

# Sustainable packaging solutions based on the circular valorization of agro-industrial by-products

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# Background and motivation

**59 million tons** of food waste (131 kg/inhabitant)/year

**132 billion euros**

**10% of food** made available to EU consumers (retail, food services and households) is wasted

**53%** of total food waste is generated at **households**

**1/3** of all **food** produced for human consumption is **lost** or **wasted**

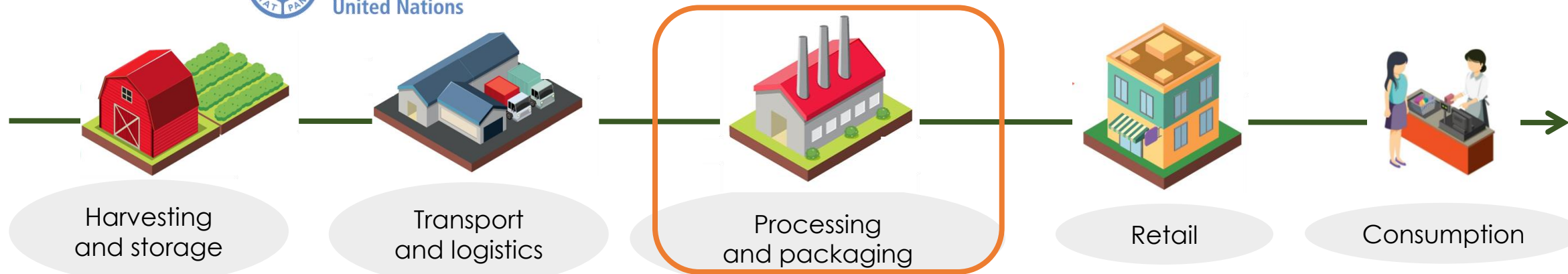
FAO estimates **14%** of all food produced **is lost from post-harvest stage up to the retail stage**

**931 million tons** of food waste in **2019**: **61% households**, 26% food service and 13% retail



Food and Agriculture  
Organization of the  
United Nations

## FOOD SUPPLY CHAIN



# Background and motivation



**PACKAGING** Protection of foodstuffs from the external environment while maintaining their quality

**DIRECTIVE (EU) 2019/904 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL**  
**of 5 June 2019**  
**on the reduction of the impact of certain plastic products on the environment**  
(Text with EEA relevance)

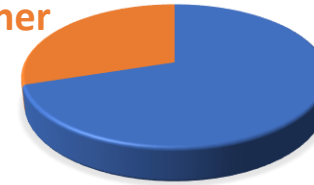


Constant fluctuation in oil prices  
High environmental impact



## MARINE LITTER IN EU

Other



Single-use plastics and fishing gear



**New bio-based packaging solutions**

**Natural biopolymers** are increasingly being used as **substitutes for petroleum derivatives worldwide**. They provide an effective alternative for the production of environmentally safe packaging materials that meet the market requirements

# Biopolymers in Packaging solutions



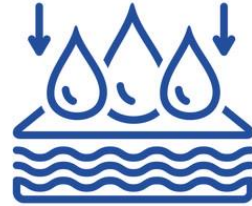
Films



Bags



Sachets



Pads



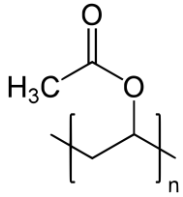
Coatings



Trays



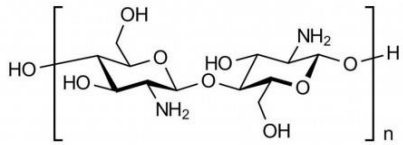
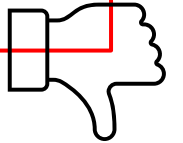
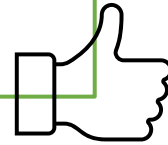
# Food Packaging Films



PVA

Fully biodegradable  
Biocompatible  
Non-toxic  
Water-soluble (PVA)  
Chemical resistance (PVA)  
Film forming ability  
Antimicrobial (CH)  
Bio-based (CH)

Limited thermal, barrier and mechanical properties



Chitosan



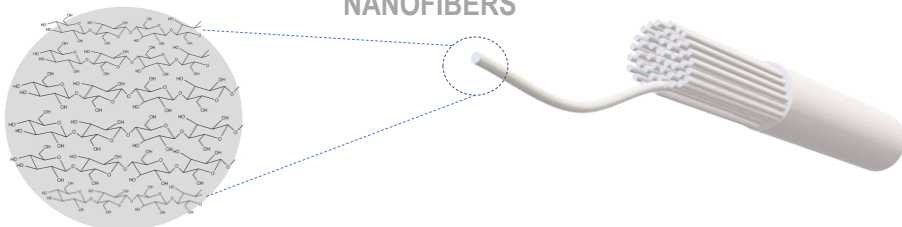
## Blending with nanomaterials

High specific surface area, providing larger reaction surface with the matrix and a better reinforcing effect



