Stabilization of oil-in-water Pickering emulsions with nanostructured cellulose for delivery of bioactives in food and cosmetic applications

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A technology platform for the sustainable recovery and advanced use of nanostructured cellulose from agri-food residues

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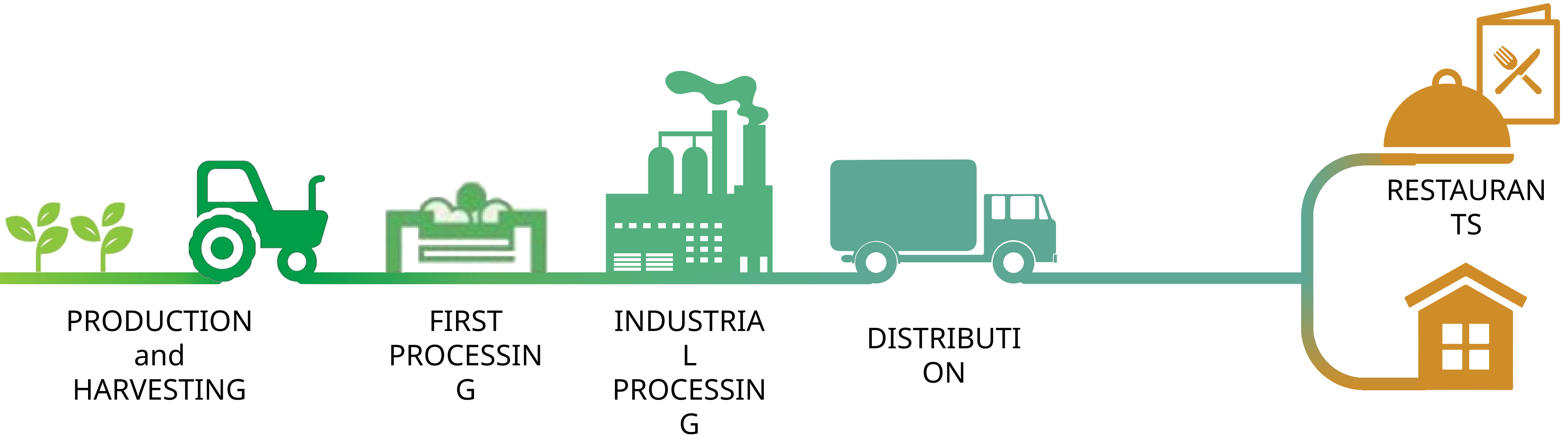
Università degli Studi di Napoli Federico II

Agri-food residues

Agri-food residues

13.3% of the world's food is lost after harvesting and before reaching retail markets

17% of total food is wasted at the consumer level




Climate change
Nature and biodiversity loss
Pollution and waste
Agri-food residues

Halve food waste and reduce food loss by 2030

Agri-food residues

Objectives

Objectives

Design a green technology platform for an efficient and sustainable valorization of **agri-food residues**, ensuring the recovery of **high value-added compounds**

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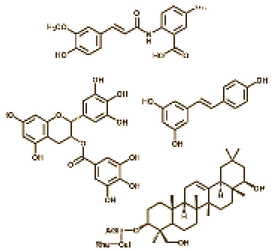
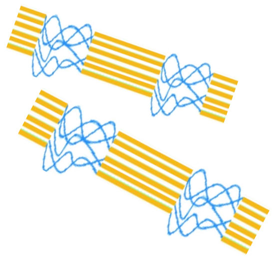
Bioactive compounds



Cellulose



Nanocellulose

Objectives

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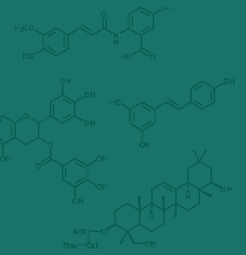
Nanocellulose

Bioactive compounds



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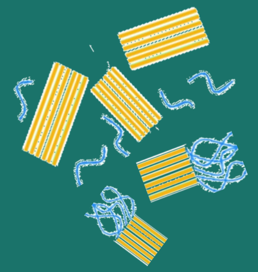
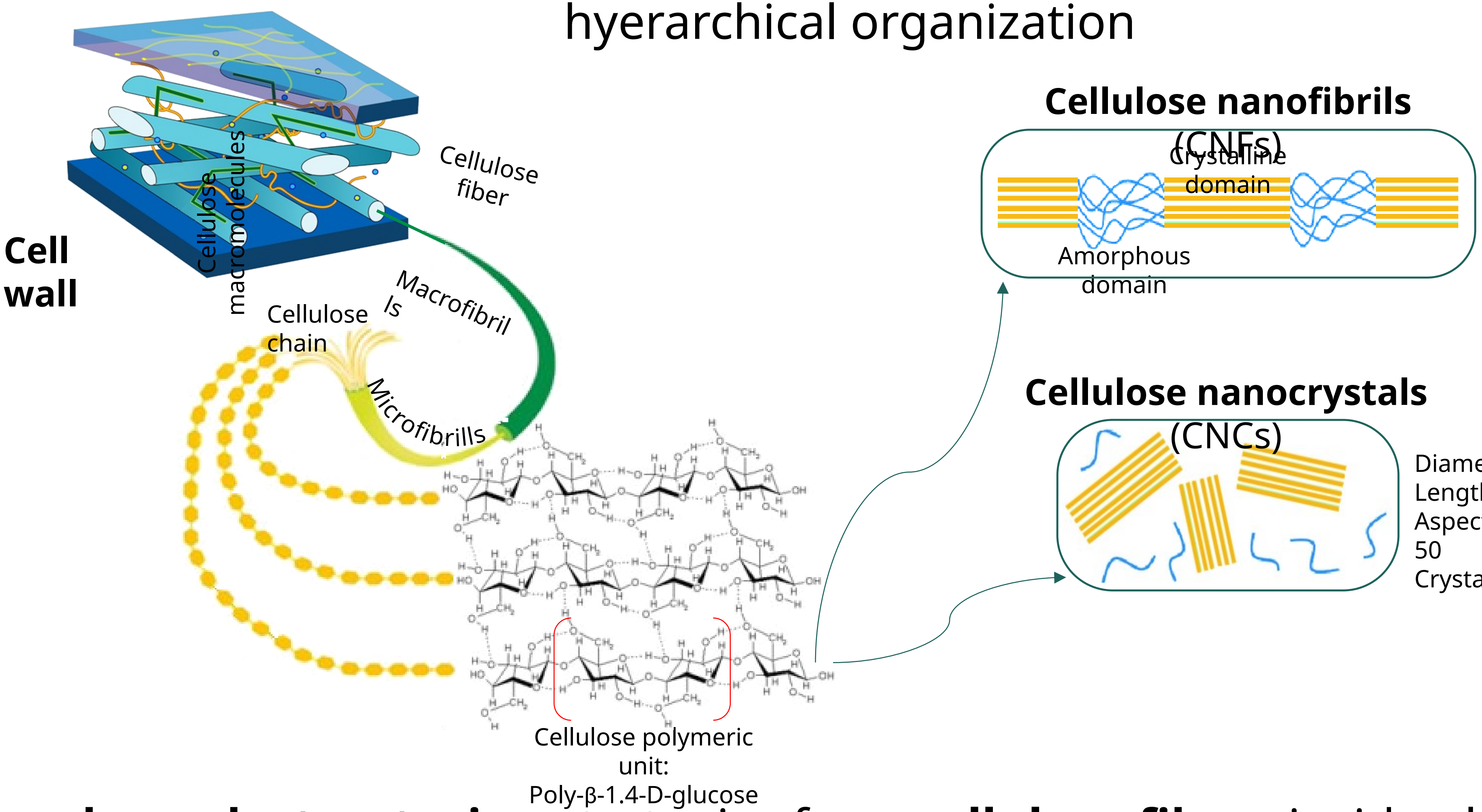


Objectives

Nanocellulose

hyerarchical organization



Cellulose nanofibrils (CNFs)

Diameter ~ 10-100 nm
Length > 1 μm
Aspect ratio (L/d) ~ 70-100
Crystallinity ~ 84.9%

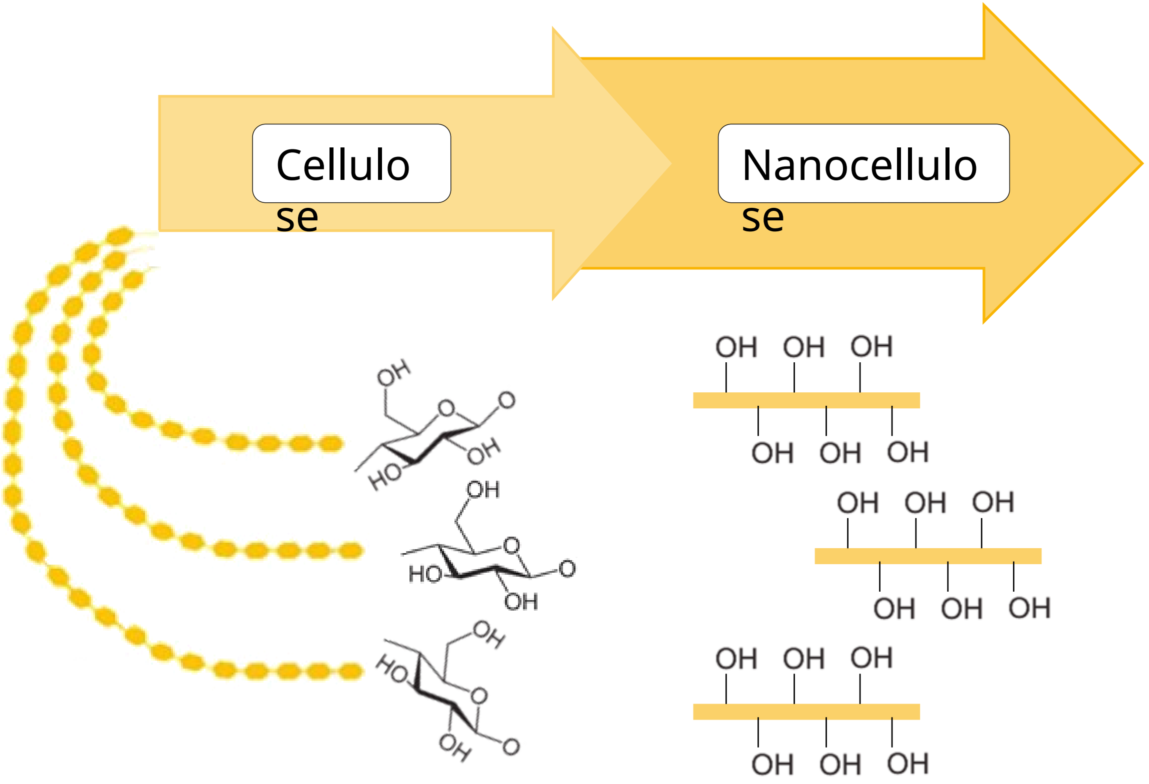
Cellulose nanocrystals (CNCs)

Diameter ~ 4-25 nm
Length ~ 100-500 nm
Aspect ratio (L/d) ~ 15-50
Crystallinity ~ 91.2%

top-down destructuring strategies from **cellulose fibers** inside plant cell wall to **nano-sized cellulose** (NCs) structure

Nanocellulose

promising material due to its important **features**



High mechanical strength

High surface area

Low density

High biodegradability

Easy functionalization

Objectives

Nanocellulose

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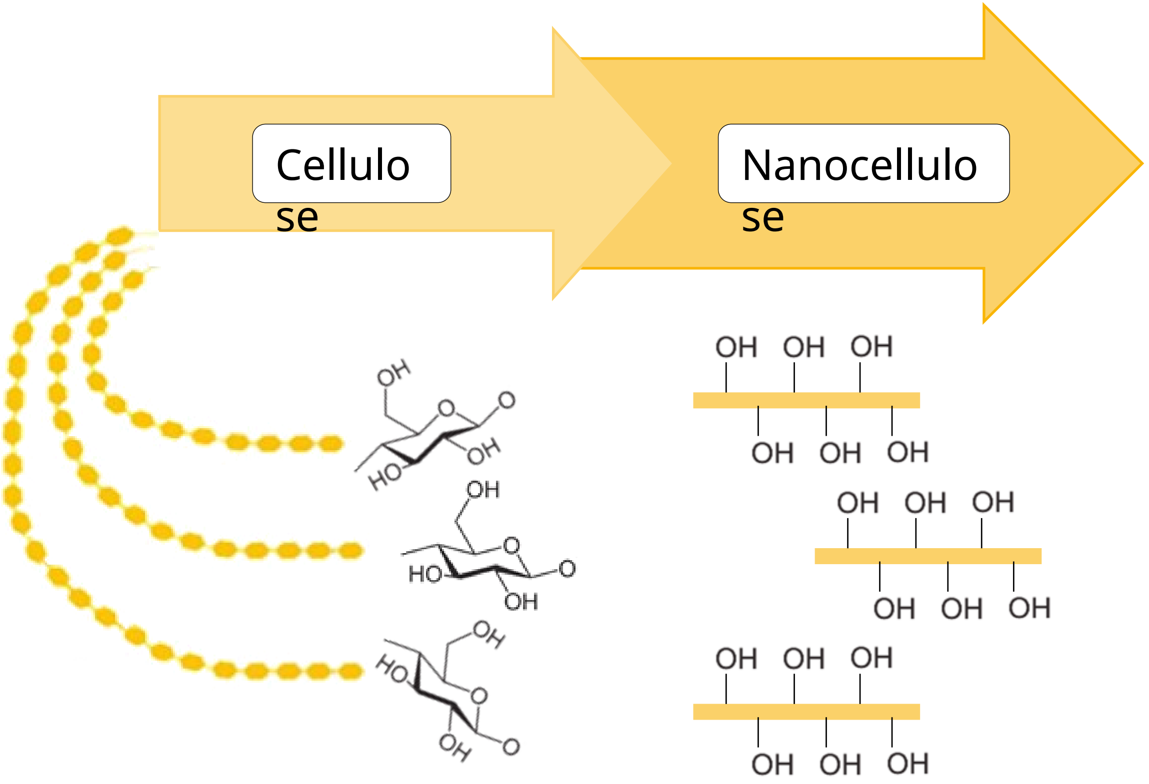

