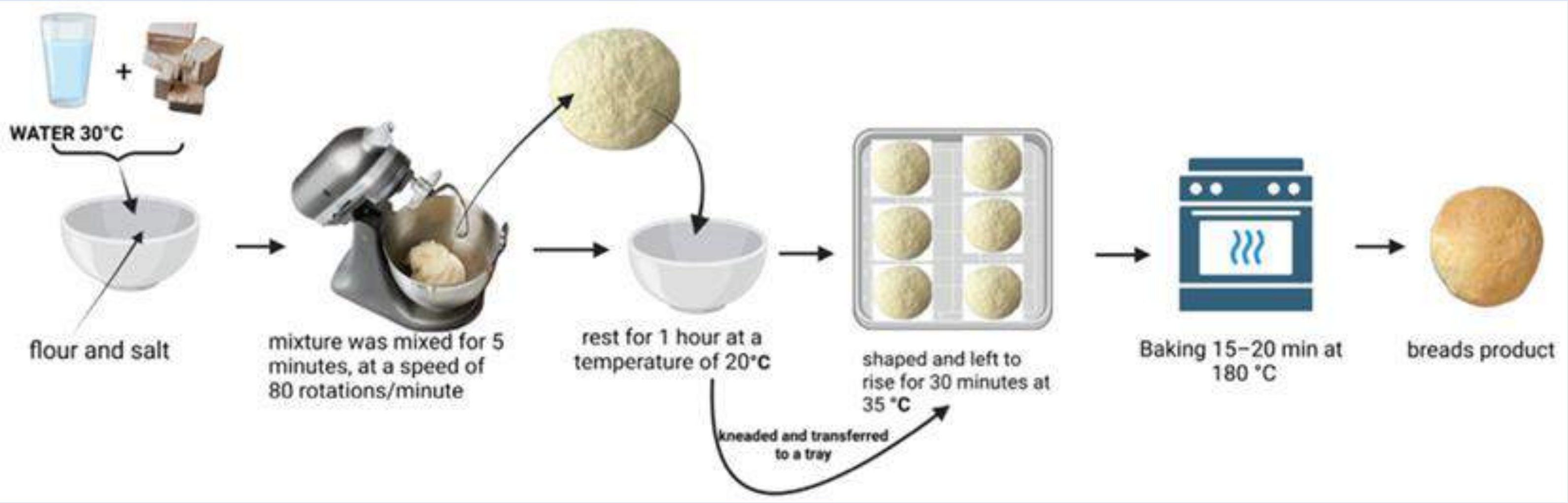
The products remained stable in structure when stored at 4 °C, though room-temperature storage led to lower pH and higher acidity after 14 days (Fluerasu et al., 2025).

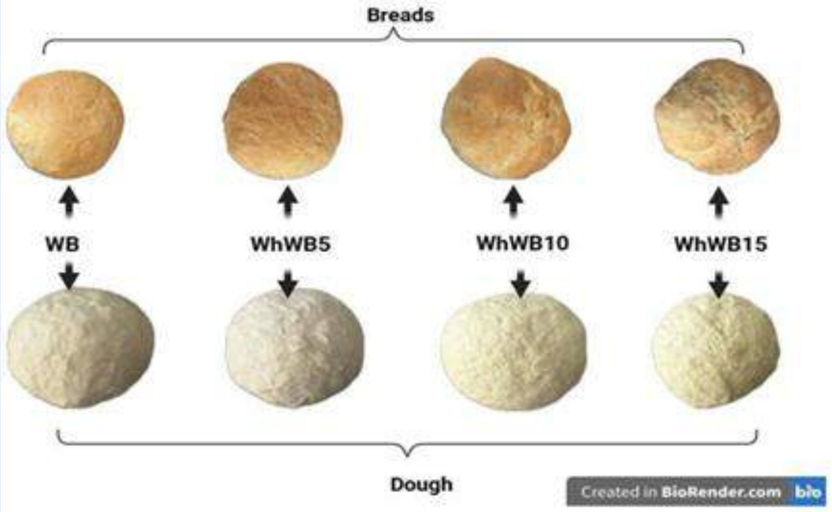
Fluerasu et al., 2025;
https://doi.org/10.3390/foods14183193

Bread with whey powder



Wheat flour can be fortified with 5%, 10%, and 15% whey powder, which significantly improves the nutritional profile of both the flour and the resulting bread. The addition of whey increases protein and mineral content while reducing carbohydrate levels. Bread fortified with 15% whey shows notable mineral enhancements, including a 27.8% increase in potassium, 7.01% in magnesium, and 28.67% in calcium compared to the control samples (Fluerasu et al., 2025).



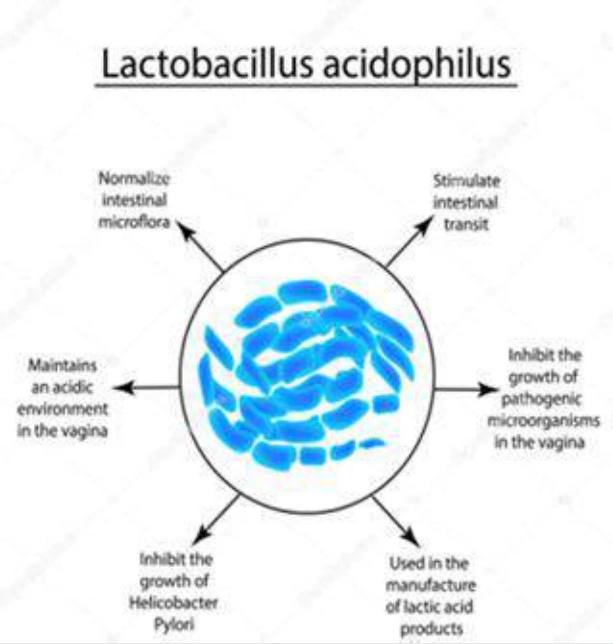


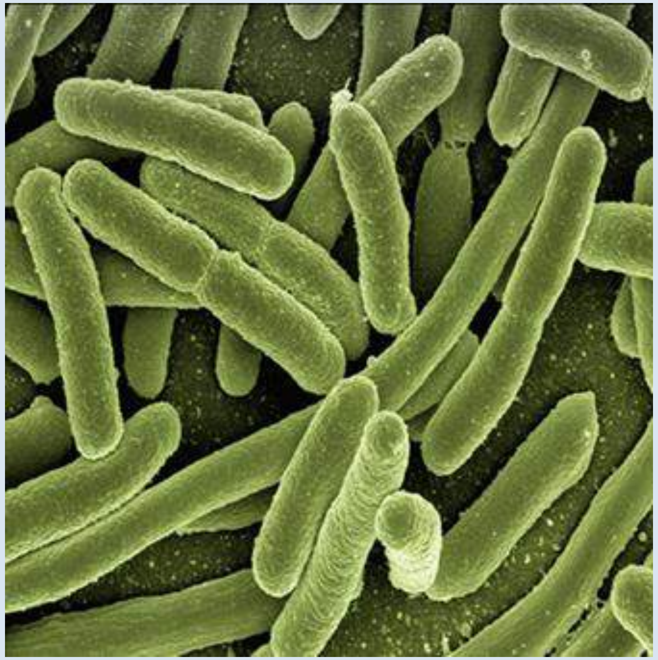
Fluerasu et al., 2025); https://doi.org/10.3390/foods14162911

Lactobacillus and Bifidobacterium strains

Lactobacillus and Bifidobacterium strains, from fermented dairy by-products (Whey, Buttermilk) enhance gut microbiota balance (Galanakis, 2021).