Uniform dispersion  
Improved chemical compatibility,  
thermal and mechanical properties

CELLULOSE  
NANOFIBERS







# Food Packaging Films


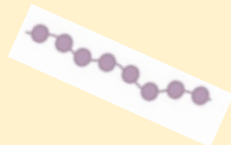
## 1 Solvent casting



## 2 Properties evaluation

- Surface and cross-section morphology (SEM)
- Chemical interactions (FTIR)
- Crystallinity (XRD)
- Transparency and UV-light-blocking capacity (Spectrometry)
- Antioxidant activity: ABTS, DPPH
- Barrier properties: Water vapor permeability
- Mechanical properties
- Thermal properties (TGA)
- Antimicrobial capacity

## BIOACTIVE FILMS

- + Natural extracts 
- + Pectins 

- Rich in phenolic compounds
- Enhanced antioxidant and antimicrobial properties
- Substitution of synthetic additives



# Food Packaging Films

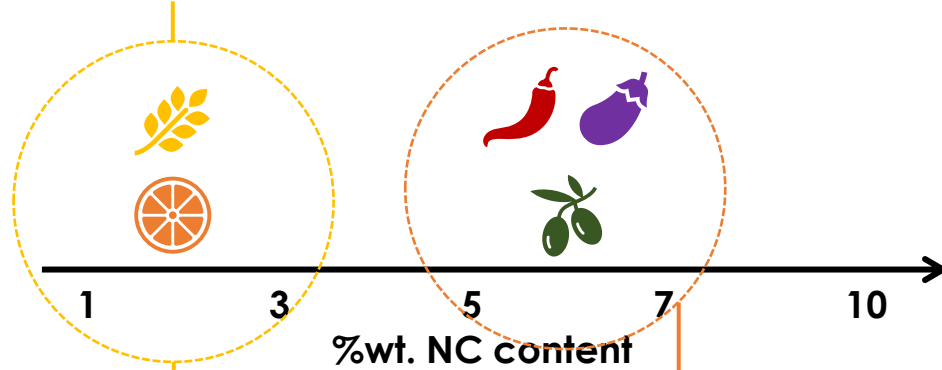
<https://doi.org/10.1016/j.ijbiomac.2019.08.262>  
<https://doi.org/10.3390/foods10071584>  
<https://doi.org/10.3390/foods10123043>  
<https://doi.org/10.1016/j.indcrop.2022.115413>  
<https://doi.org/10.1016/j.carbpol.2021.118477>