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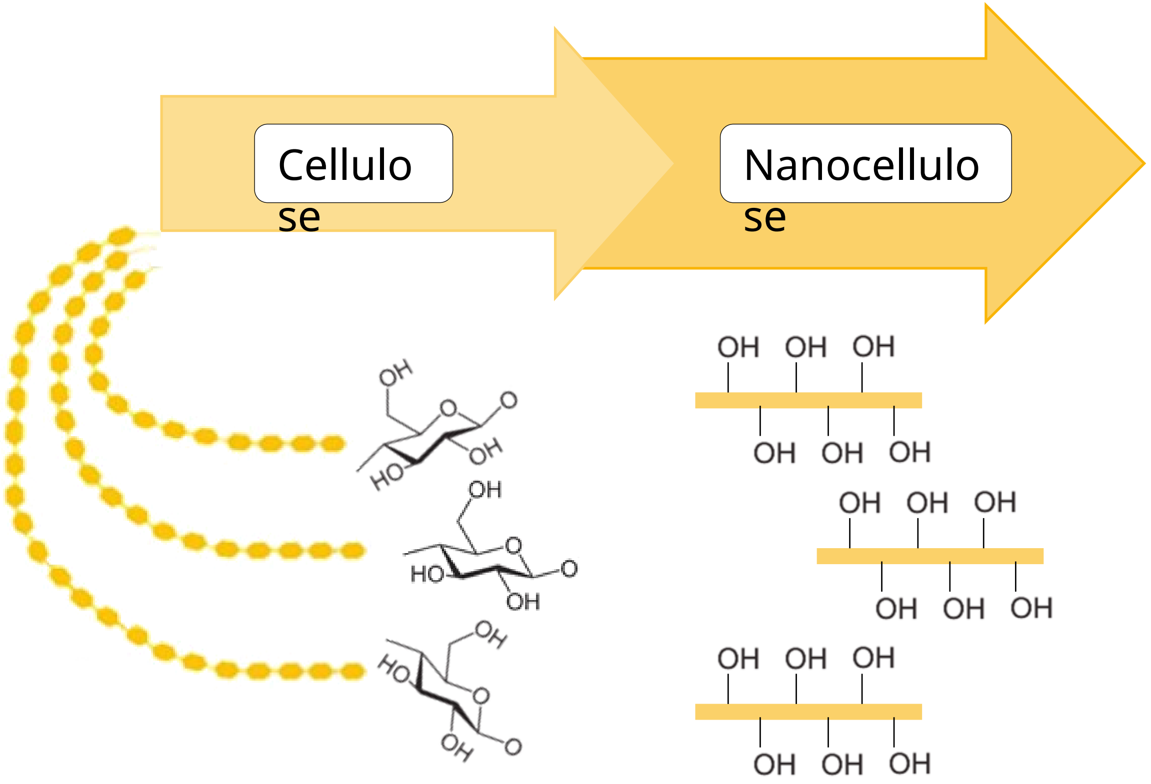

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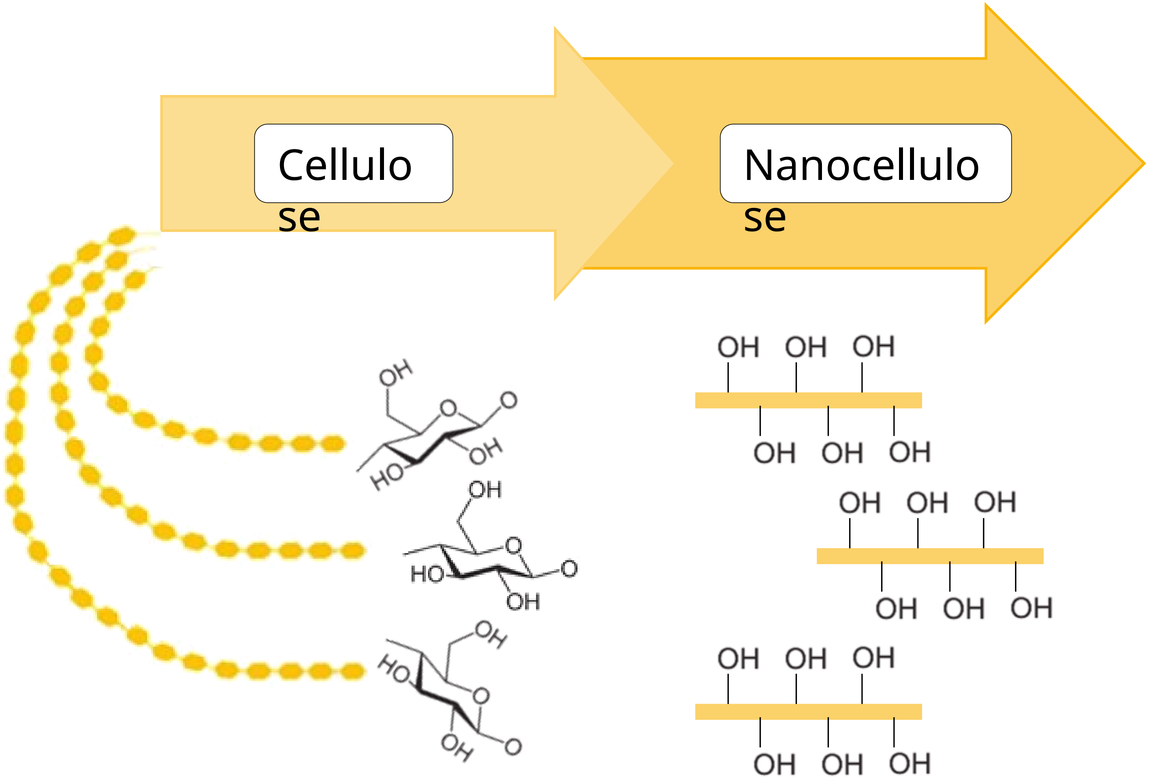

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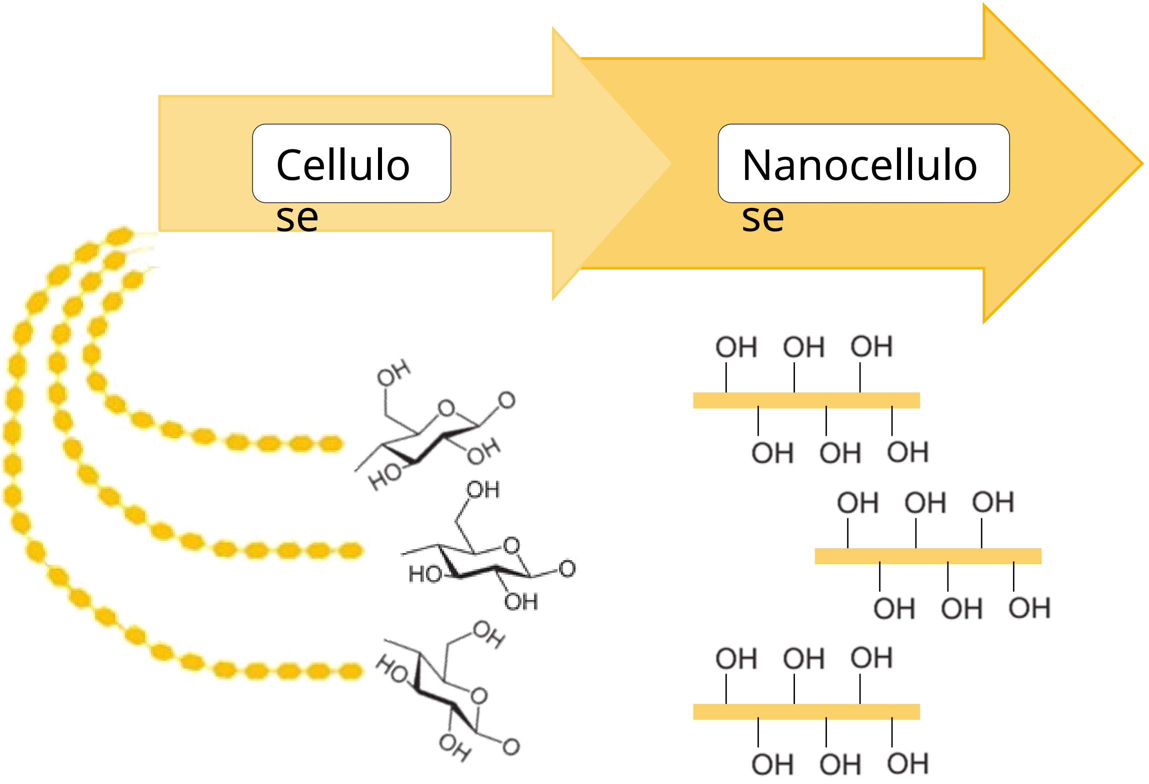