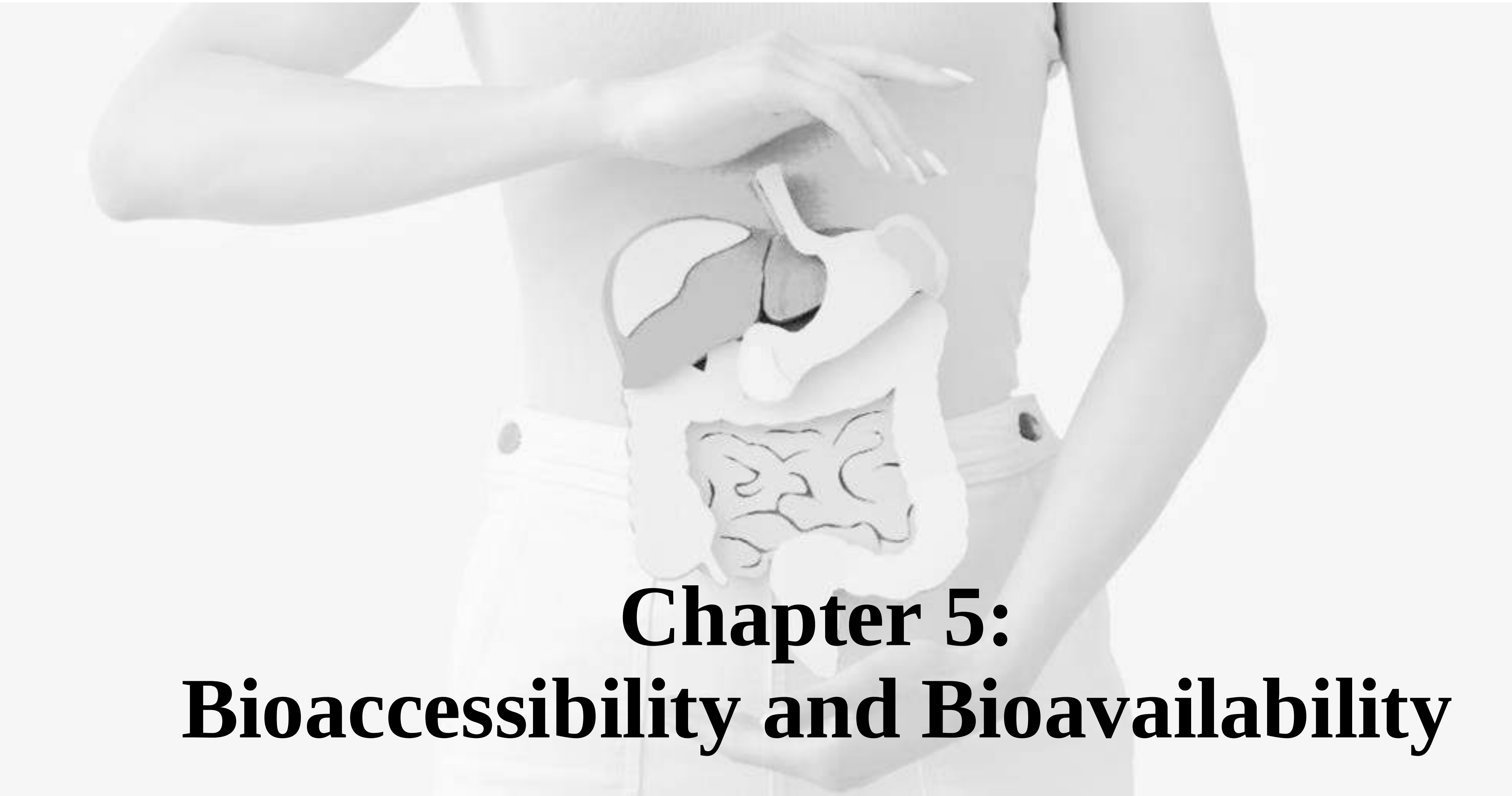
Probiotics are live microorganisms that contribute to gut health by improving digestion and immune function.





Galanakis, 2021, doi: 10.1016/C2019-0-01446-X

Project code: 2024-1-RO01-KA220-HED-000246776



Chapter 5:
Bioaccessibility and Bioavailability

Co-funded by the European Union

INDEX

1. In Vitro Digestion Models

Historical evolution of in vitro digestion models

Representative in vitro digestion models

2. INFOGEST Protocol (Reference Model)

Development and validation of the INFOGEST method

Detailed outline of the INFOGEST protocol

Static vs. dynamic INFOGEST digestion

Parameters and measured results

3. Bioactivity Evaluation

Applied cell models

Combination of in vitro models + cellular models

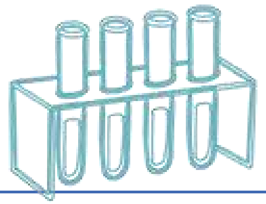
Functional bioactivity assays

Microphysiological systems

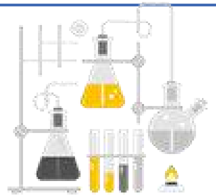
4. Conclusions and Future Directions

In Vitro Digestion Models

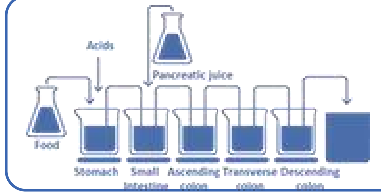
Historical Evolution of In Vitro Digestion Models



Early Static Models (Before 2000s)
- Simple test tube digestion using enzymes (e.g., pepsin, pancreatin).
- Basic pH adjustments and temperature control.
- Limitations: No simulation of peristalsis, secretion timing, or dynamic transit.



Advanced Static Models (2000s)
- More physiological enzyme concentrations and digestion times.
- Inclusion of bile salts and stepwise digestion phases.
- Still limited by the absence of dynamic gastrointestinal functions.