## Main findings

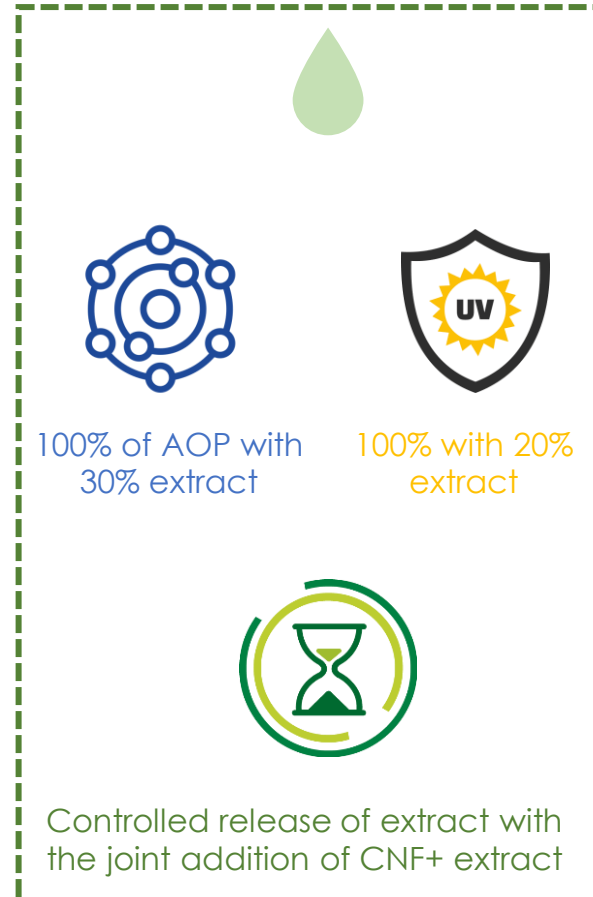
### IMPROVEMENTS ACHIEVED WITH NANOCELLULOSE

High nanofibrillation yield (>50%)  
High DP (500-1300)  
Aspect ratio 200-400

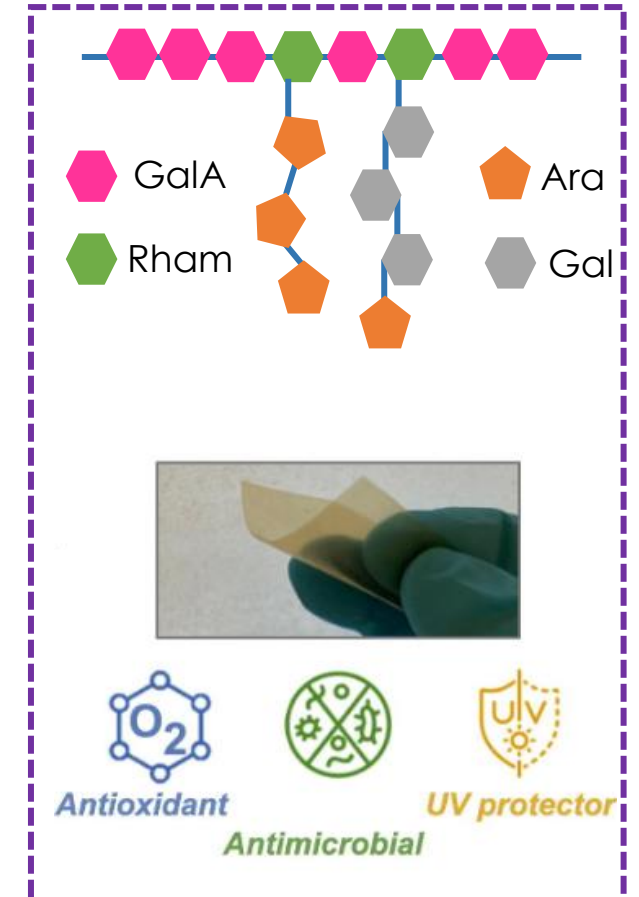


UV-light blocking capacity >50%  
Increased mechanical performance: chain stiffness and nanocellulose rigidity, homogeneous distribution and high compatibility  
Enhanced barrier properties (water vapor and oxygen)  
10% antioxidant capacity

### + NATURAL EXTRACTS



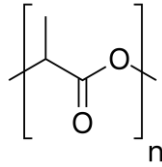
### + PECTINS





# Bags

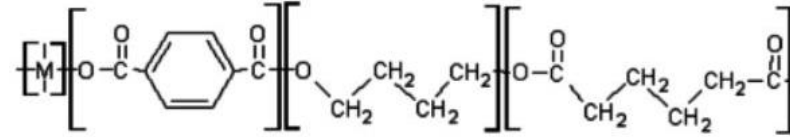
<https://doi.org/10.1016/j.jclepro.2022.133597>



PLA



LCNF



Ecoflex®

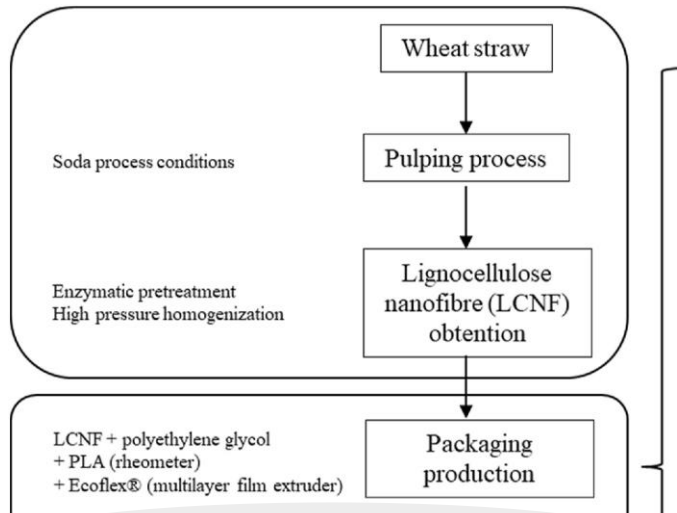
Biodegradable  
Biocompostable  
Rigidity  
Transparency

Low WVP  
Moderate gas barrier

Improved barrier properties by increasing crystallinity and acting as impermeable region

Biodegradable to basic monomers  
1 year of life cycle  
High film-forming capacity