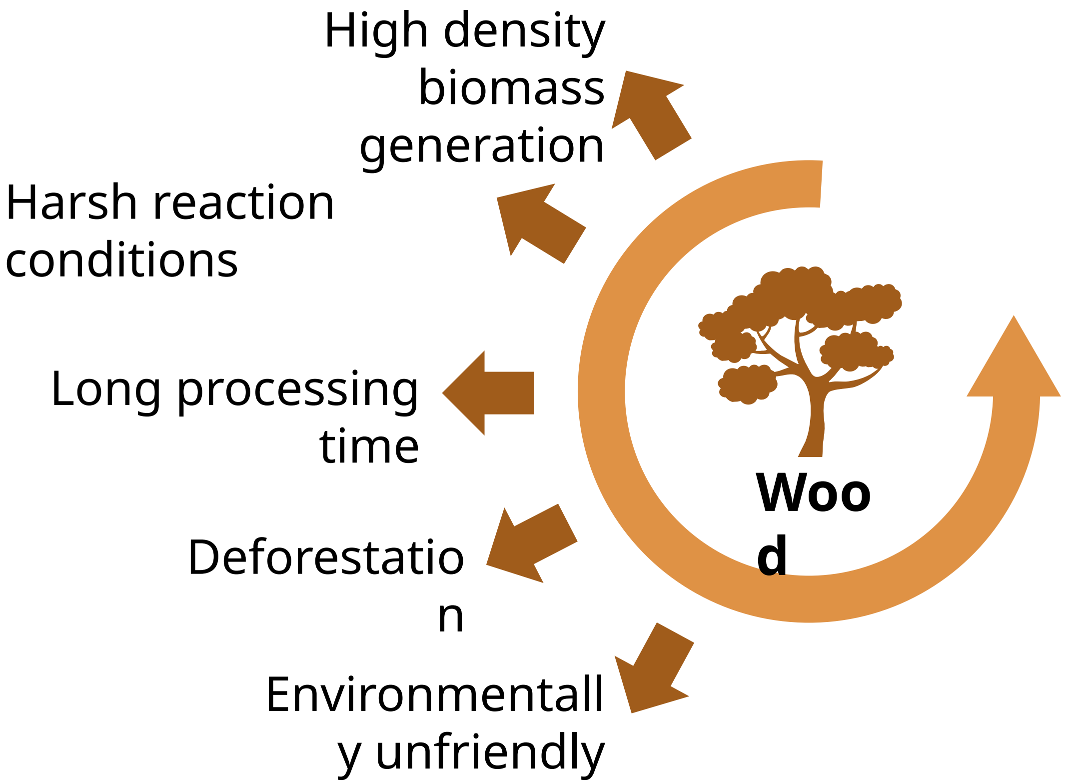
High biodegradability

Easy functionalization

Objectives

Biomass sources

for **cellulose** and **nanocellulose** isolation



Objectives

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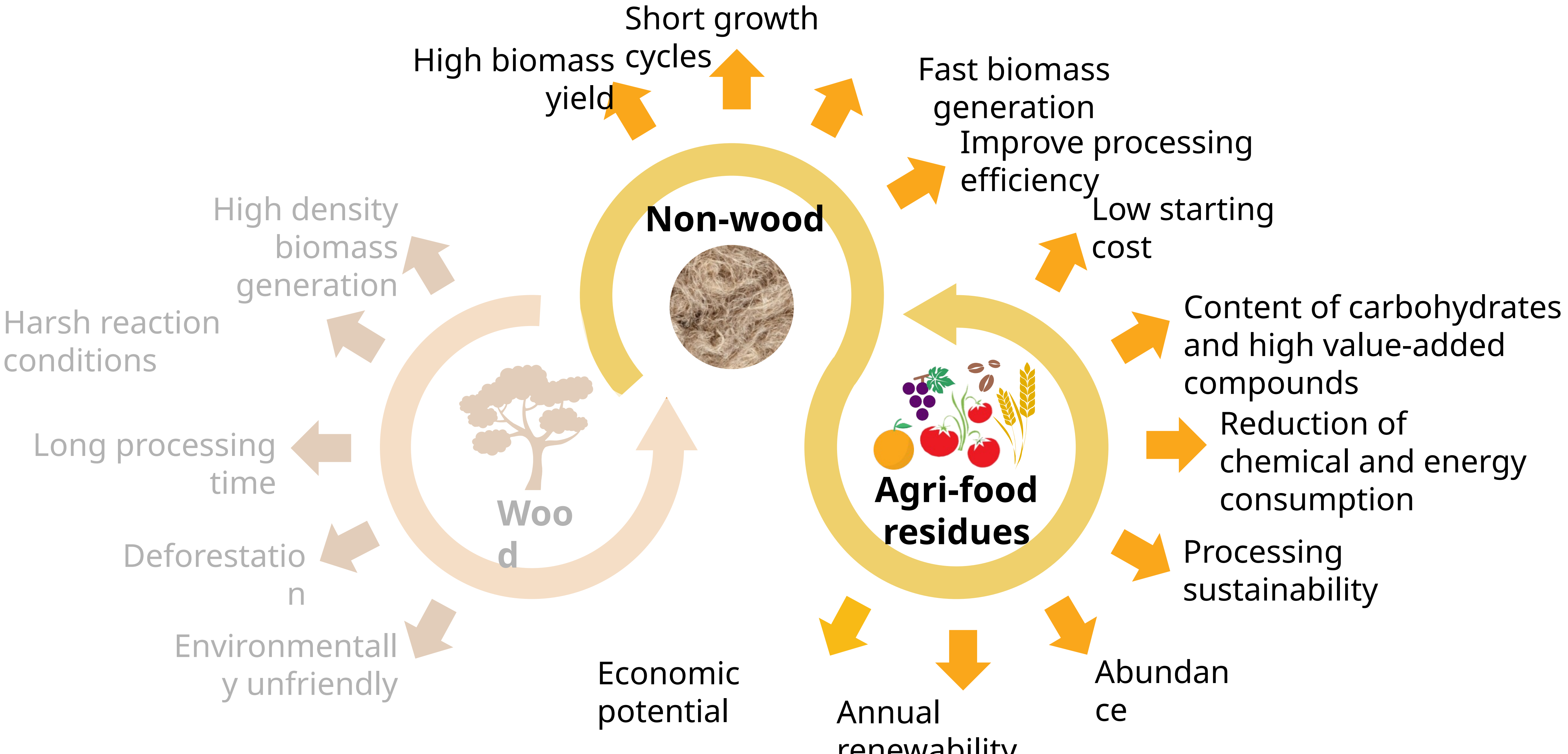
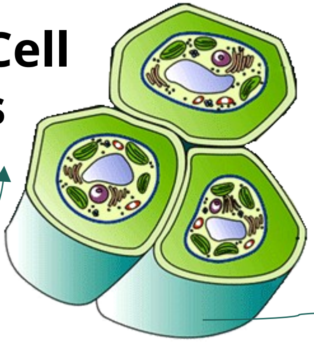
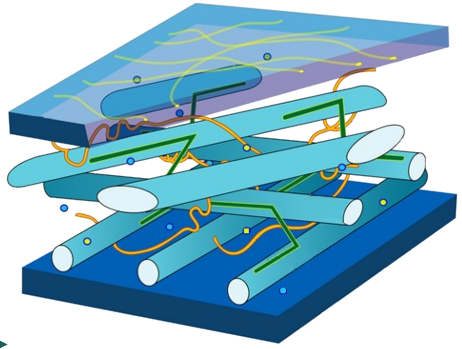


Agri-food residues

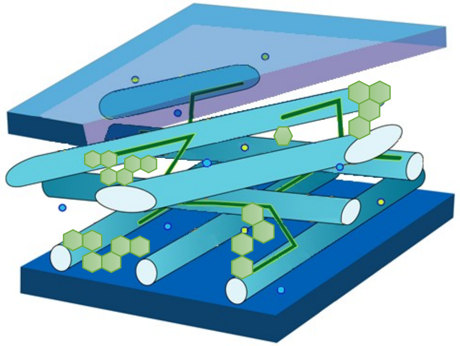
cheap source containing **value-added** compounds

Cell
s

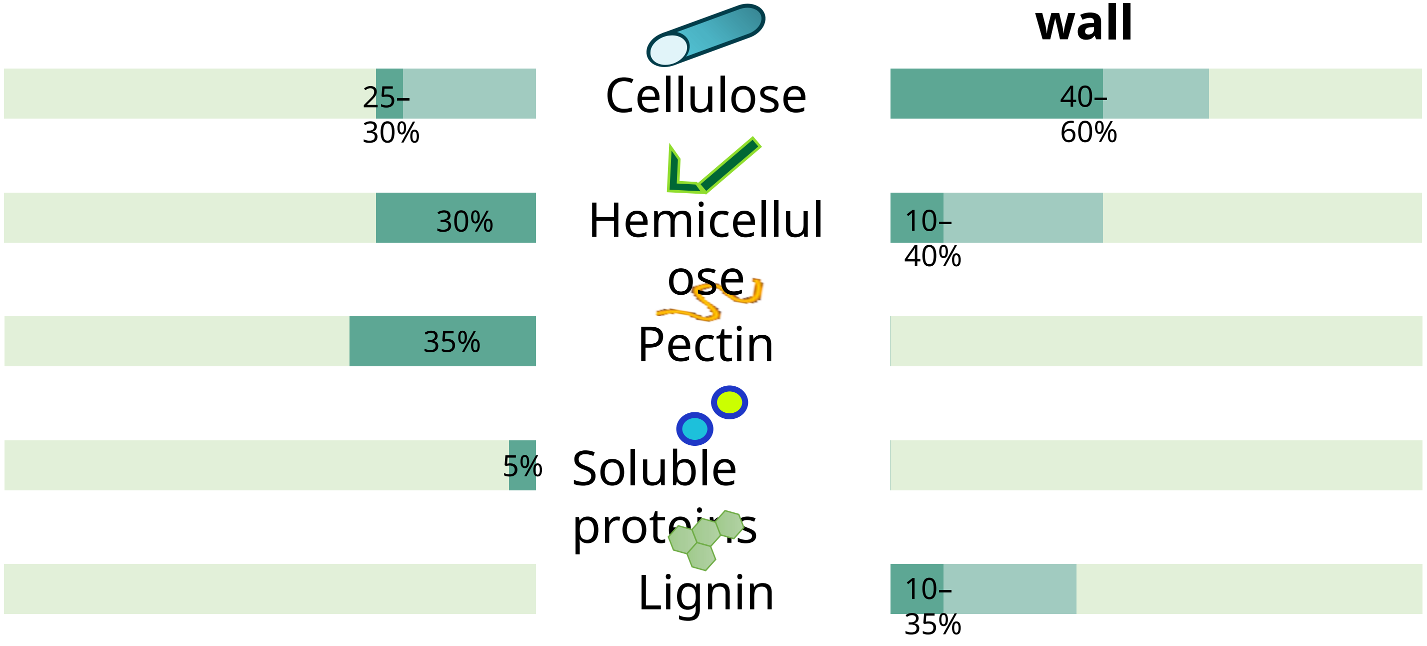




Primary cell wall



Secondary cell wall



Agri-food residues (AFRs)

* Composition percentage considering dry weight

Objectives

Agri-food residues

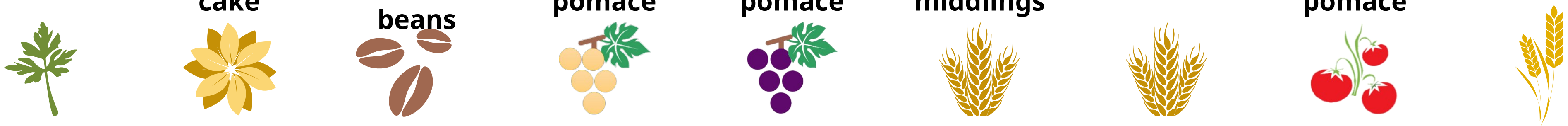
cheap source containing **value-added** compounds

- Hemp cake
- Sunflower cake
- Roasted coffee beans
- White grape pomace
- Red grape pomace
- Wheat middlings
- Wheat bran
- Tomato pomace
- Rice husk

Objectives

Agri-food residues

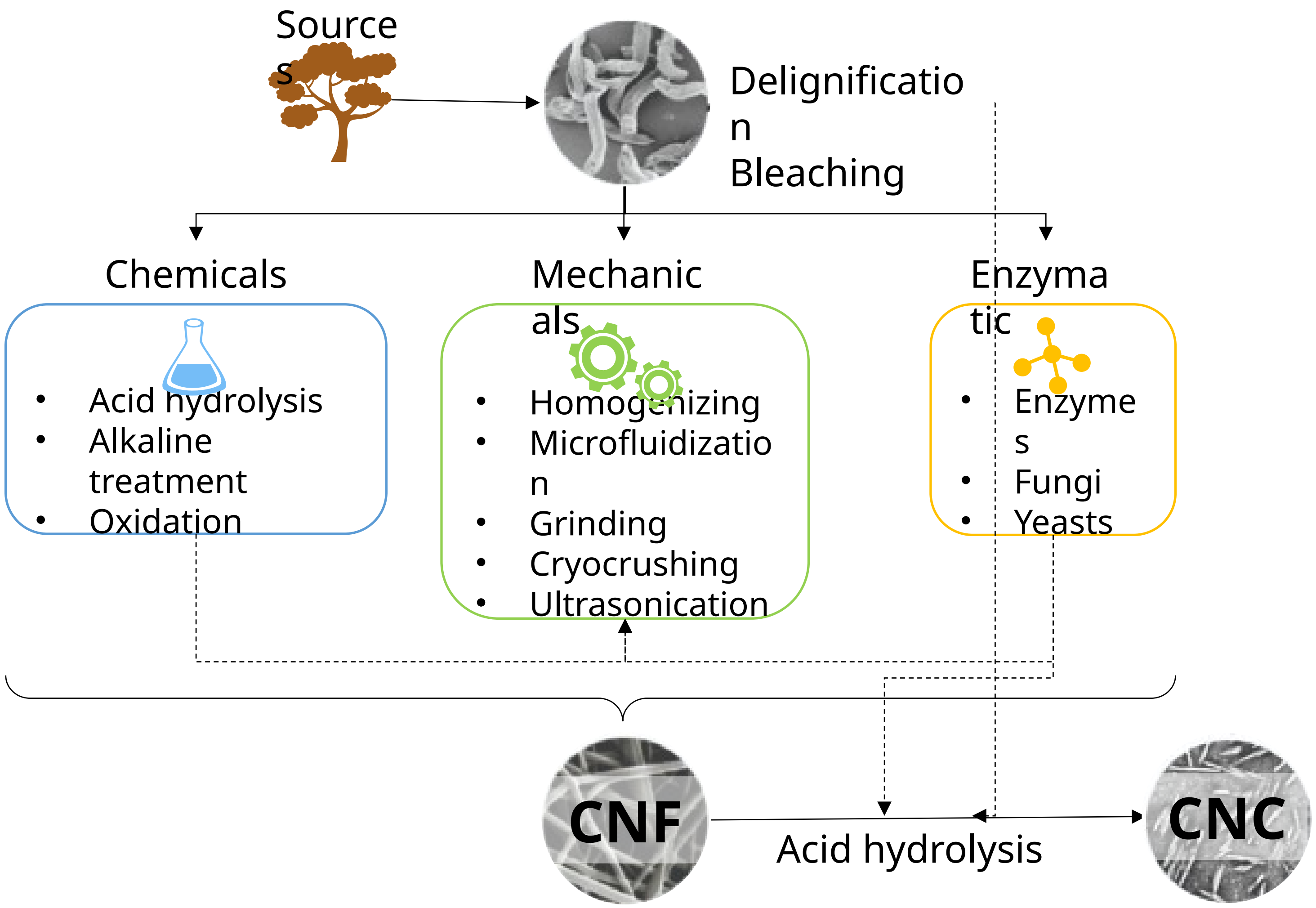
chemical characterization



	Hemp cake	Sunflower cake	Roasted coffee beans	White grape pomace	Red grape pomace	Wheat middlings	Wheat bran	Tomato pomace	Rice husk
Moisture (%)	7.99 ± 0.06	10.75 ± 0.06	5.97 ± 0.04	80.41 ± 1.99	62.58 ± 2.21	10.59 ± 0.01	11.54 ± 0.10	80.70 ± 0.83	6.72 ± 0.13
Ash ($\%_{DM}$)	6.40 ± 0.04	5.93 ± 0.03	5.10 ± 0.81	10.52 ± 3.08	35.88 ± 5.80	3.79 ± 0.25	5.83 ± 0.60	4.90 ± 0.27	18.71 ± 0.23
Protein ($\%_{DM}$)	24.78 ± 0.49	24.30 ± 1.24	16.96 ± 0.41	58.13 ± 7.95	51.88 ± 1.77	18.53 ± 1.21	19.10 ± 0.40	14.65 ± 0.21	2.56 ± 0.25
Fat ($\%_{DM}$)	5.30 ± 0.09	2.30 ± 0.21	1.00 ± 0.02	1.55 ± 0.14	2.70 ± 0.33	0.79 ± 0.06	0.85 ± 0.10	1.20 ± 0.14	0.82 ± 0.15
Carbohydrates ($\%_{DM}$)	63.52 ± 0.49	68.47 ± 1.24	76.94 ± 0.91	29.80 ± 9.84	9.54 ± 3.55	76.90 ± 1.23	74.22 ± 0.72	79.25 ± 0.34	76.44 ± 0.34