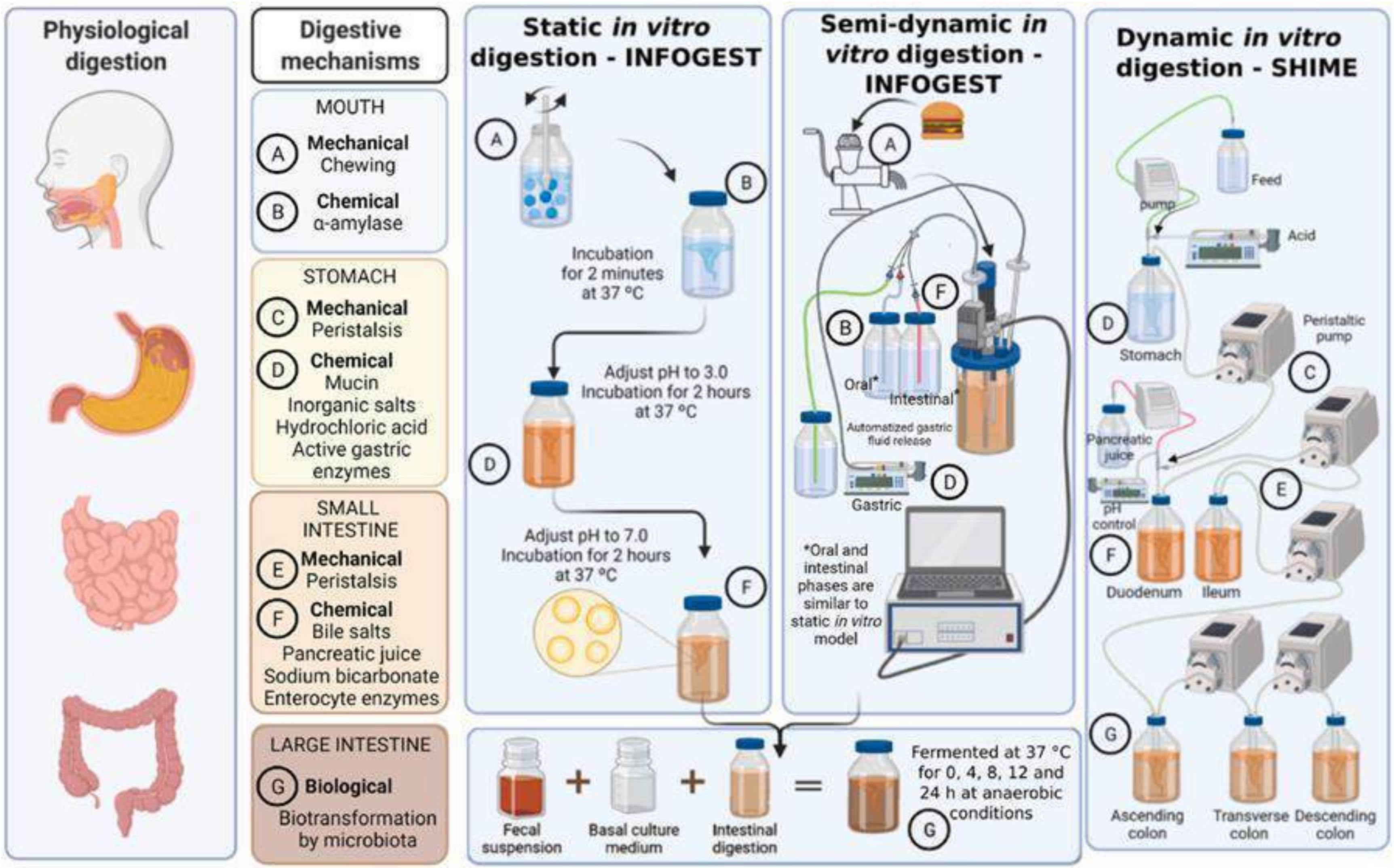
Dynamic Multi-Compartmental Models (2000s–2010s)
- Examples: TIM-1, SHIME, Dynamic Gastric Model (DGM).
- Simulate peristalsis, secretion, pH gradients, and digestion kinetics.
- Advantages: Closer to in vivo conditions, useful for studying nutrient bioaccessibility and delivery systems.
- Limitations: High cost and complexity.

INFOGEST

INFOGEST Static Protocol (2014–present)
- Developed through international collaboration.
- Advantages:
  - Harmonized protocol for reproducibility across labs.
  - Widely adopted in food and nutritional sciences.
  - Suitable for assessing digestibility and bioaccessibility of various food matrices.

References:
- Minekus M. et al. (2014). Food & Function, 5(6), 1113–1124.
- Brodkorb A. et al. (2019). Nature Protocols, 14, 991–1014.

Representative In Vitro Digestion Models



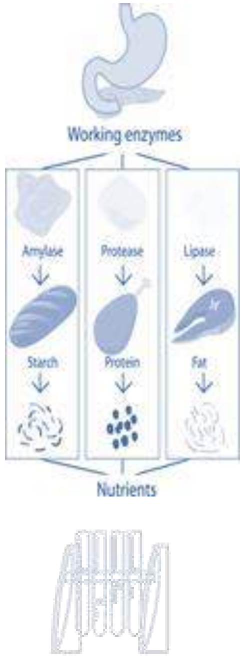
Rodrigues, D. B., et al. (2022). *[Figure 2. Comparison between physiological human digestion and in vitro digestion (IVD) methods]* [Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence: CC BY-NC-ND 4.0.

3. INFOGEST Protocol (Reference Model)

Development and validation of the INFOGEST method

The INFOGEST method was designed to simulate the oral, gastric, and small intestinal phases of human digestion in a reproducible and physiologically relevant way. This protocol was validated by the INFOGEST consortium in 2014 (actualized in 2019)