Low thermal stability  
Poor mechanical strength



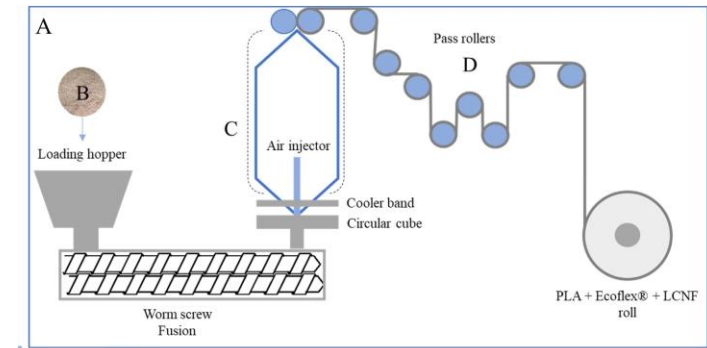
**Pilot scale production**

Packaging characterisation

- Spectroscopy analysis
- Mechanical properties
- Thermogravimetric analysis
- Antioxidant activity
- Optical properties
- Water vapor permeability
- Gas permeability

Packaging application

- Headspace gas analysis
- Sensory analysis
- Microbiological analysis





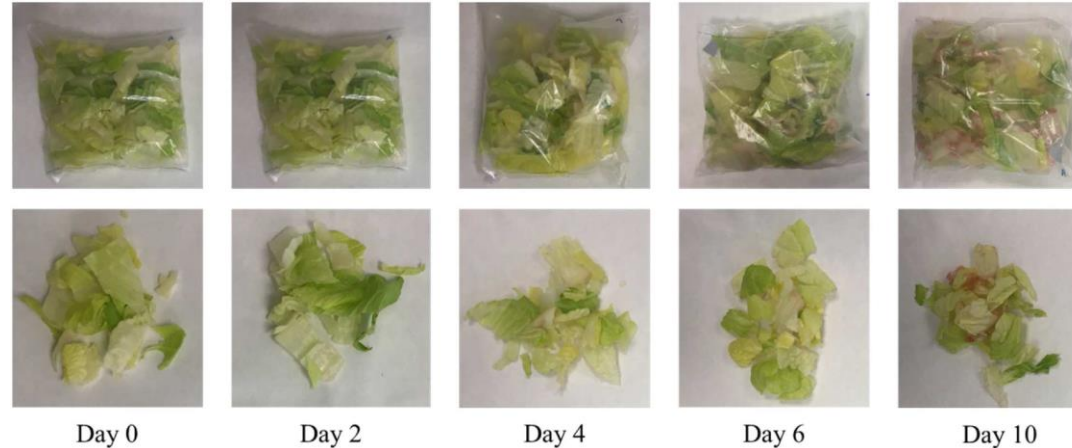


# Bags

<https://doi.org/10.1016/j.jclepro.2022.133597>

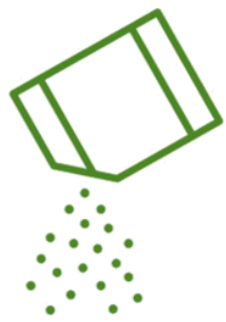


Fresh-cut lettuce



## Main findings

- Improved **optical properties** (31% improvement), **WVP** (386% improvement) and **antioxidant capacity** in formulations 70:30 PLA: Ecoflex® with 0.5-1% LCNF.
- Analogous mechanical properties to commercial PET or PS.
- Comparable **sensory microbiological quality** over storage at 4°C to commercial formulations.