Conventional treatments

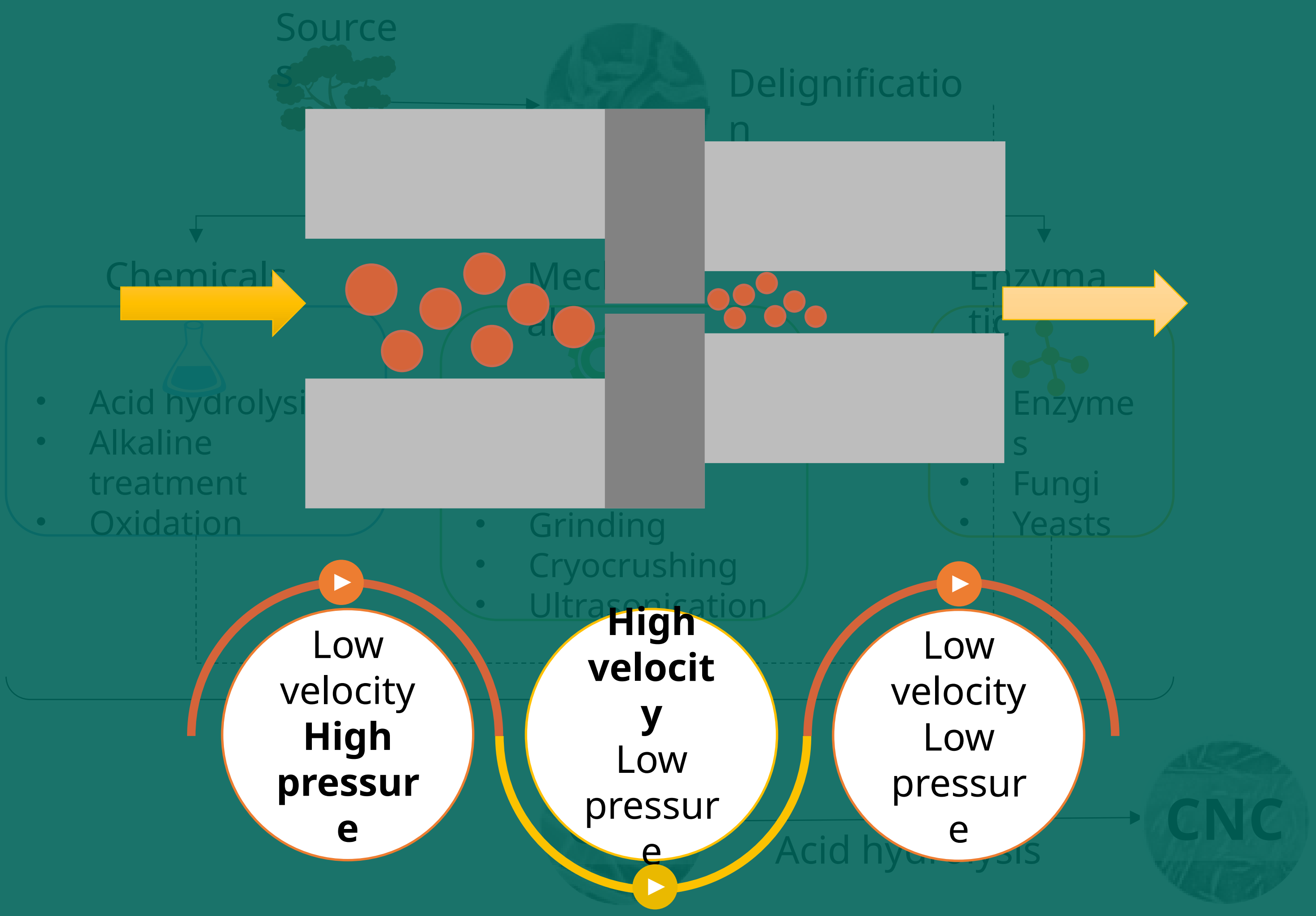
to obtain **cellulose nanoparticles**



Objectives

Non conventional treatments

to obtain **cellulose nanoparticles**



High-pressure homogenization (HPH)

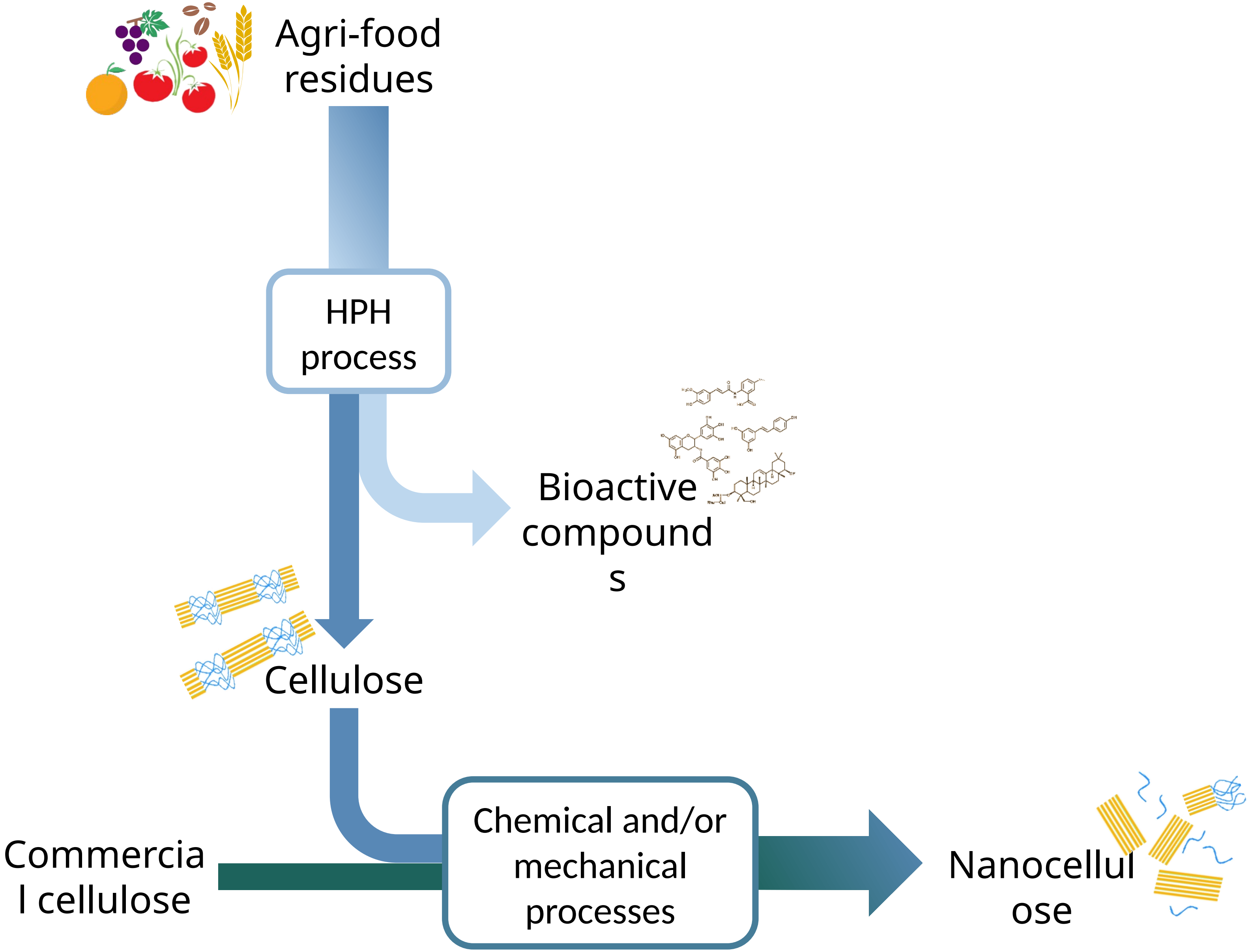
Emerging *nonthermal* and purely physical treatments to **defibrillate different biomass** and producing **nanosized cellulose,** while extracting high value-added compounds from agri-food

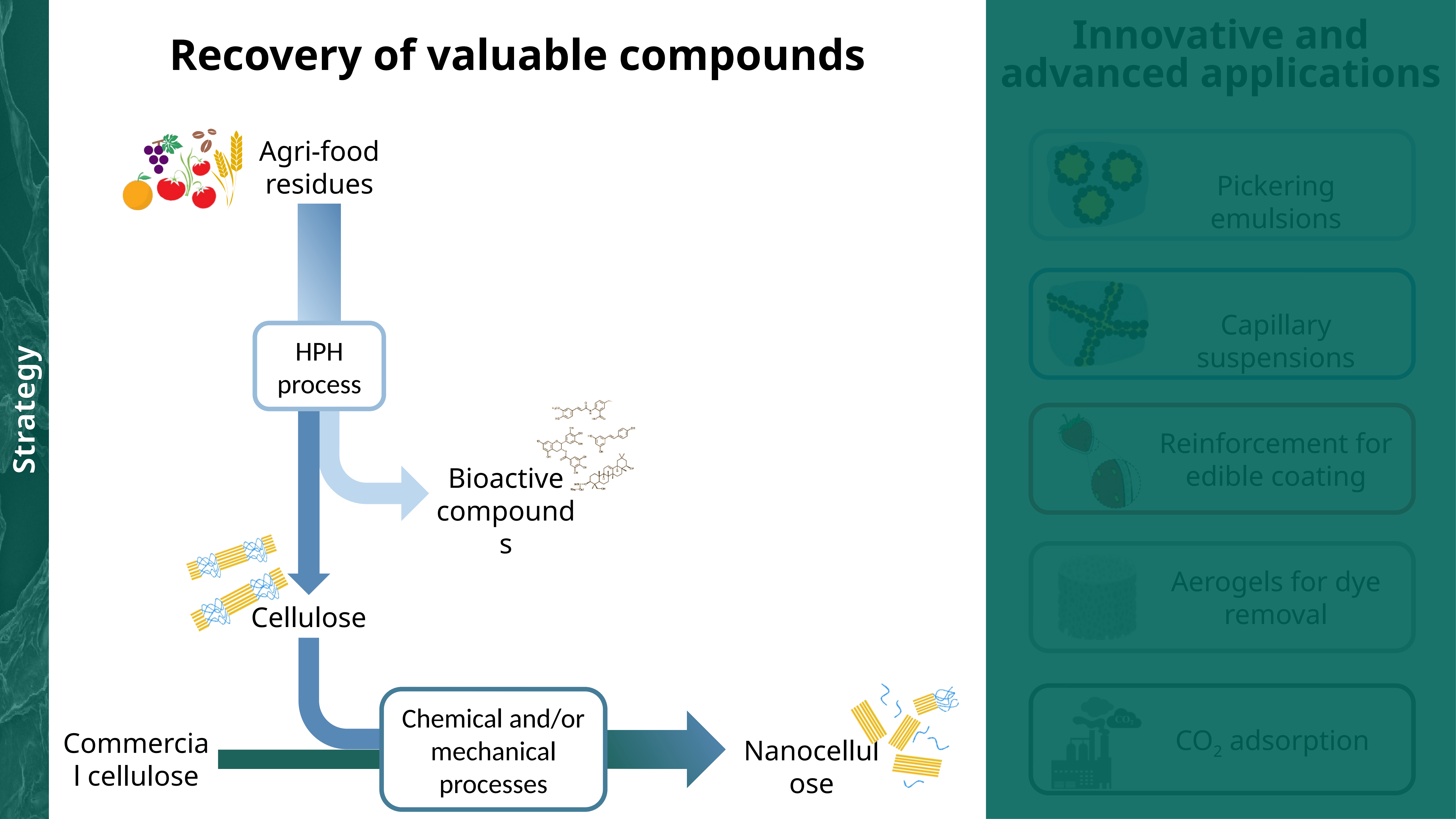
Objectives

Strategy

Strategy

Recovery of valuable compounds

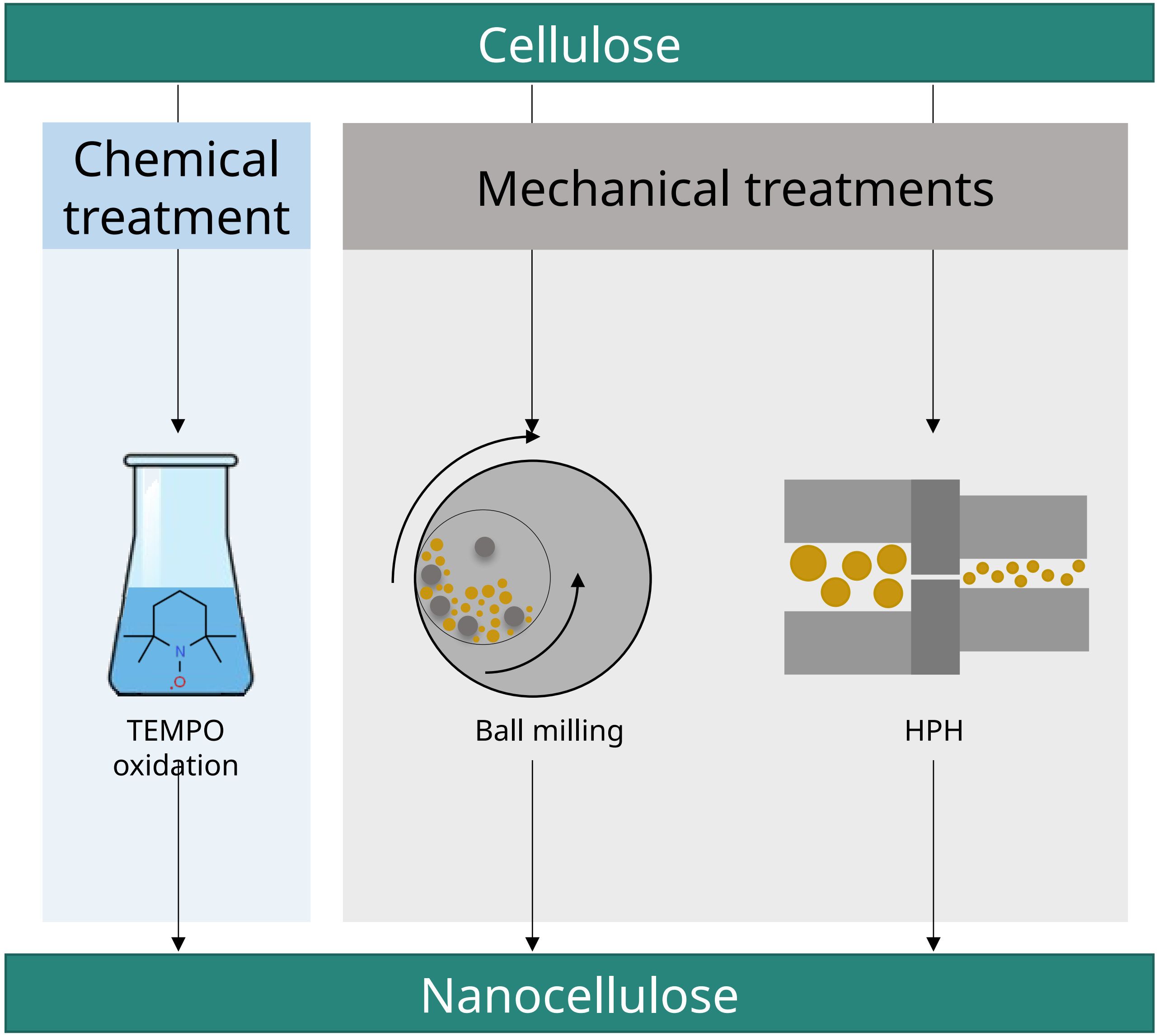




Strategy
Recovery of valuable compounds
Agri-food residues
HPH process
Bioactive compounds
Cellulose
Commercial cellulose
Chemical and/or mechanical processes
Nanocellulose
Innovative and advanced applications
Pickering emulsions
Capillary suspensions
Reinforcement for edible coating
Aerogels for dye removal
CO_2 adsorption