GENERAL CONSIDERATIONS



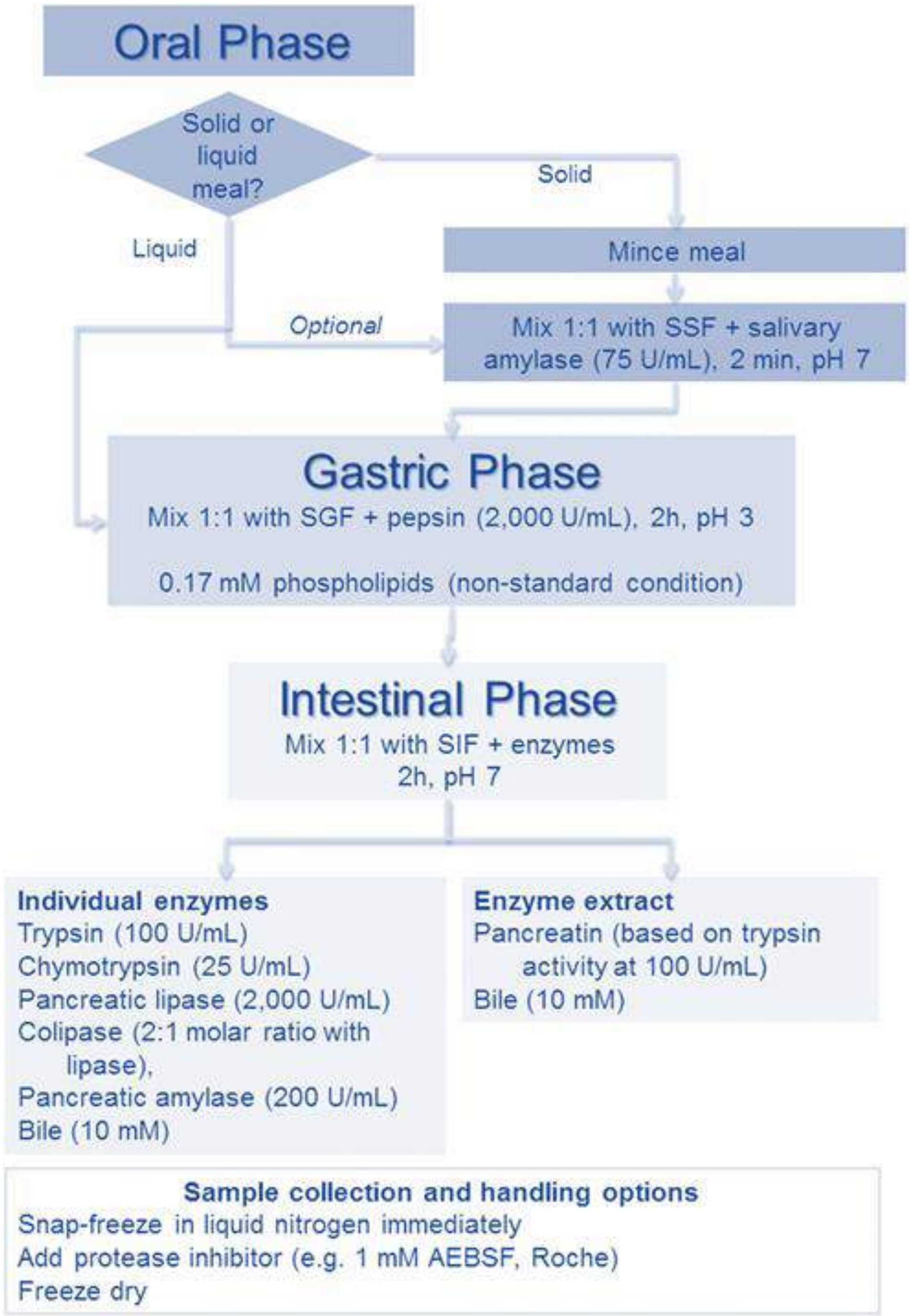
Purpose: Simulate human gastrointestinal digestion for bioaccessibility, food structure, and nutrient release studies.

Control parameters: pH, enzyme activity, electrolyte composition, digestion time, and agitation speed.

Applicability: All types of food matrices (liquid, semi-solid, solid, emulsions).

Volume ratios: Standard total digestion volume is 10 mL (can be scaled proportionally).

Detailed outline of the INFOGEST protocol (Static In Vitro Digestion)

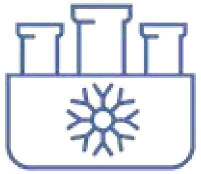


Minekus, M., et al.(2014). *[Fig. 1 Overview and flow diagram of a simulated in vitro digestion method.]* [Image]. In A standardised static in vitro digestion method suitable for food–an international consensus. Food & function, 5(6), 1113-1124..

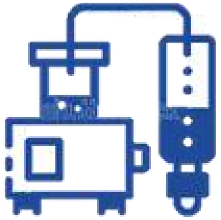
Detailed outline of the INFOGEST protocol (Static In Vitro Digestion)

POST-DIGESTION PROCESSING

- **Separation**: Centrifugation or filtration to obtain the **bioaccessible fraction**.



- **Storage**: Immediate analysis or storage at −80 °C for biochemical assays.

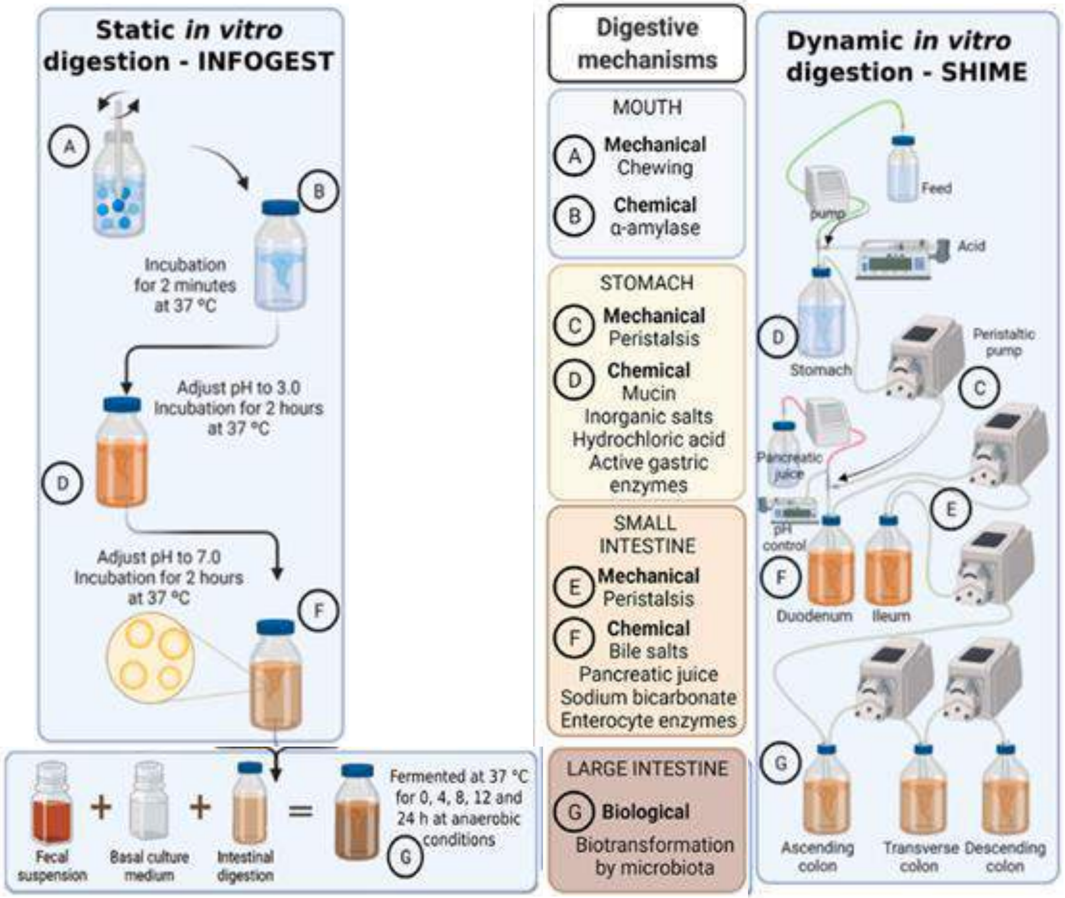


- **Optional assays**: Micelle formation, particle size, enzyme activity, nutrient release, antioxidant capacity.