# Sachets

<https://doi.org/10.1002/app.53102>

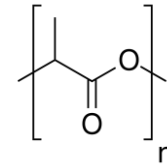
Acorn shell



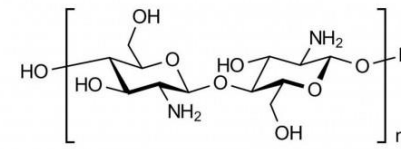
Extracts



Biopolymer-based sachets



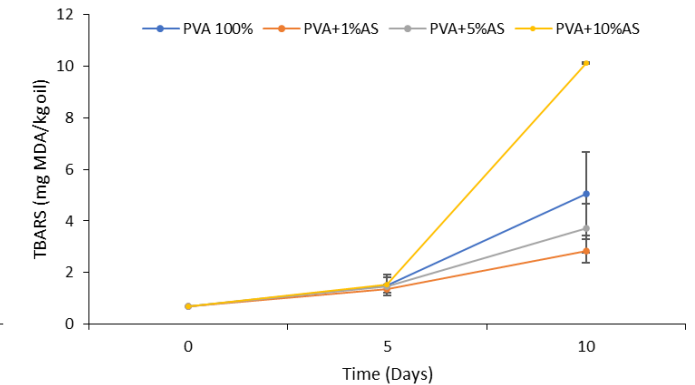
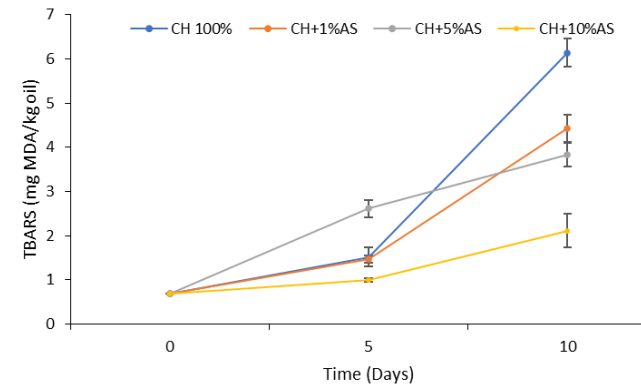
PVA



Chitosan



Natural extracts



## Main findings

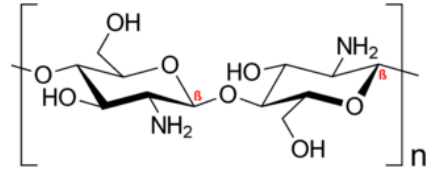
- Increased **water resistance** and **UV-light blocking capacity (97%)**
- Maintained mechanical performance
- **High radical scavenging activity**
- Effective **delay of soybean oil oxidation** during 10 days of storage



# Pads

<https://doi.org/10.3390/polym15040866>

## Meat packaging



## Chitosan



Nontoxic, biodegradable  
Antimicrobial, biocompatible



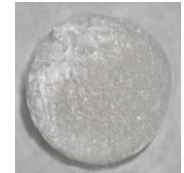
## Chitosan aerogels

Low porosity  
Irregular structure  
Easy deformation

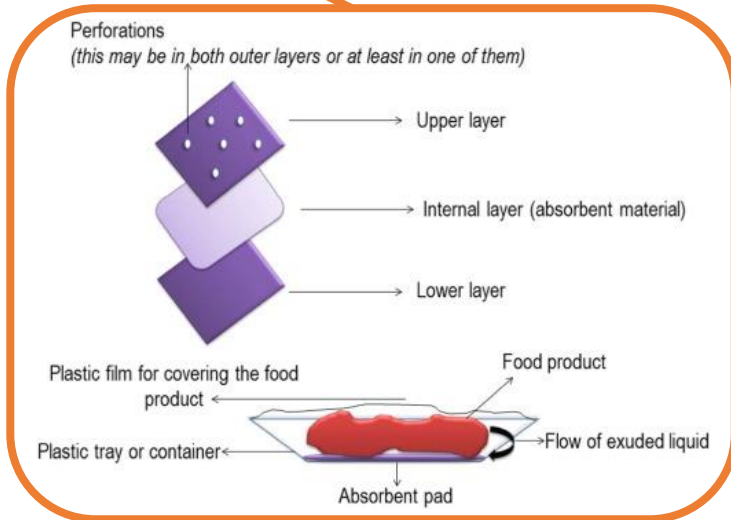


## CNF-aerogels

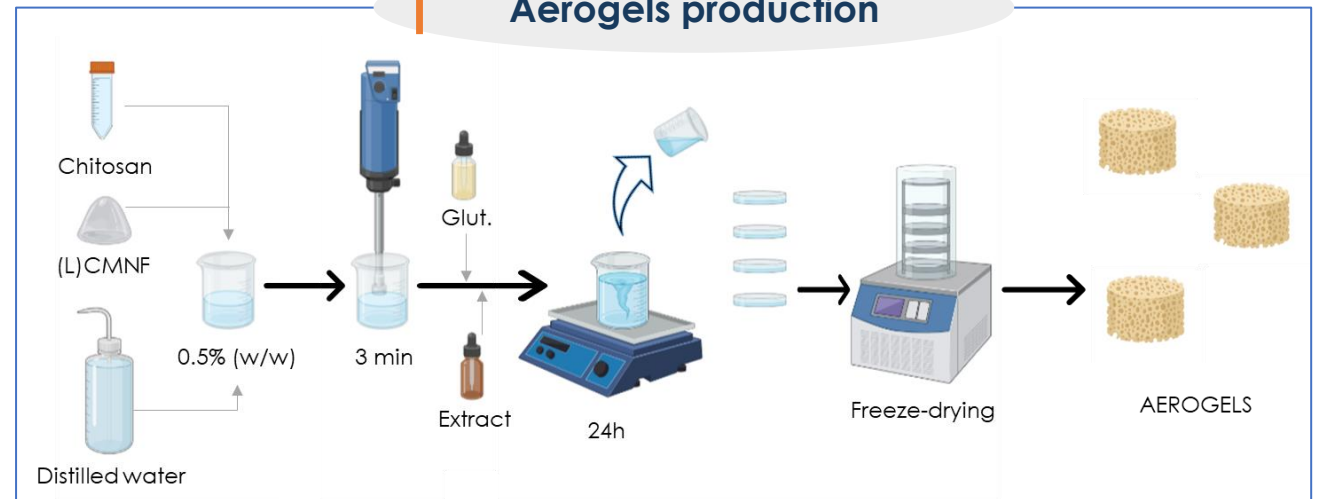
High strength  
Adaptable pores  
Modifiable surface