Nanocellulose

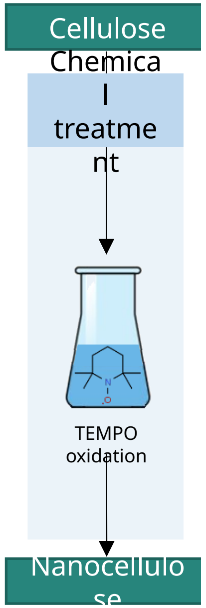
Nanocellulose



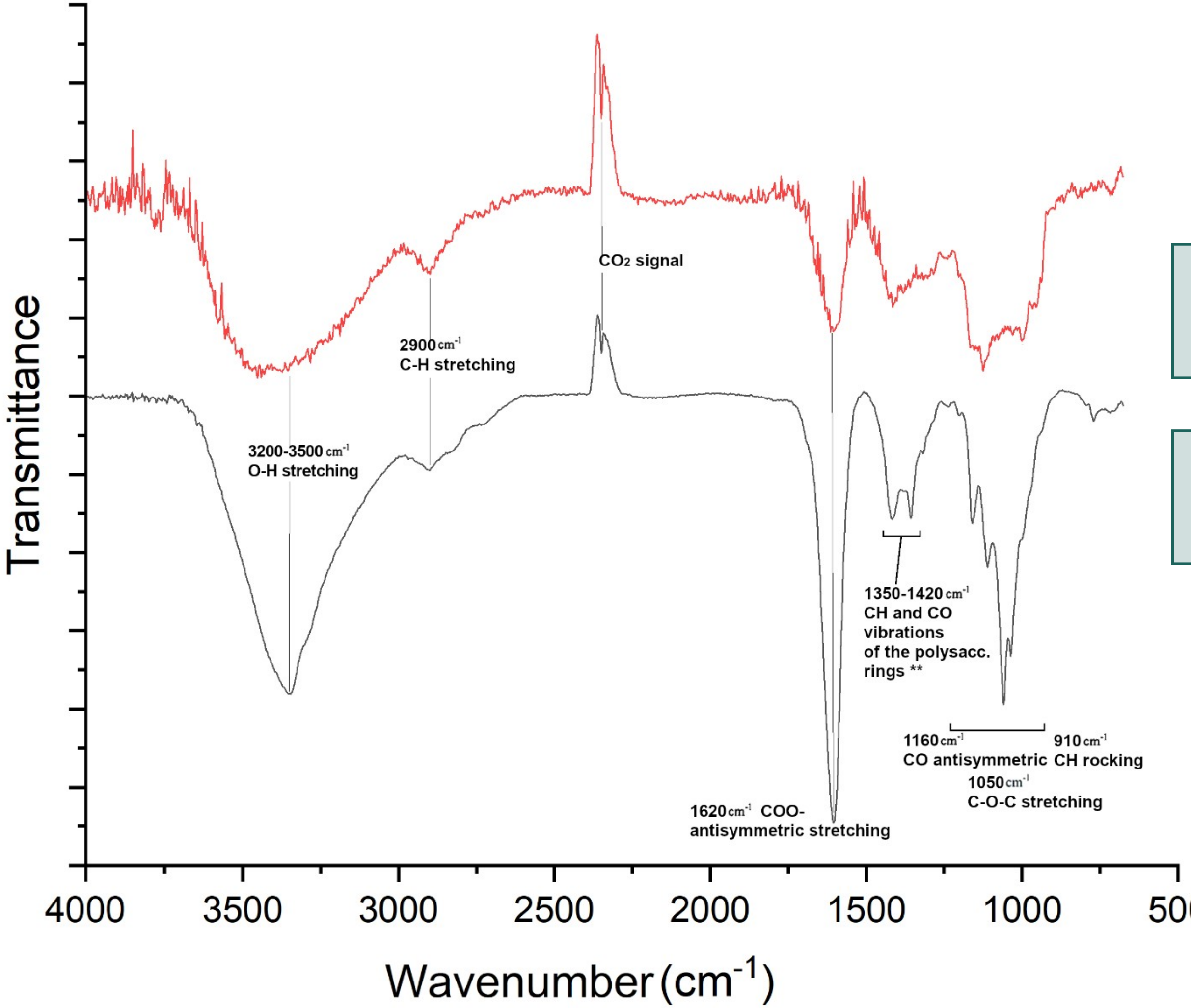
Recovery of valuable compounds

Nanocellulose

from **commercial cellulose** through **TEMPO oxidation**

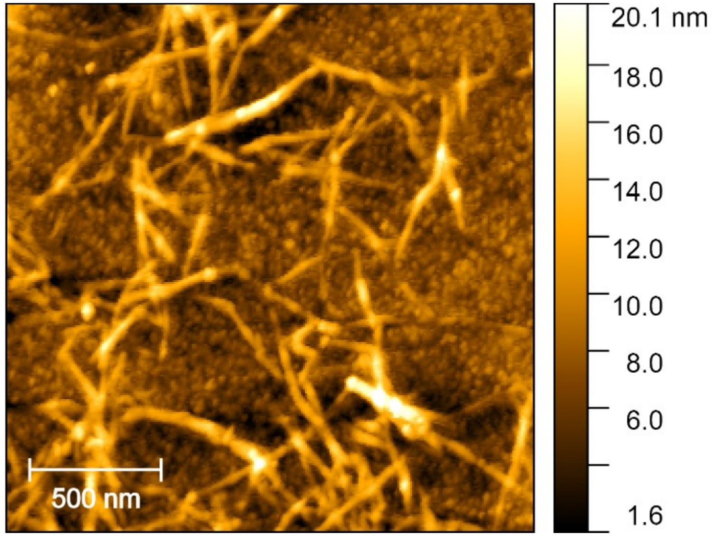


FT-IR analysis



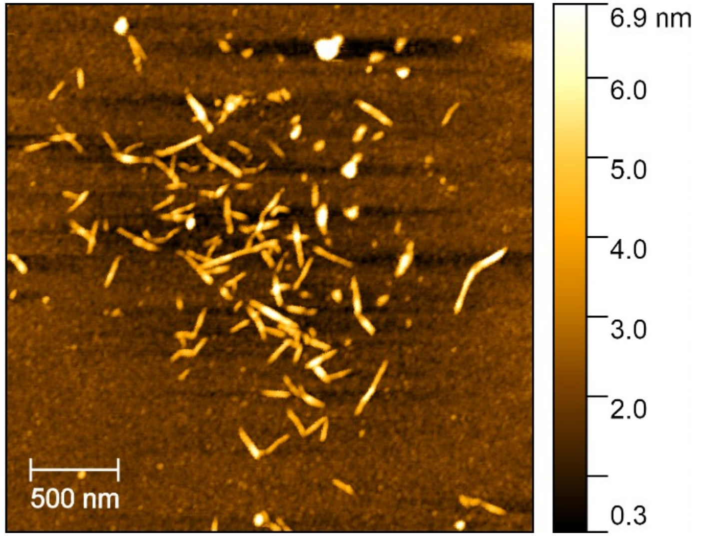
CNFs

Fibrous netwotk
Diameter ~ 10 nm
Length ~ μm



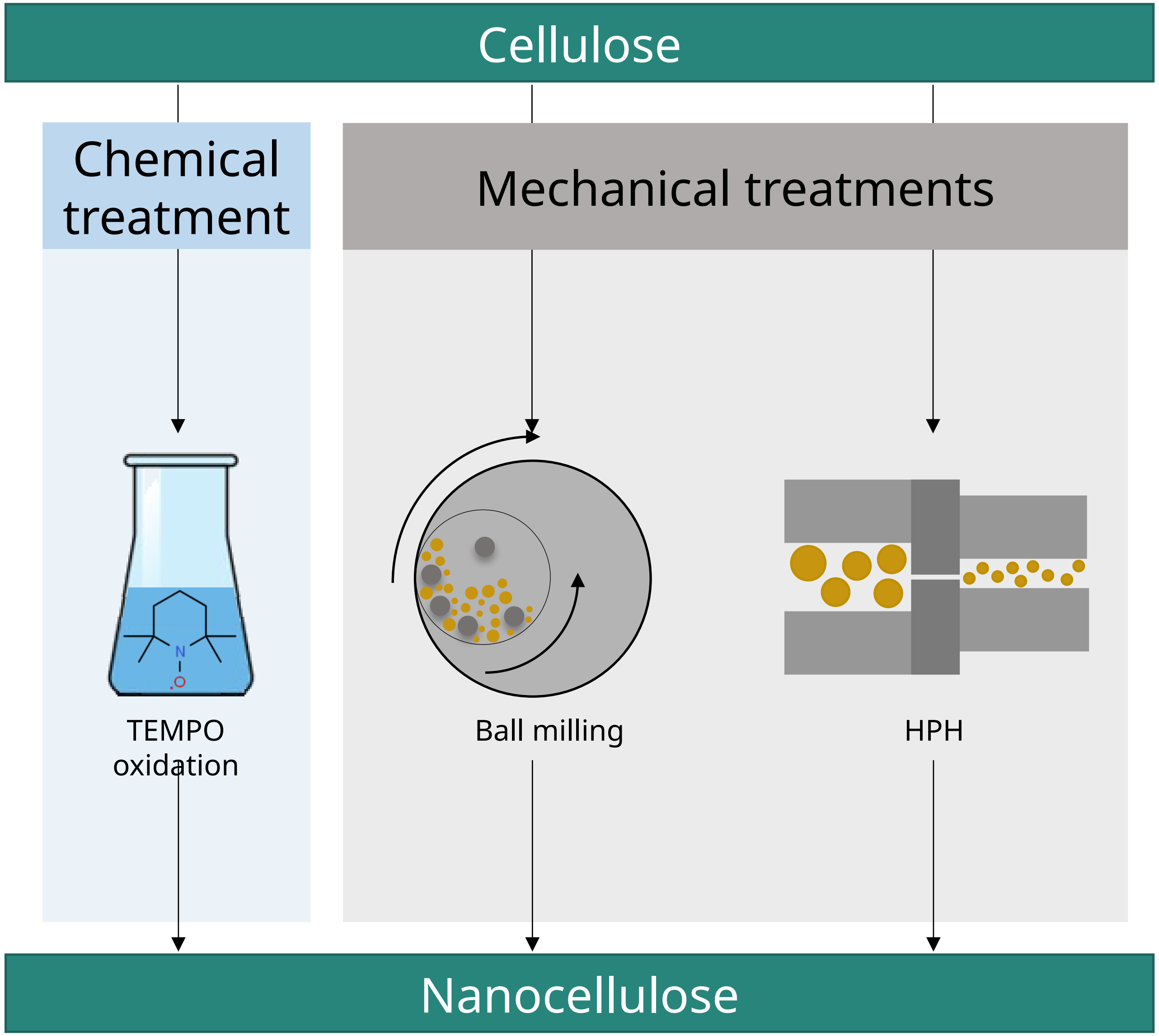
CNCs

Needle-like structure
Diameter ~ 3 nm
Length ~ 170 nm



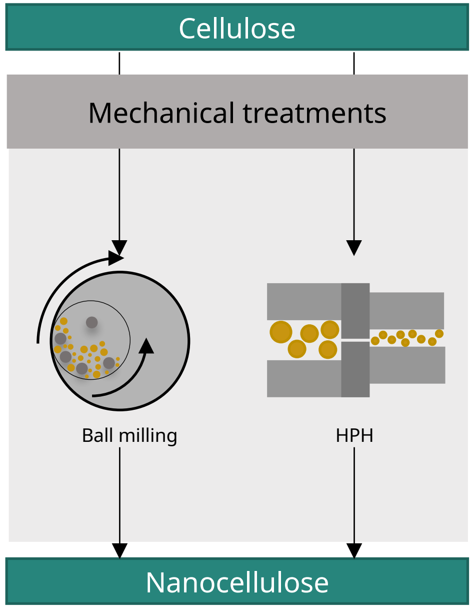
Pirozzi et al., 2023. *LWT*, Under review