Static vs. dynamic INFOGEST digestion

Static In Vitro Digestion

- **Fixed conditions**: Uses constant pH, enzyme concentrations, and time points.
- **Simplified model**: Represents average digestive conditions without simulating physiological changes.
- **Low cost and easy to replicate**: Ideal for high-throughput screening.
- **Limited realism**: Does not mimic peristalsis, secretion dynamics, or gradual pH shifts.
- **Common use**: Preliminary assessment of digestibility, bioaccessibility, or food structure breakdown.



Dynamic In Vitro Digestion

- **Variable conditions**: Simulates real-time changes in pH, enzyme secretion, and transit times.
- **More physiologically relevant**: Mimics gastric emptying, peristalsis, and intestinal absorption.
- **Complex and costly**: Requires specialized equipment and protocols.
- **Higher predictive power**: Better reflects in vivo digestion and nutrient release.
- **Common use**: Advanced studies on nutrient bioavailability, drug delivery, or functional foods.

Rodrigues, D. B., et al.(2022). *[Modified from Figure 2. Comparison between physiological human digestion and in vitro digestion (IVD) methods]* [Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence: CC BY-NC-ND 4.0.

Parameters and measured results

***IN VITRO* DIGESTION PERCENTAGE – IVD (%)**

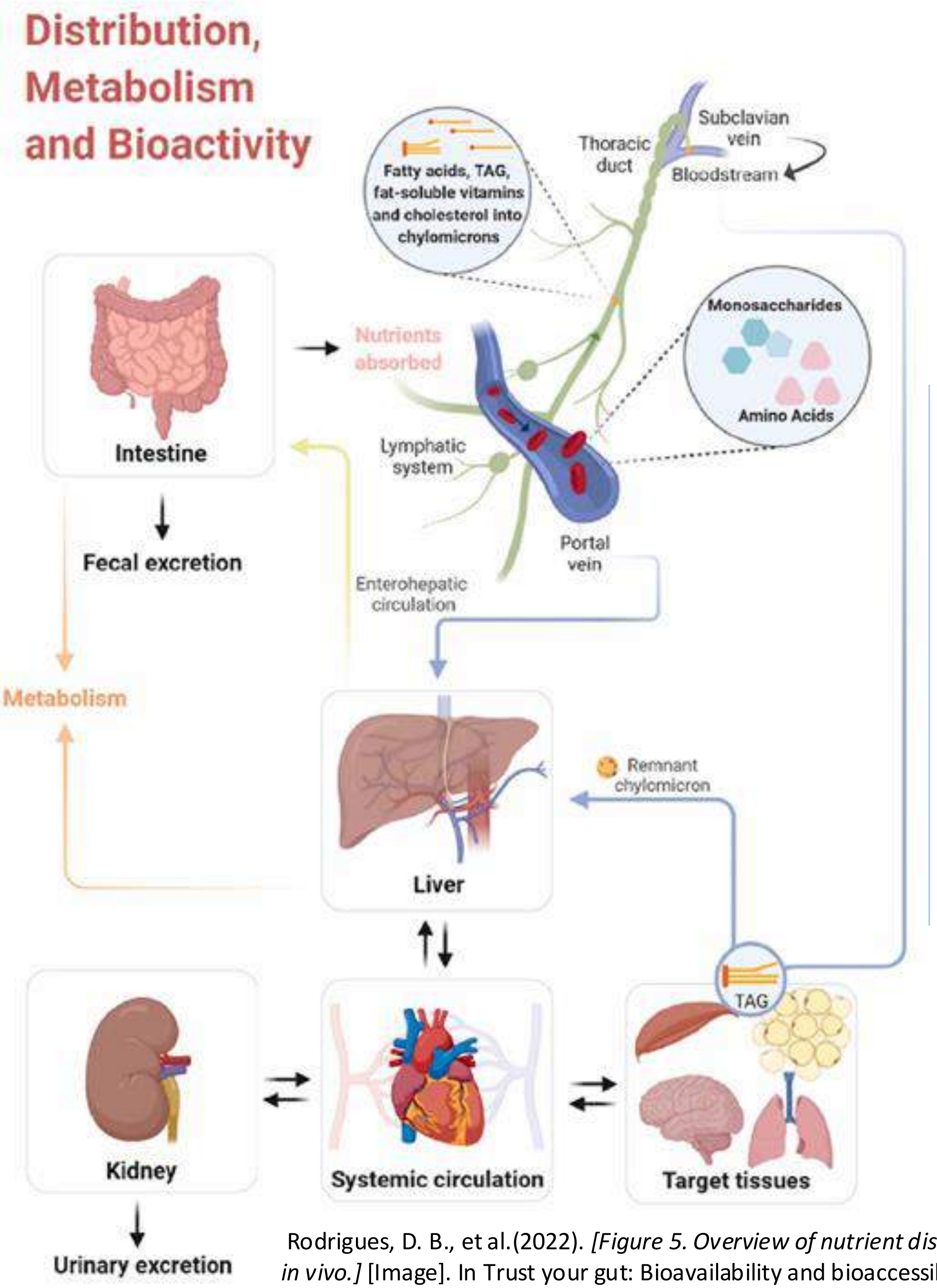
$$IVD = \left(\frac{Initial\ mass - Undigested\ mass}{Initial\ mass}\right) \times 100$$

BIOACCESSIBILITY OF A COMPOUND (%)

$$Bioaccessibility = \left(\frac{A}{B}\right) \times 100$$

A: concentration of the compound in the bioaccessible fraction corrected with compound present in tap water and the reagents