## Absorbent pads



## Aerogels production



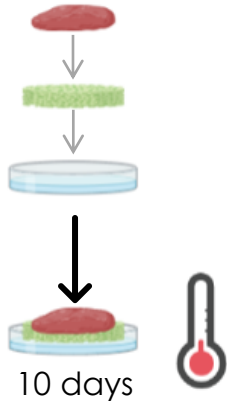
**Lignocellulosic biomass** is an ideal source of **biopolymers** and natural **antioxidant** compounds



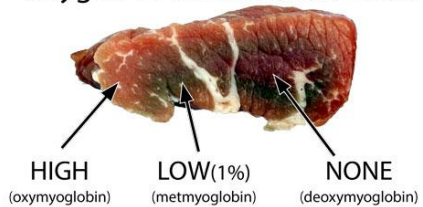
# Pads

<https://doi.org/10.3390/polym15040866>  
<https://doi.org/10.21203/rs.3.rs-2740851/v1>

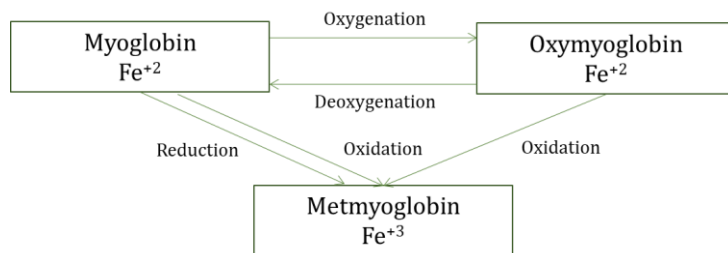
## 3 Meat preservation tests



### Oxygen Level and Meat Color

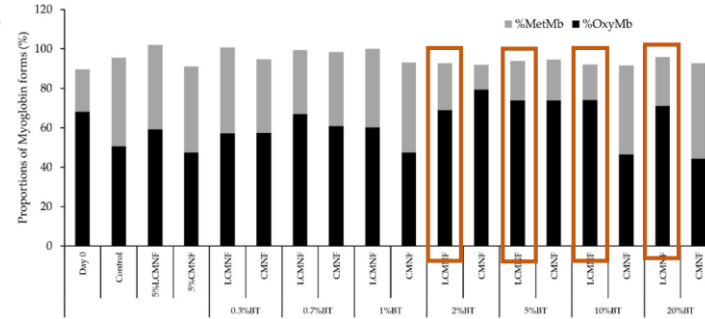


<https://genuineideas.com/ArticlesIndex/srmeatmyoglobin.html>



## 2 Characterization

Density and porosity  
 Mechanical performance  
 Water and oil absorption capacities  
 Antioxidant activity (DPPH)

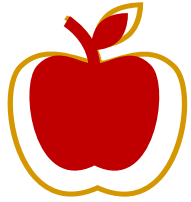


## Main findings

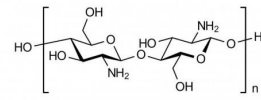
- Optimal reinforcing effect of (L)CNF at 5% (80% improvement)
- **Increased water absorption capacity** (42%).
- The presence of residual lignin led to a **faster increase in antioxidant power** in the first hours (80% AOP in 30 min).
- **Great potential as active food pads:** the developed formulations maintained the freshness of the burger meat after 10 days of storage, as a result of a synergistic effect between the residual lignin and the extract.