Nanocellulose

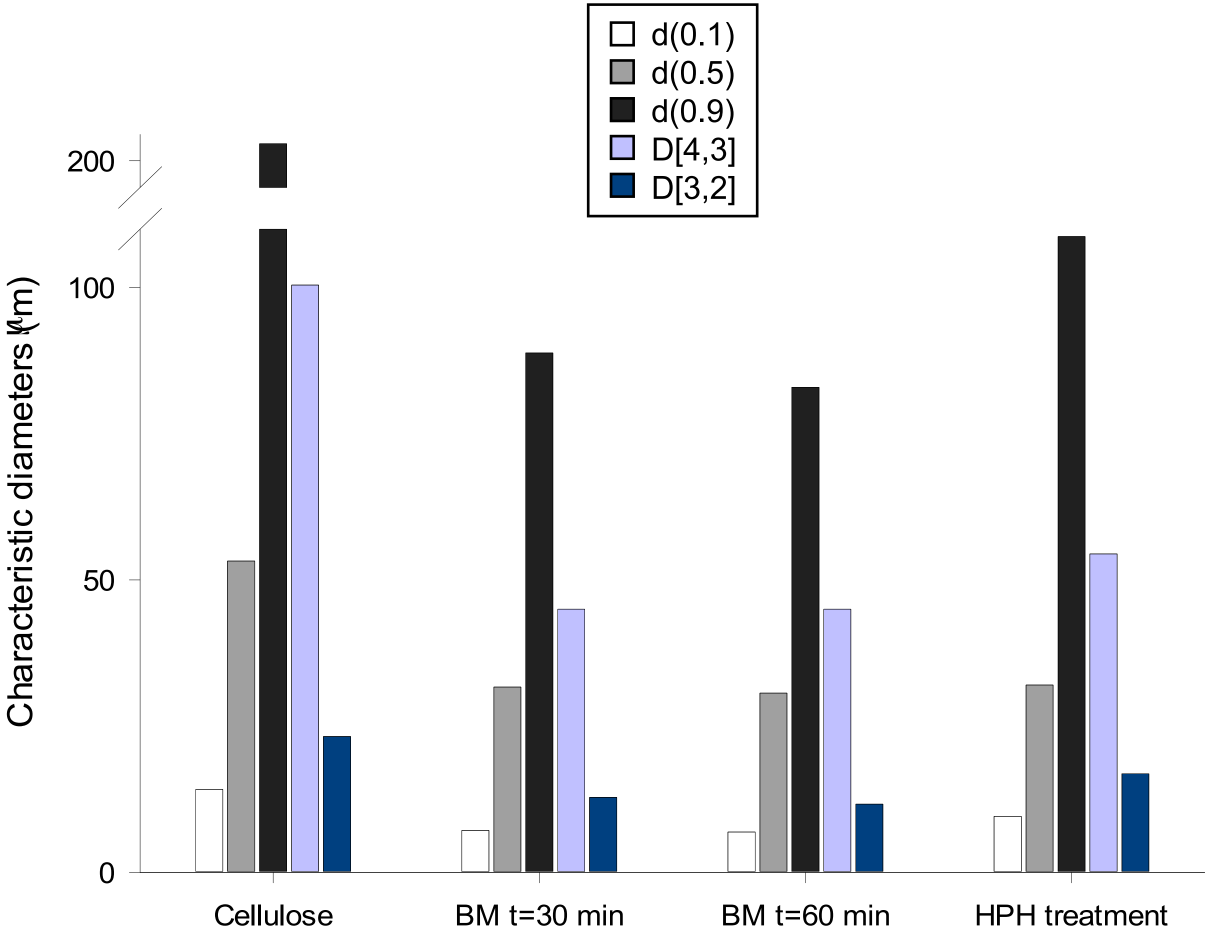


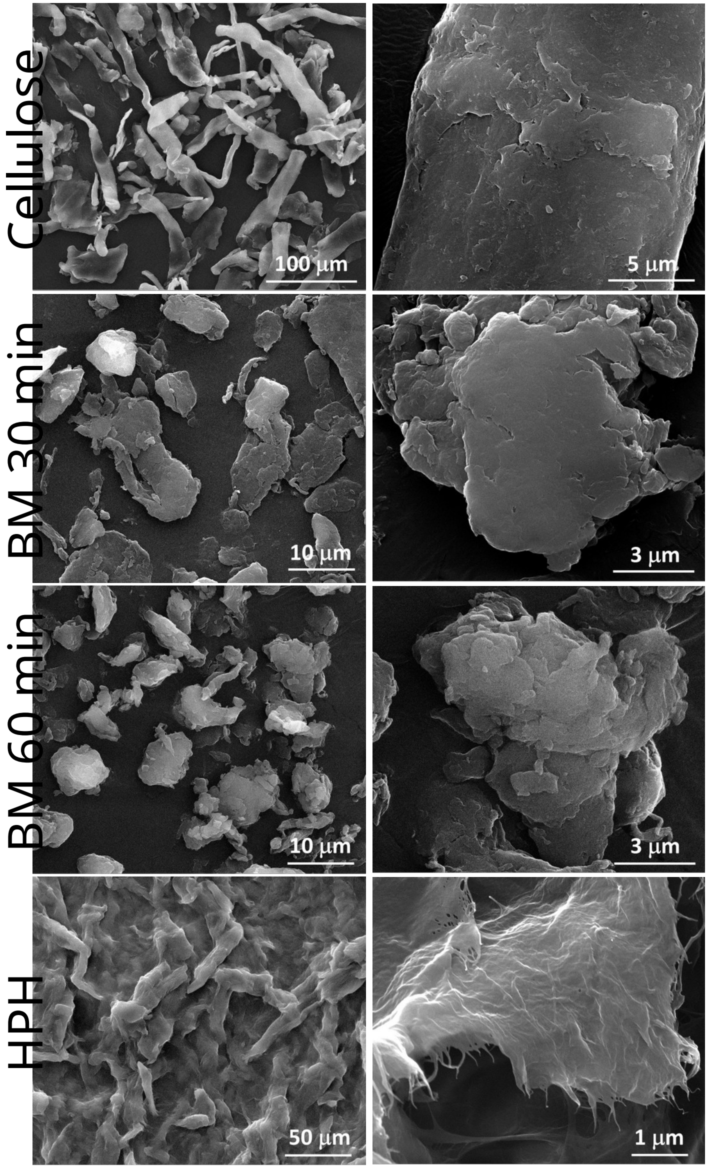
Nanocellulose

from **commercial cellulose** through **mechanical treatments**



Particle size analysis

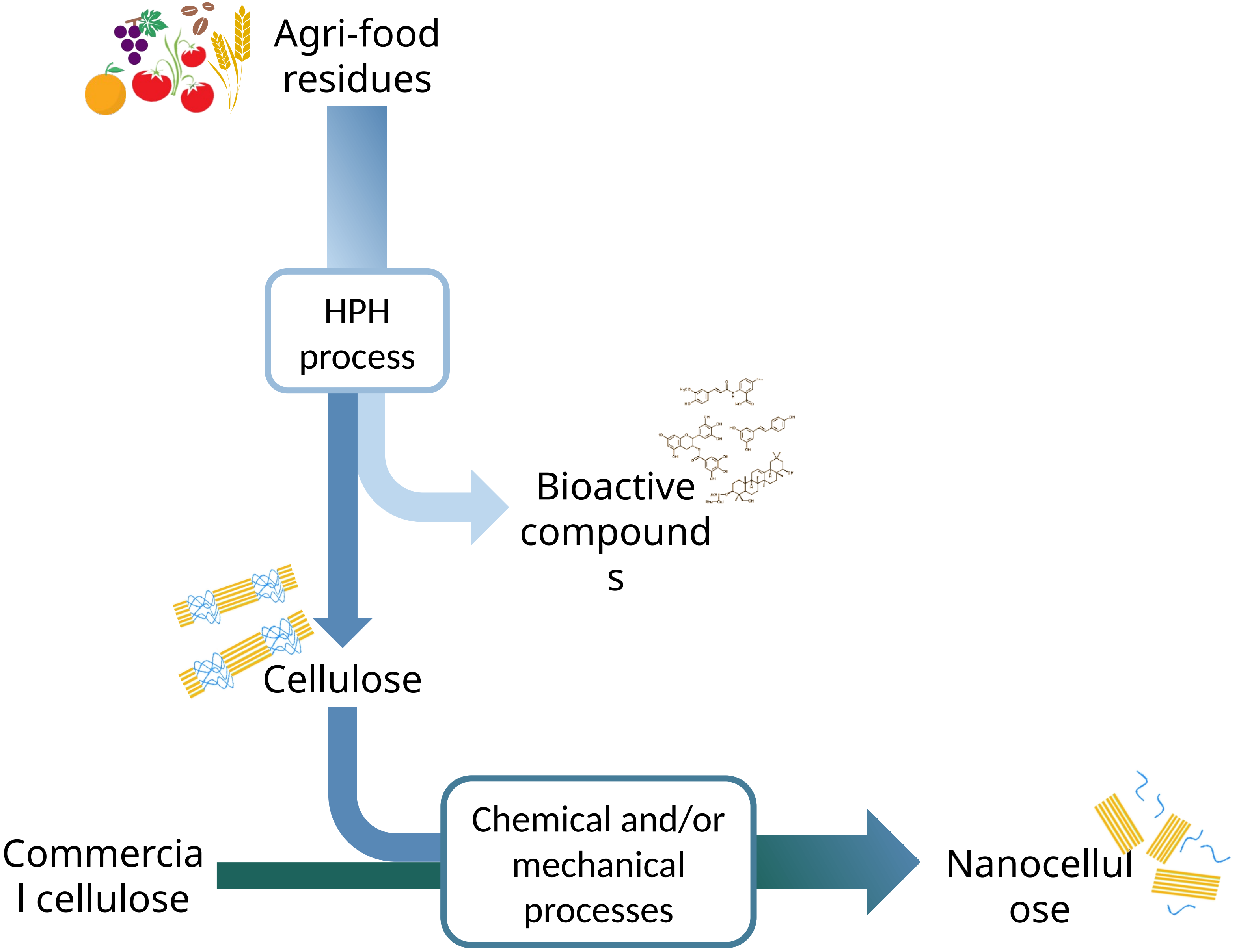




Pirozzi et al., 2021. *Foods*, 10, 1886. https://doi.org/10.3390/foods10081886

Recovery of valuable compounds

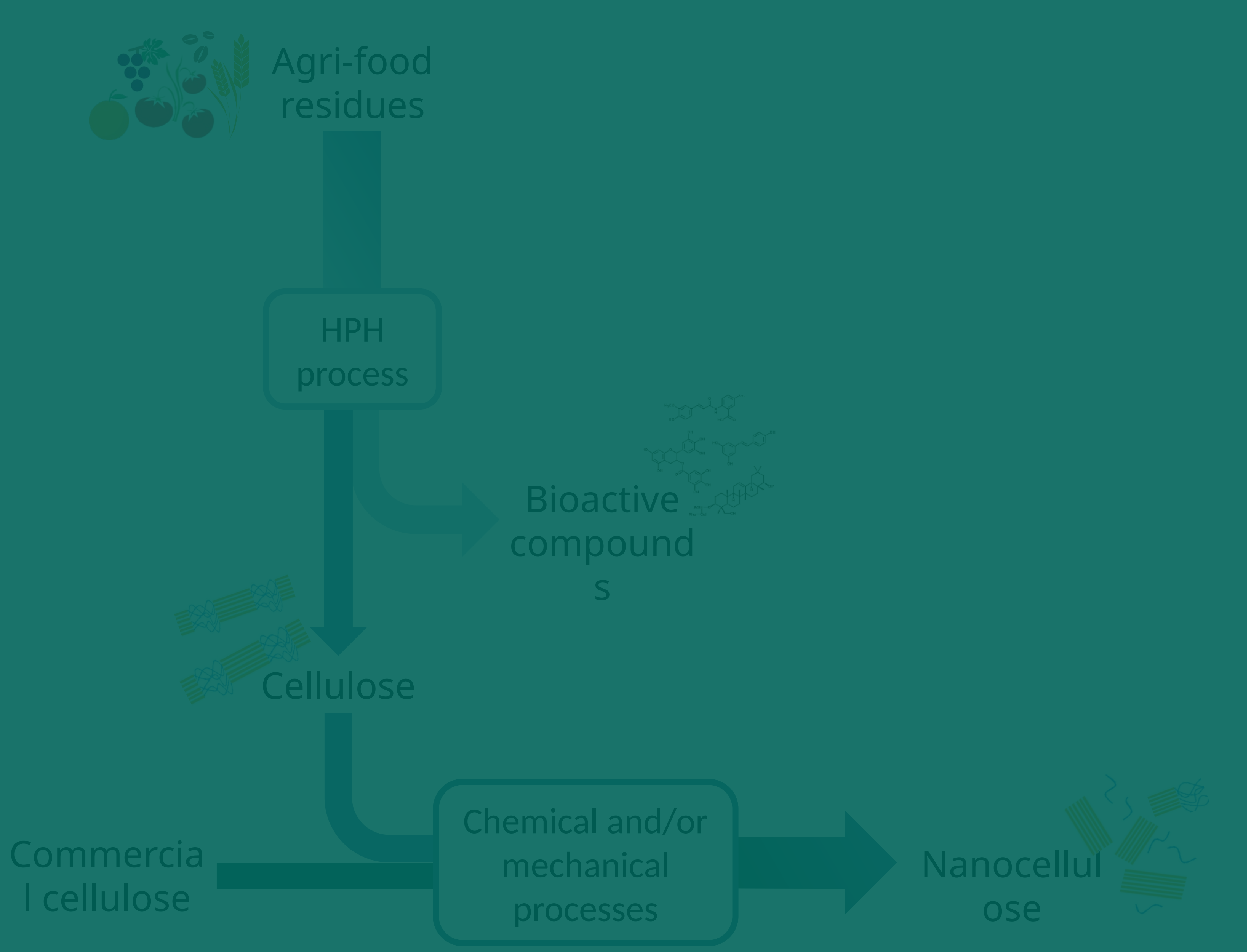
Rercovery of valuable compounds



Innovative and advanced applications

Recovery of valuable compounds

Rercovery of valuable compounds



Innovative and advanced applications

- Pickering emulsions
- Capillary suspensions
- Reinforcement for edible coating
- Aerogels for dye removal
- CO_2 adsorption