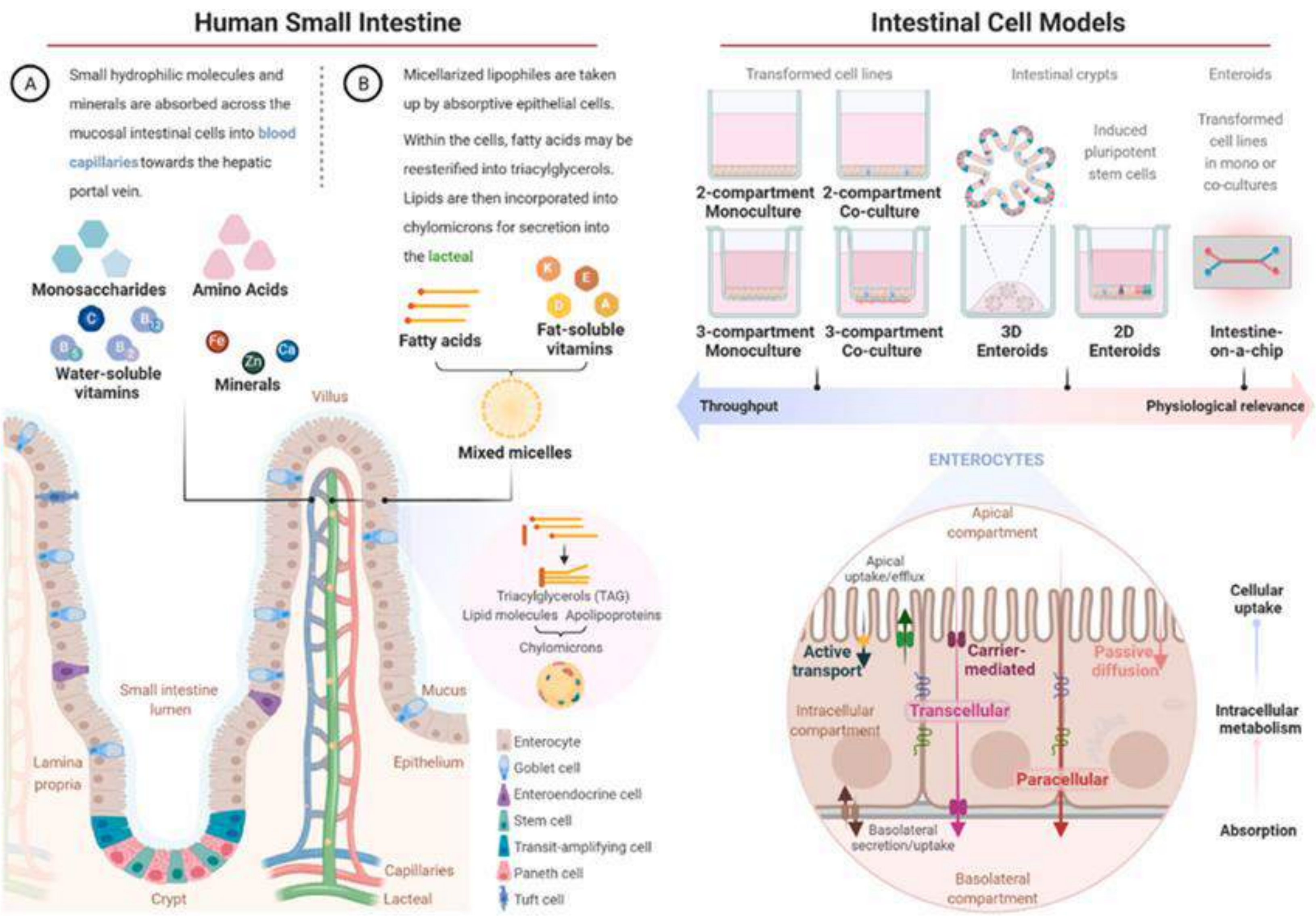
B: concentration of the compound in the sample before digestion.



Rodrigues, D. B., et al. (2022). *[Figure 5. Overview of nutrient distribution between systemic circulation and tissues after intestinal absorption, in vivo.]* [Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence: CC BY-NC-ND 4.0.

4. Bioactivity Evaluation

4. Applied cell models



Rodrigues, D. B., et al. (2022). *[Figure 4. Intestinal uptake, metabolism, and absorption of nutrients in vivo and intestinal cell models of varying degrees of complexity, potential throughput, and physiological relevance.]* [Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence: CC BY-NC-ND 4.0.

Basic Concepts: Applied Cell Models for Nutrient Absorption

1. Objective of Cell Models

To simulate **intestinal absorption** after digestion.

Focus on **bioaccessible nutrients**:

- Water-soluble (e.g., vitamins, amino acids)
- Fat-soluble (e.g., carotenoids, vitamin D)

2. Cellular Transport Pathways

Apical uptake by enterocytes from intestinal lumen.

Intracellular processing: metabolism, utilization, or efflux.

Basolateral transport indicates actual absorption:

- Water-soluble nutrients → blood capillaries → liver
- Fat-soluble compounds → chylomicrons → lymphatic system

3. Types of In Vitro Models

Transformed Cell Monolayers:

- Caco-2 (enterocyte-like)
- HT-29 (goblet-like)
- Used in 2- or 3-compartment systems (apical, cellular, basolateral)

Advanced Models:

- **Enteroids** (2D/3D stem cell-derived structures)
- **Gut-on-a-chip** (dynamic flow, better simulation of physiology)

4. Cell Culture Configuration

Static systems:

- Flat monolayers on plastic or membrane inserts

Three-compartment systems:

- Simulate apical → cellular → basolateral passage
- Allow study of actual nutrient absorption

5. Limitations of Transformed Models

Caco-2 and clones (e.g., TC7) may not fully mimic normal enterocytes.

Differences in **transporters and enzymes**.

Uptake ≠ absorption unless basolateral transport is demonstrated.

6. Transport Mechanisms

Transcellular (passive or active transport)

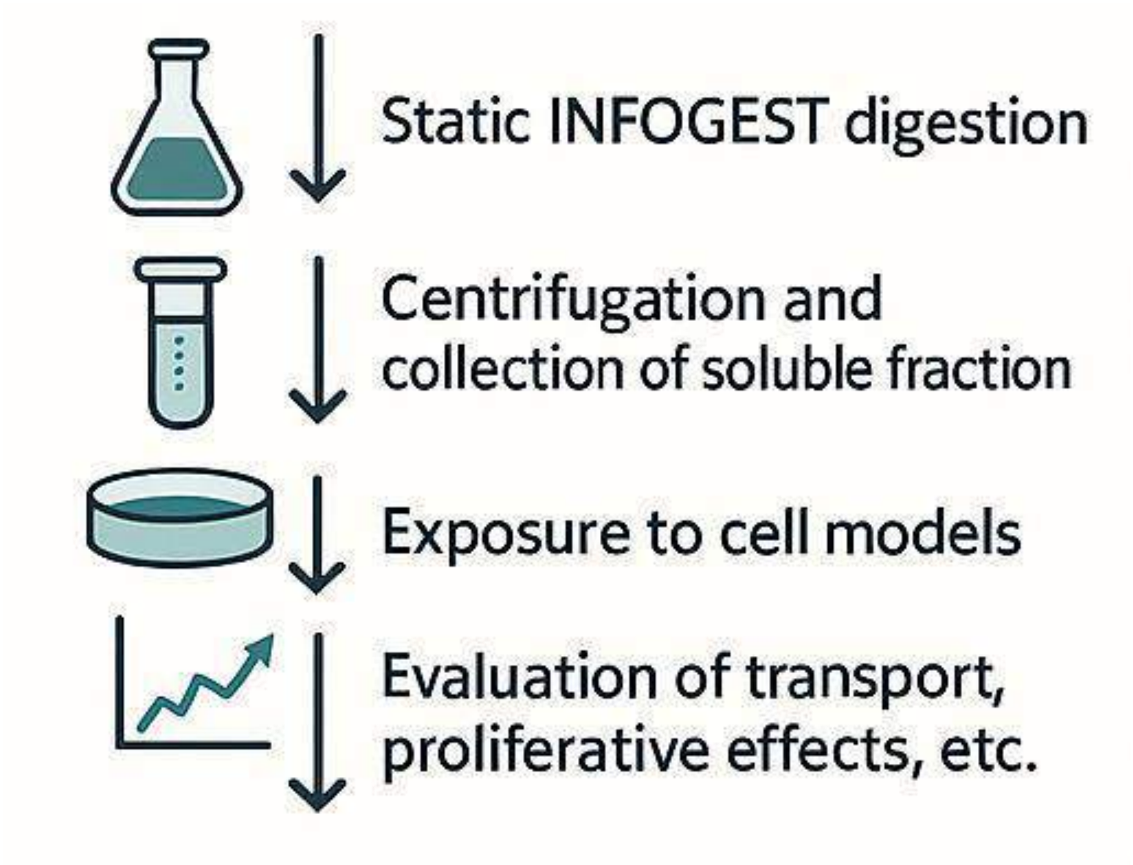
Paracellular (diffusion through tight junctions)