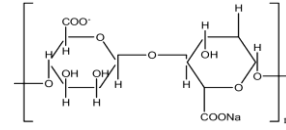
# Coatings



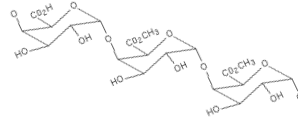
Thin, edible and continuous matrix around the food surface as a protecting agent



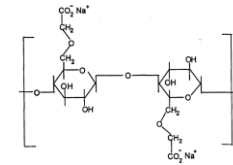
Chitosan



Alginate



Pectins



CMC



(L)CNF

1

## Coating application



Spray



Immersion

2

## Characterization

- Weight loss
- Firmness
- Color
- pH
- ° Brix
- Acidity
- Microbiological analysis: Aerobic Mesophilic Bacteria (AMB)



Cucumber



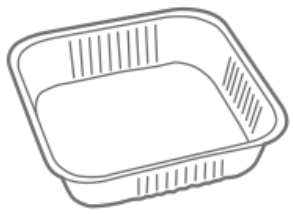
Raspberries



## Main findings

Coatings with concentrations of up to 10% LCNF on raspberry fruit resulted in **improved firmness** values as well as **lower AMB** counts after 7 days of storage.

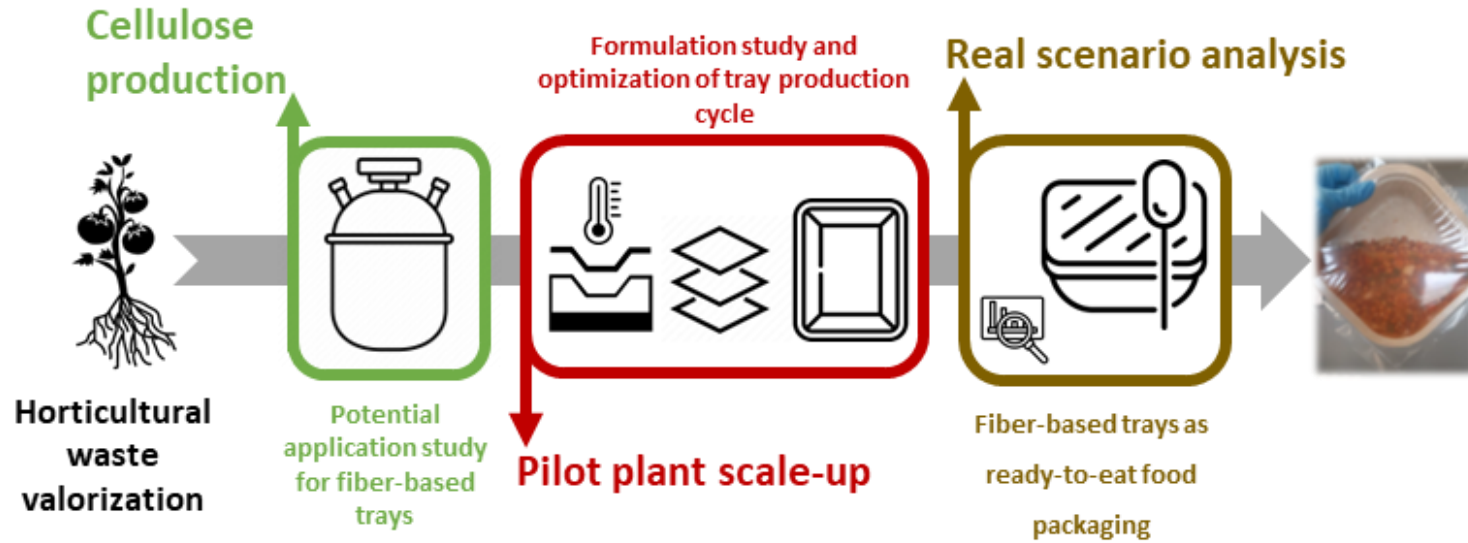




# Trays

## Cellulose fiber-based packaging

- Many advantages: recyclable in currently developed infrastructure
- Virgin fiber has undergone a considerable increase in price



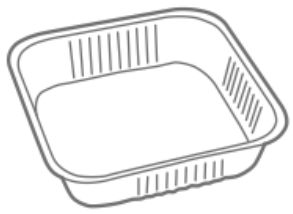
Cycle: hot filling (lentils at 80-90 °), sealing, collapsing, oven/microwave regeneration and peelability.