O/W emulsions

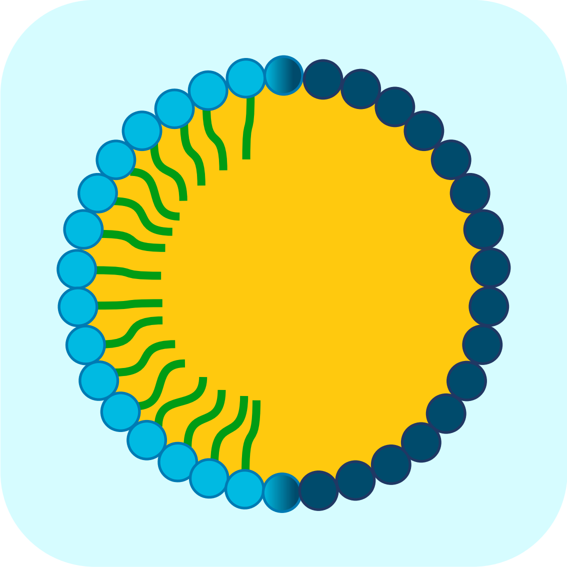
Conventional emulsions

thermodynamically **unstable** systems

short shelf life

sensitive to environmental stimuli

surfactants or emulsifiers molecules could increase **chronic diseases**



Pickering emulsions

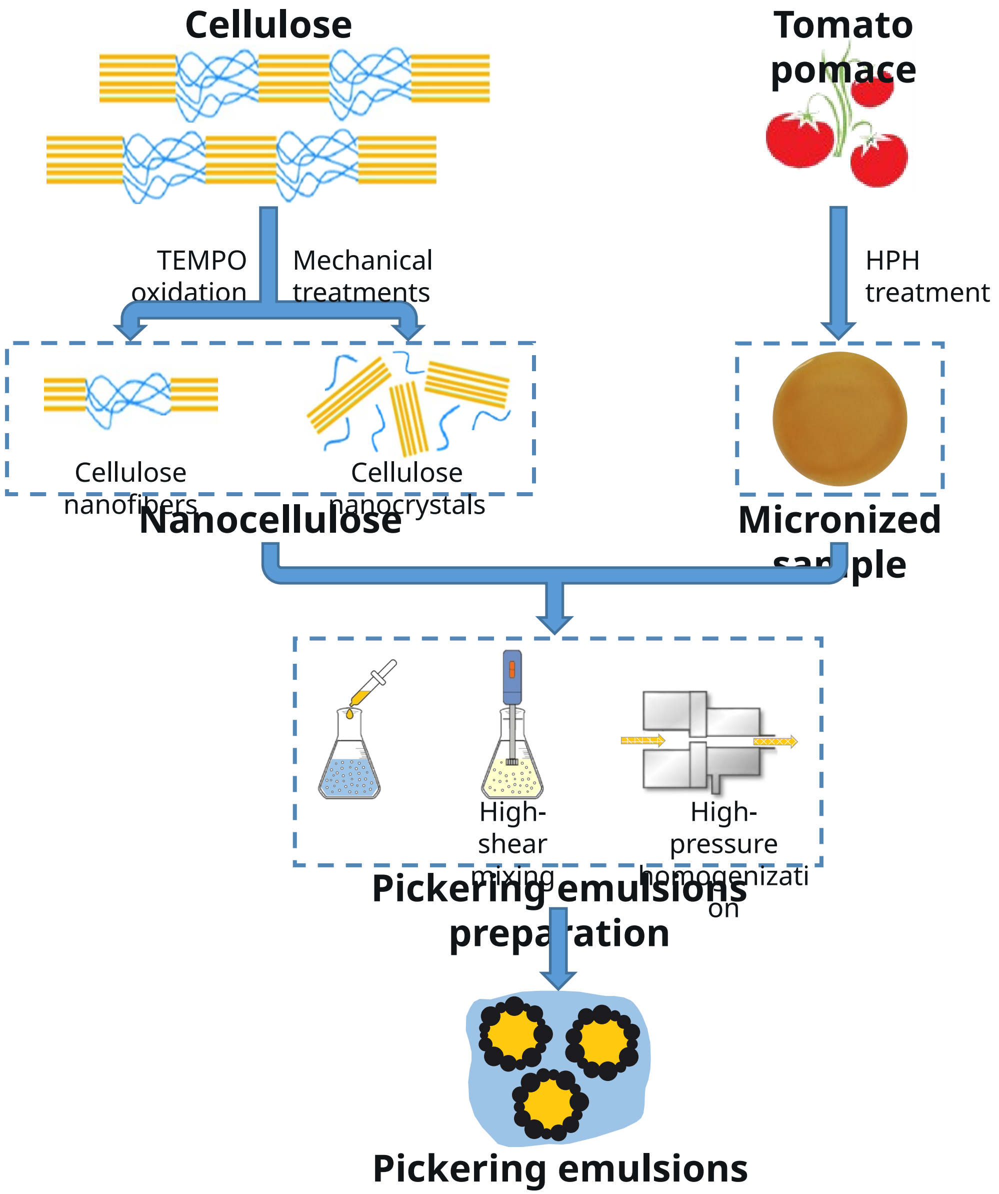
polysaccharide-based particles as stabilizers

long-term stability

good **biocompatibility** and tunable properties

less adverse effects, **low toxicity**, and favorable

Pickering emulsions

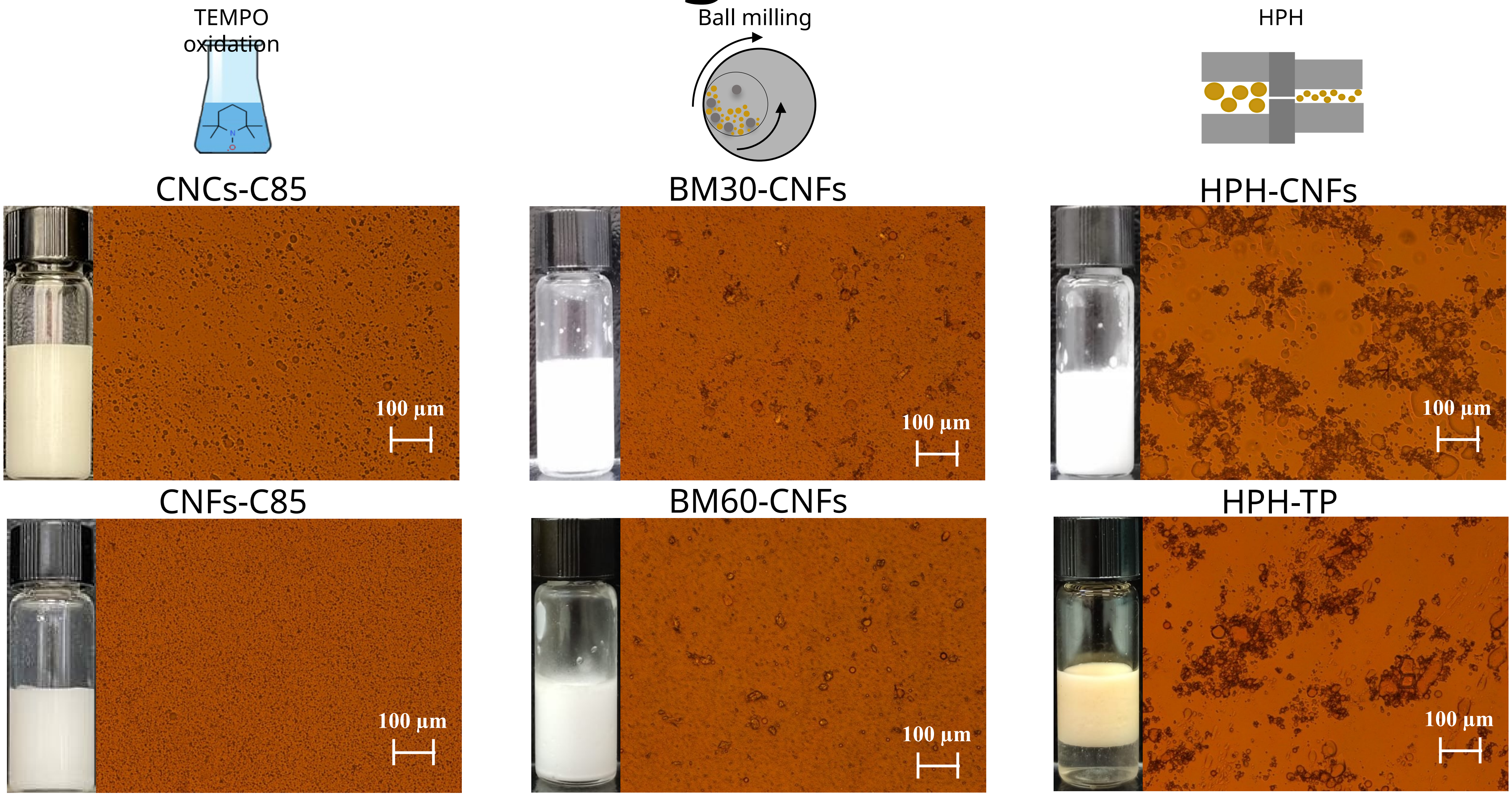


Nanostructured cellulose obtained through chemical or mechanical treatments and **micronized agri-food residues** have been used for the stabilization of edible **O/W Pickering emulsions** fabricated through **high-pressure homogenization** to improve emulsion

Objective

Problem

Pickering emulsions



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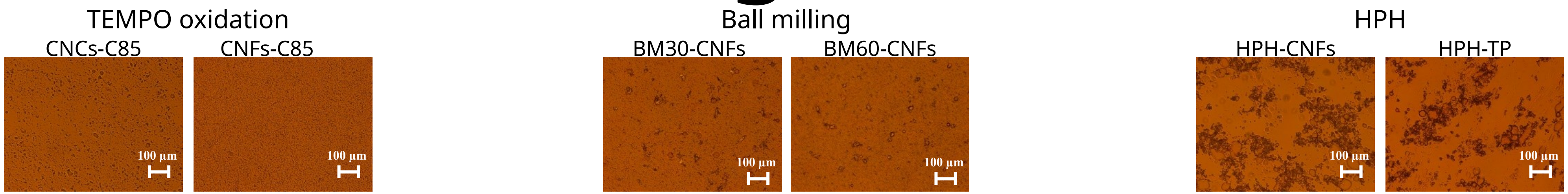
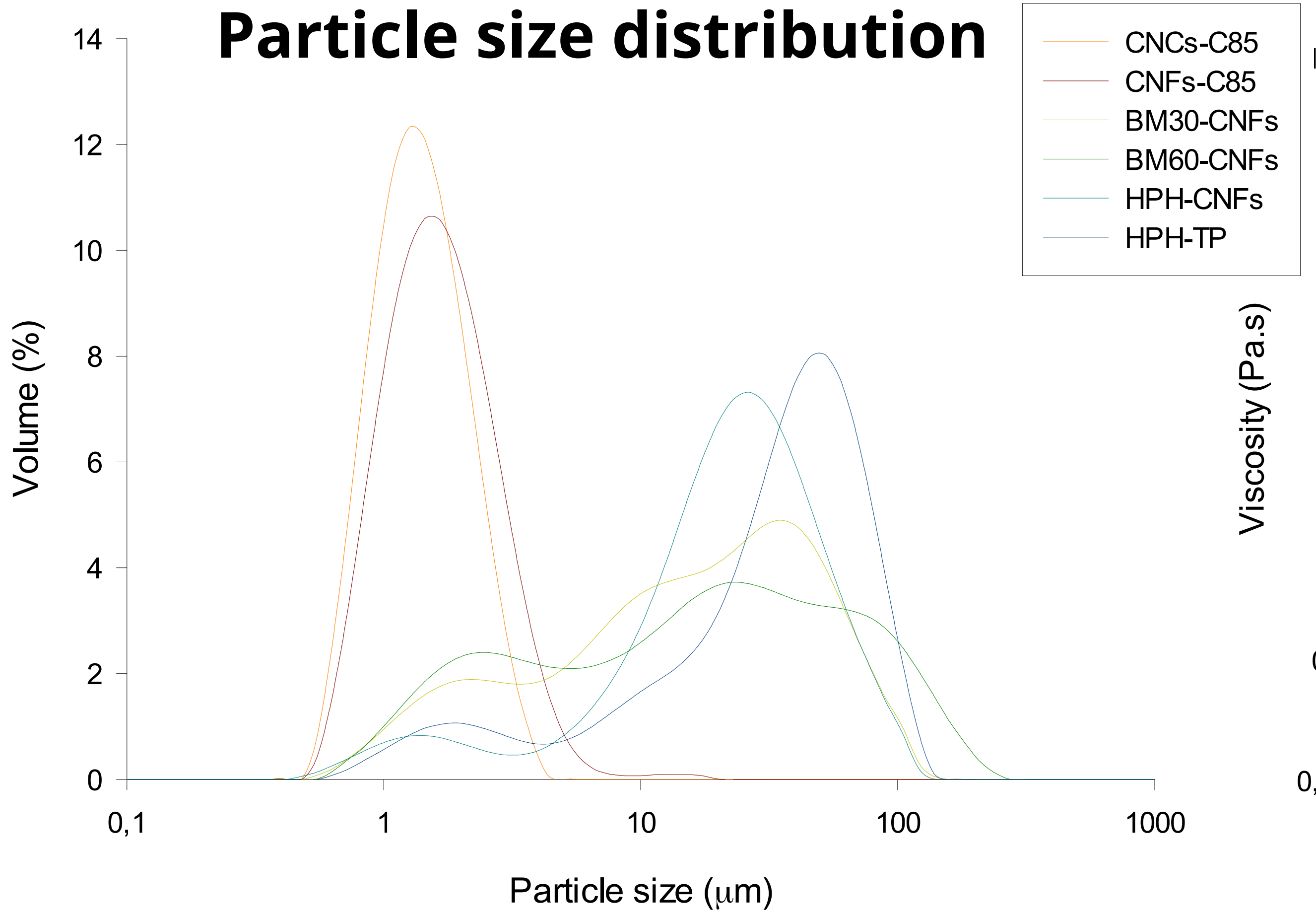
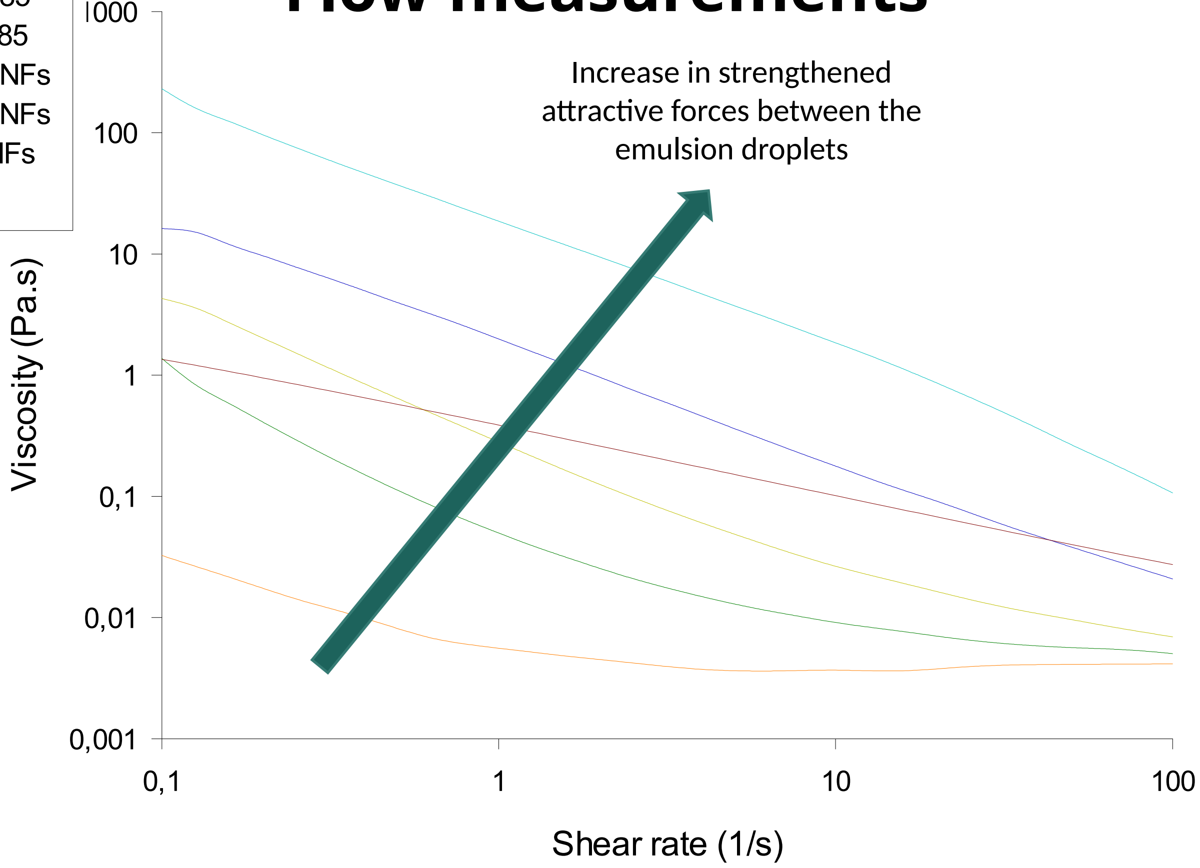
Pickering emulsions