7. Delivery of Compounds in Vitro

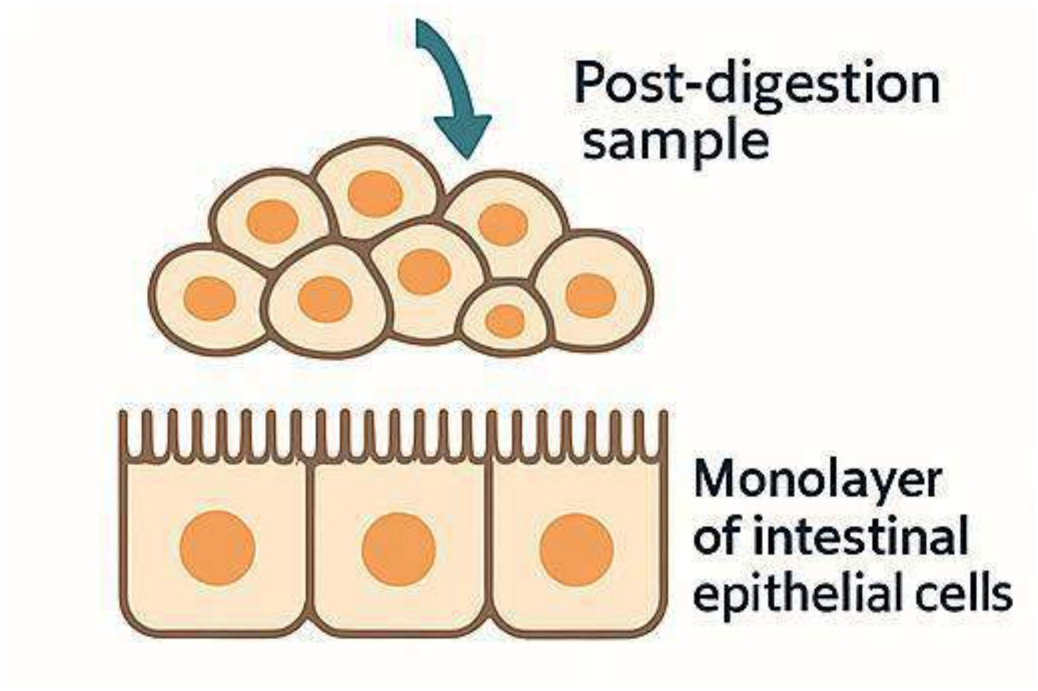
Typically to **apical compartment** using:

- Soluble or micellar fractions from digested chyme
- Compound extracts or artificial micelles

Combination of in vitro models + cellular models



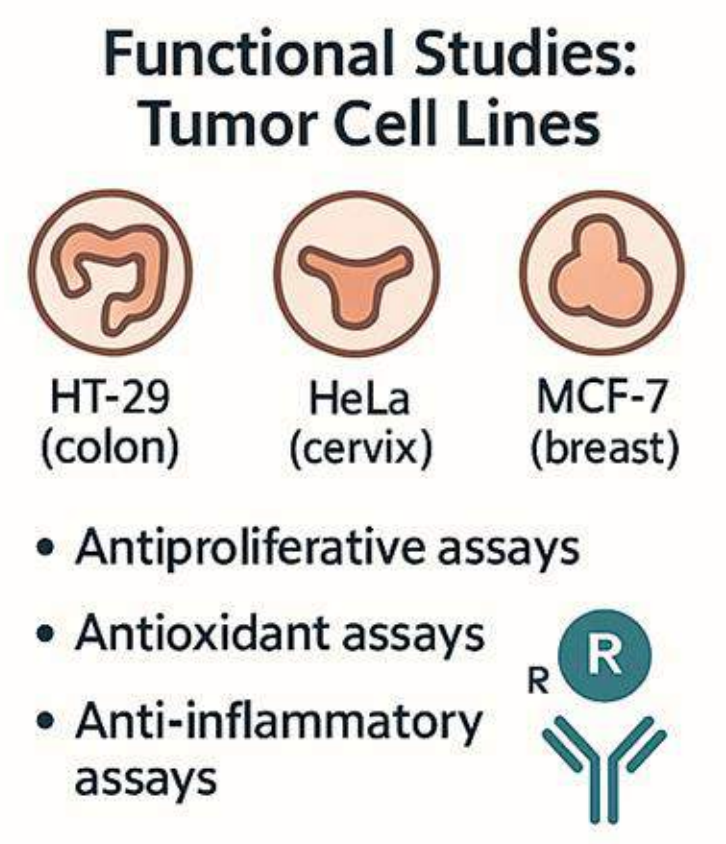
Functional bioactivity assays:
CaCo-2 model simulated intestinal absorption



- Human epithelial cells (CaCo-2) form monolayers that simulate the intestinal epithelium.
- The soluble fraction is exposed to post-digestion to assess transepithelial absorption.
- This model is widely used in studies of carotenoids, phenols and other nutrients.

Functional bioactivity assays:
Antiproliferative studies with tumour cell lines

- Lines such as HT-29 (colon), HeLa (cervix) and MCF-7 (breast) are used to evaluate this activity.
- Antioxidant assays: ORAC, ABTS and DPPH.
- Anti-inflammatory assays: ELISA (IL-6, TNF-α) and qPCR.



Microphysiological systems (MPS), or multi-organs-on-a-chip

These advanced methods are in vitro platforms that simulate the interaction between different organs—such as intestine, liver, and kidney—using interconnected organ chips.

KEY FEATURES:

- Mimic digestion, absorption, metabolism, and excretion (ADME) of dietary compounds.
- Organs are connected by microfluidic channels simulating blood and urine flow.
- Allow study of nutrient bioactivity in dynamic and physiologically relevant conditions.