### Characterization

- Visual defects establishing a 3-range category: primary defects, secondary defects and no defects
  - Weight suitability
  - Compressive strength
- Pesticide analysis in fiber-based trays
  - Lamination suitability





# Trays

## Cellulose fiber-based packaging



### Main findings



Control (100%PN)



80:20 PN:M-HR



60:40 PN:M-HR



40:60 PN:M-HR



70:30 PN:SC-HR



60:40 PN:SC-HR



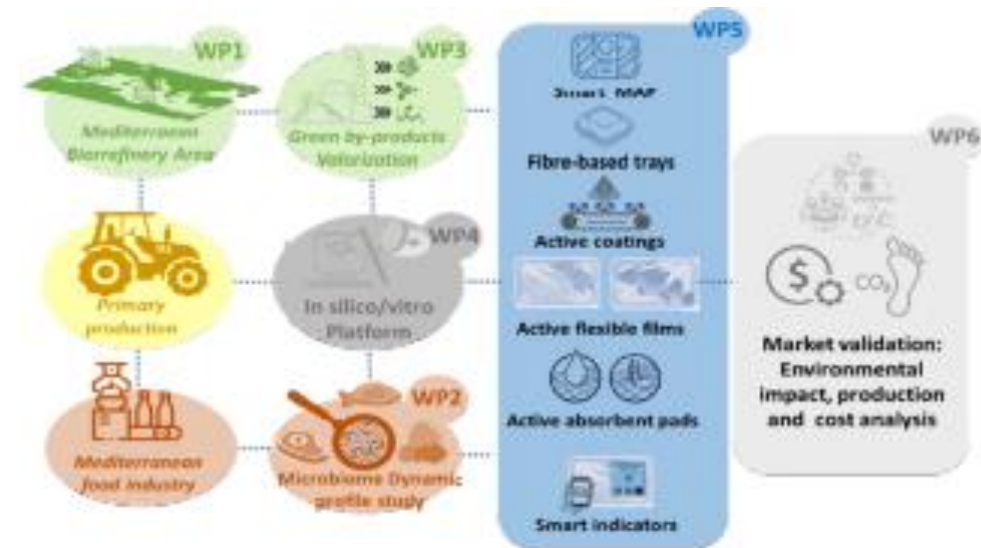
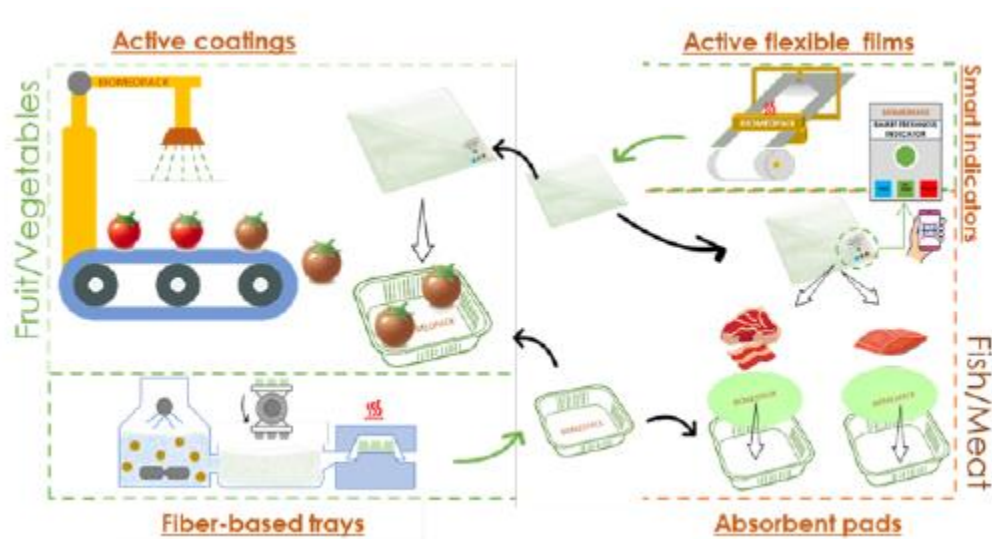
50:50 PN:SC-HR

- The optimum formulation will depend on the characteristics of the fibers used. The fibers obtained by mechanical pulping (**M-HR**) are short with a high refining degree (65 °SR) while the fibers obtained by semi-chemical pulping (**SC-HR**) are long with a lower refining degree (13 °SR).
- Trays of adequate weight and free of defects with the formulation: **20% M-HR** and **40% SC-HR**.
- The mechanical properties are **analogous to commercial pine trays**.
- More than 10 pesticides are detected in the trays due to the origin of the fiber but in no case the limits established in the regulation are reached.
- **The trays successfully passed the lamination and cooking tests carried out in the industry to simulate consumer use.**

## New PRIMA project!

Shelf-life enhancing packaging systems for mediterranean food through innovative and circular solutions based on agri-food multi-product cascade biorefinery

### BIOMEDPACK



# Thanks for your attention

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