Particle size distribution



Flow measurements



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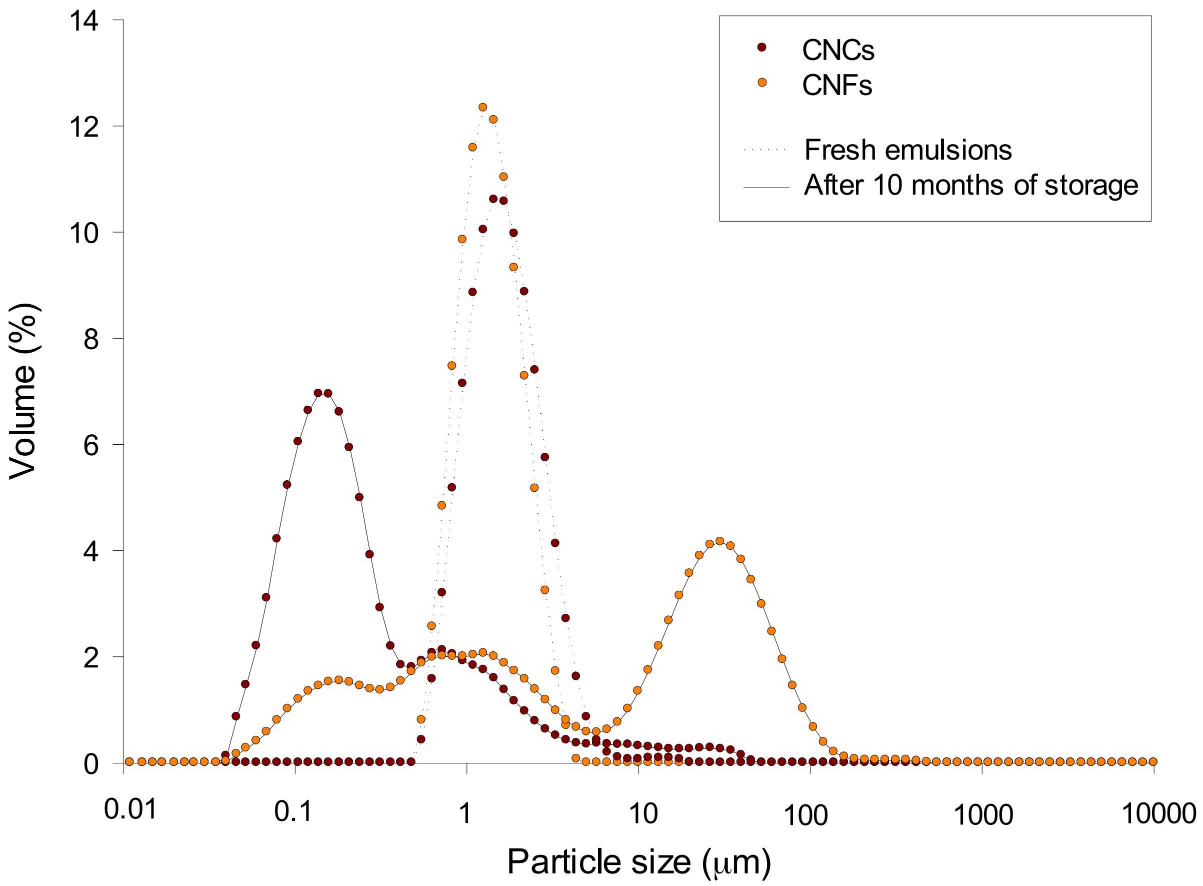
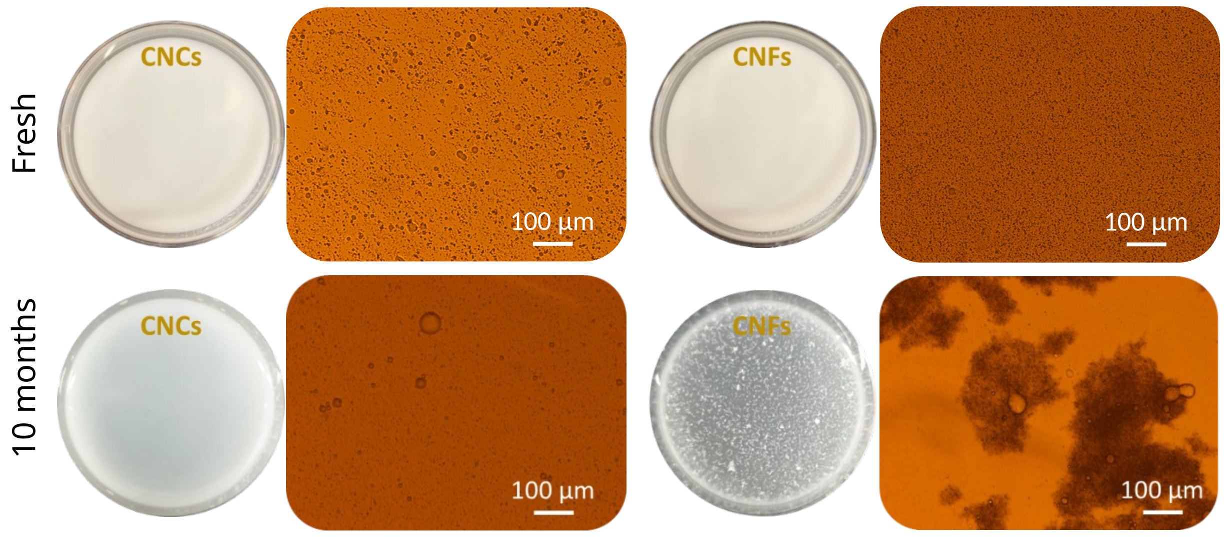
Stability of Pickering emulsions

with NCs isolated through **TEMPO-mediated oxidation**

Particle size distribution



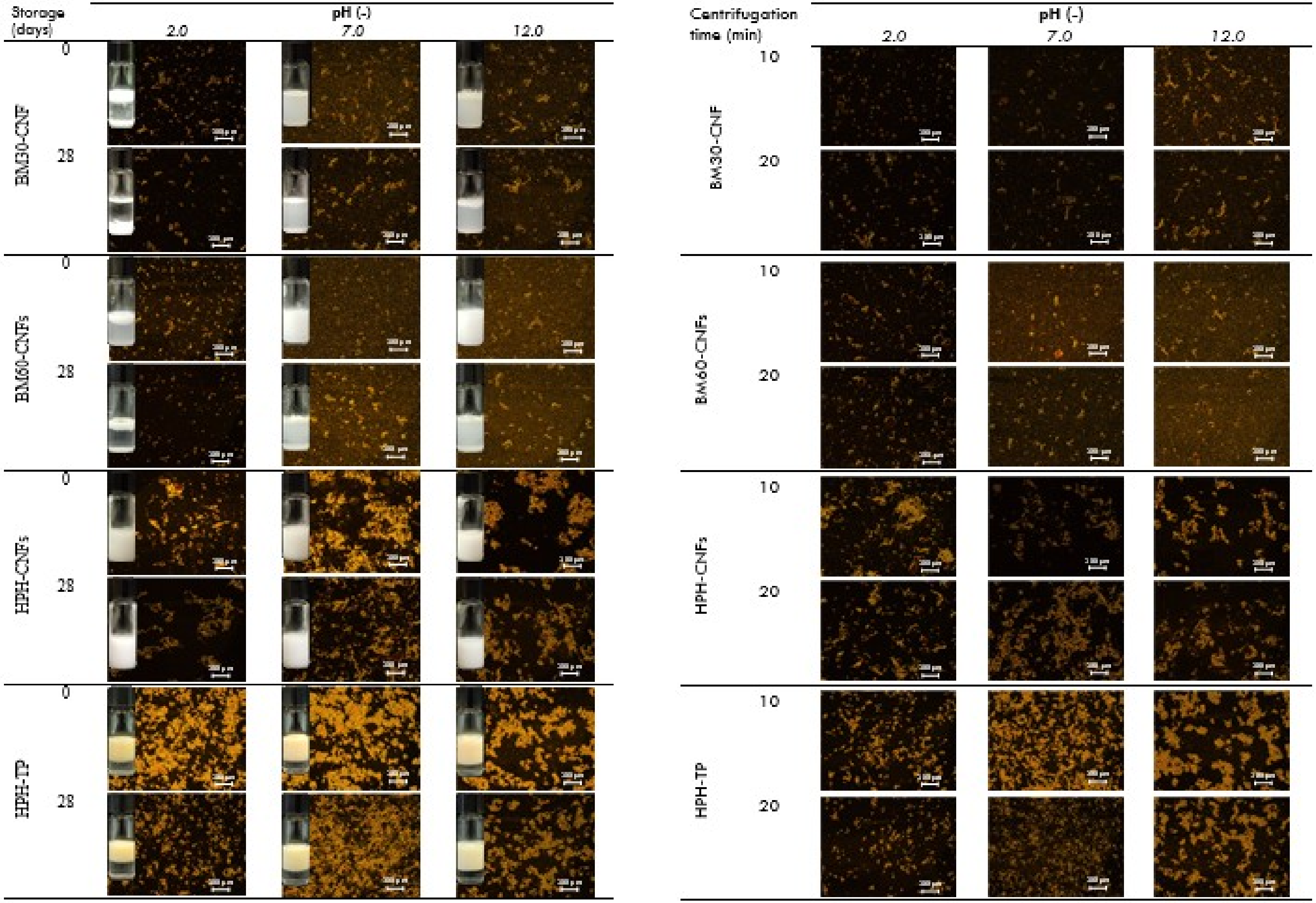


	Fresh emulsions		After 10 months of storage	
	CNCs-C85	CNFs-C85	CNCs-C85	CNFs-C85
EAI (m^2/g)	186.03 ± 4.40^d	150.02 ± 2.98^c	54.27 ± 4.02^b	45.23 ± 4.16^a
ESI (%)	0.14 ± 0.03^a	0.33 ± 0.09^b	0.17 ± 0.10^a	0.32 ± 0.02^b

Pirozzi et al., 2021. *Foods*, 10, 1886. https://doi.org/10.3390/foods10081886
Pirozzi et al., 2023. *LWT*, Under review

Stability of Pickering emulsions

with NCs isolated through **mechanical treatments**



Conclusions

Conclusions

1 Based on the treatment performed, various types of **nanocellulose** can be derived from the cellulose extracted from AFRs, each exhibiting **distinct morphological and physical characteristics.**

2 HPH-treated NCs demonstrated exceptional mobility, flexibility, and a high degree of defibrillation at the oil-water interface. As a result, they exhibited an **efficient emulsifying ability**, with the fibrils effectively enveloping the oil droplets to stabilize the emulsion.

3 By extracting cellulose from agri-food residues, the emulsion stabilizing layer acquires an **inherent loading of bioactive compounds**.

Conclusions

Future perspectives

Future perspectives
Future perspectives

Although promising results have been reported at the laboratory scale for cellulose recovery and nanocellulose deconstruction methods, the key challenge lies in achieving a breakthrough in the **scaled-up process** to optimize the economic feasibility of the proposed approach.

Future research should prioritize investigating the impact of nanocellulose-based Pickering emulsions or capillary suspensions on the **quality of food products**. This should encompass aspects such as texture in food systems, in vitro gastrointestinal digestion, microbial stability, and organoleptic and sensorial properties. Understanding these effects will be crucial in harnessing the full potential of nanocellulose for enhancing food products.

Further studies should be conducted to explore the effects of nanocellulose on **other innovative applications**, including packaging and paper products. Understanding how nanocellulose can enhance these areas will open up new possibilities and promote the adoption of sustainable and advanced materials in various industries.

While high costs might be justified for high-value products, it is essential to conduct economic analyses for commercial-scale processes. Understanding the **economic viability of large-scale production** is crucial for determining

Than
you

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