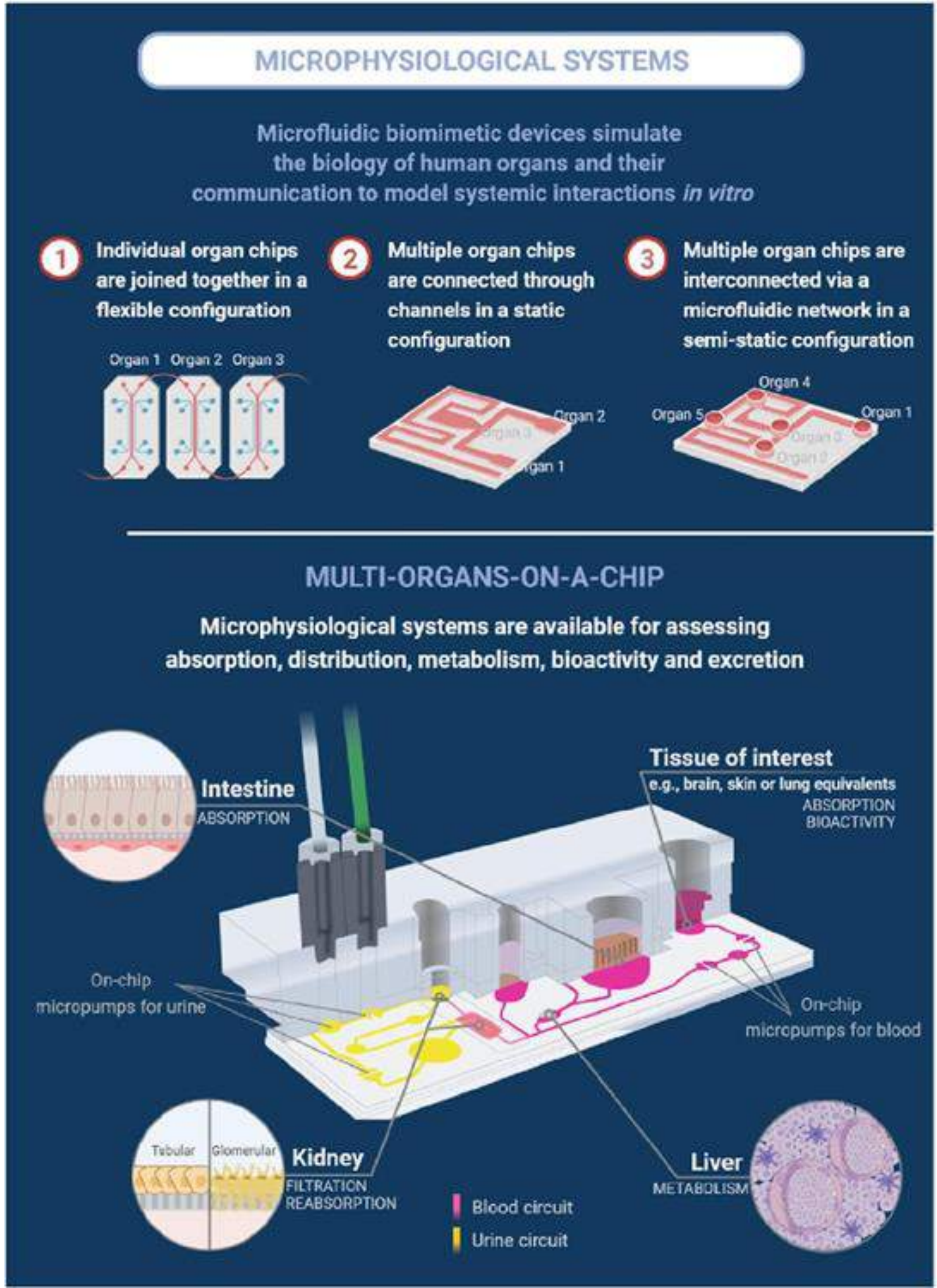
PLATFORM TYPES

1. Modular: Separate organ chips connected by tubing
2. Fixed Microfluidic Board: Permanent organ connections with constant Flow
3. Reconfigurable Single Plate: Chips inserted and linked via built-in channels

Example: Humimic Chip4 (TissUse GmbH)

- ➢ Connects intestine, liver, kidney, and another tissue.
- ➢ Supports complex cultures (organoids, spheroids).
- ➢ Useful for simulating nutrient absorption and metabolism.

Still in early development; used mainly in pharma, but promising for Food & Nutrition Science.



Rodrigues, D. B., et al.(2022). [*Figure 5b. Overview of microphysiological systems*.[Image]. In Trust your gut: Bioavailability and bioaccessibility of dietary compounds. Current Research in Food Science, 5, 100123. https://doi.org/10.1016/j.crfs.2022.01.002. Licence: CC BY-NC-ND 4.0.

5. Conclusions and Future Directions

In vitro digestion, especially the INFOGEST model, allows a reproducible and standardised assessment of bioaccessibility.

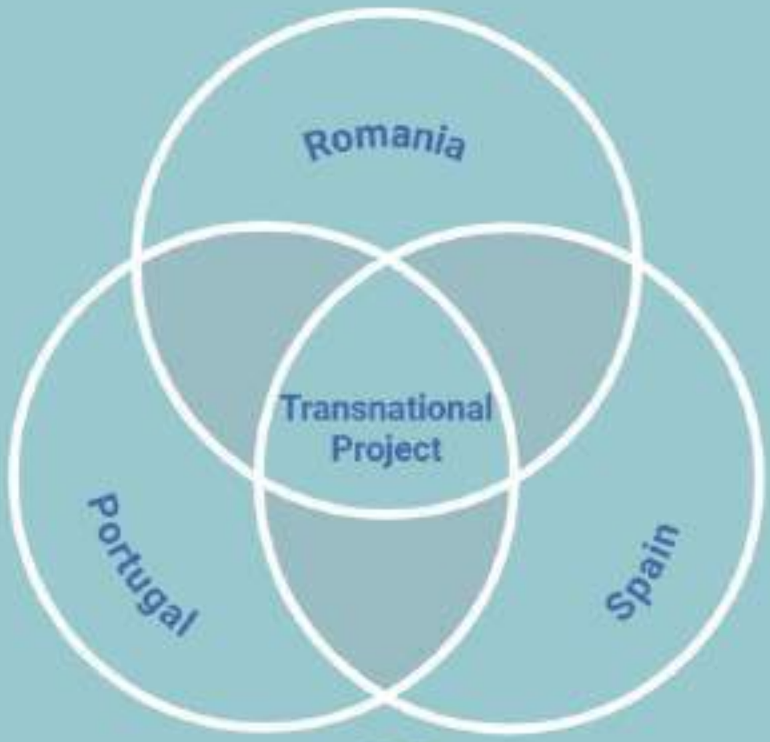
The combination with functional cellular models (CaCo-2, HT-29...) offers a more realistic approach to bioavailability and bioactivity.

Validation of in vitro effects provides useful evidence for the development of functional food and reformulation strategies.

Further studies integrating digestion, absorption, and secondary metabolism are required to approximate human physiological conditions.

New in silico and organ-on-chip strategies represent promising avenues for the future.

Coordinator and partners:



eAfoBy

Project Reference: 2024-1-RO01-KA220-HED-000246776

Co-funded by the European Union