UNIVERSITÀ DEGLI STUDI DI MILANO
University of Milan

Packaging sustainability and innovation: Bio-Based Materials for functional packaging

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DEFENS
DEPARTMENT OF FOOD, ENVIRONMENTAL AND NUTRITIONAL SCIENCES

3rd International ISEKI Food Conference

International Workshop "State of Research in Europe in the Field of Food Science and Technology"

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UNIVERSITÀ DEGLI STUDI
DI MILANO

DEPARTMENT OF
FOOD, ENVIRONMENTAL AND
NUTRITIONAL SCIENCES

University of Milan

*The Department of Food, Environmental and Nutritional Sciences - **DeFENS***

(formerly DiSTAM, Dept. of Food Science & Microbiology)

DEPARTMENT OF FOOD, ENVIRONMENTAL AND NUTRITIONAL SCIENCES

http://users.unimi.it/packlab/default.htm

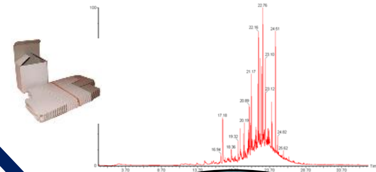
An Operative Unit exclusively devoted to food packaging (the Packlab) has been established in our University since 1985.

Packlab is the only unit in the University of Milan engaged in research, teaching and testing in the Food Packaging field

FOOD PACKAGING RESEARCH at PACKLAB

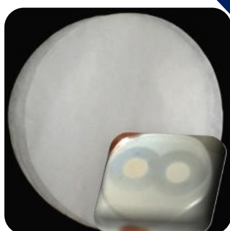
NIAS (non intentionally added substances)

Transference of contaminants from cellulosic packaging and innovative approach for food contact material safety.



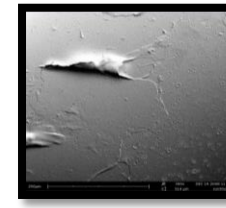
Antimicrobial proteins (LZ and LF) controlled release from paper sheets

The figure shows the activity of paper sheets against food spoilage microorganisms.



Sealable bio-coatings

SEM image shows a polypropylene coated films after rupture of sealed strips



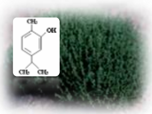
FOOD CONTACT COMPLIANCE

ACTIVE PACKAGING SYSTEMS

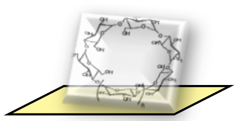
INNOVATIVE BIOBASED MATERIALS

SHELF LIFE TESTING & MODELLING

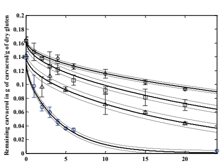
Incorporation and diffusion of natural volatile antimicrobials from bio-coating



Essential oil of carvacrol



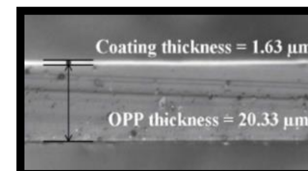
Cyclodextrin



Studies of release of carvacrol from biocoating at different RH

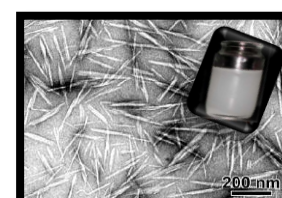
Barrier bio-coatings

A very thin bio-coating can improve the oxygen barrier property of a plastic film.



Nano-Cellulose applications

Cellulose properties including hydrophilicity, biocompatibility, stereoregularity, biodegradability, chemical stability, multi-chirality, reactive hydroxyl groups and the ability to form superstructures.



Beverages

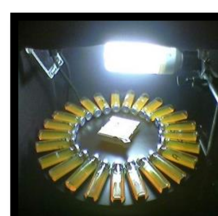
Effects of light exposure and protection efficacy of packaging

Meat & Processed Meat

Optimization of active packaging solutions

Low -moisture and dried foods

Modelling of moisture diffusion across the packaging material



Packaging sustainability and innovation: Bio-Based Materials for functional packaging

The TOC of this talk:

- Packaging Sustainability
- Bio-based materials (BBMs) and Bio-plastics in food packaging
- The coating technology for flexible packaging materials
- The Research on BBMs at Packlab:

1. *Hybrid coatings for high oxygen barrier*
2. *Multifunctional Nanocellulose coating on plastic films*
3. *Functional barrier against migration by means of Bio-based coatings*
4. *Development of a Bio-based active packaging device*

- Conclusions

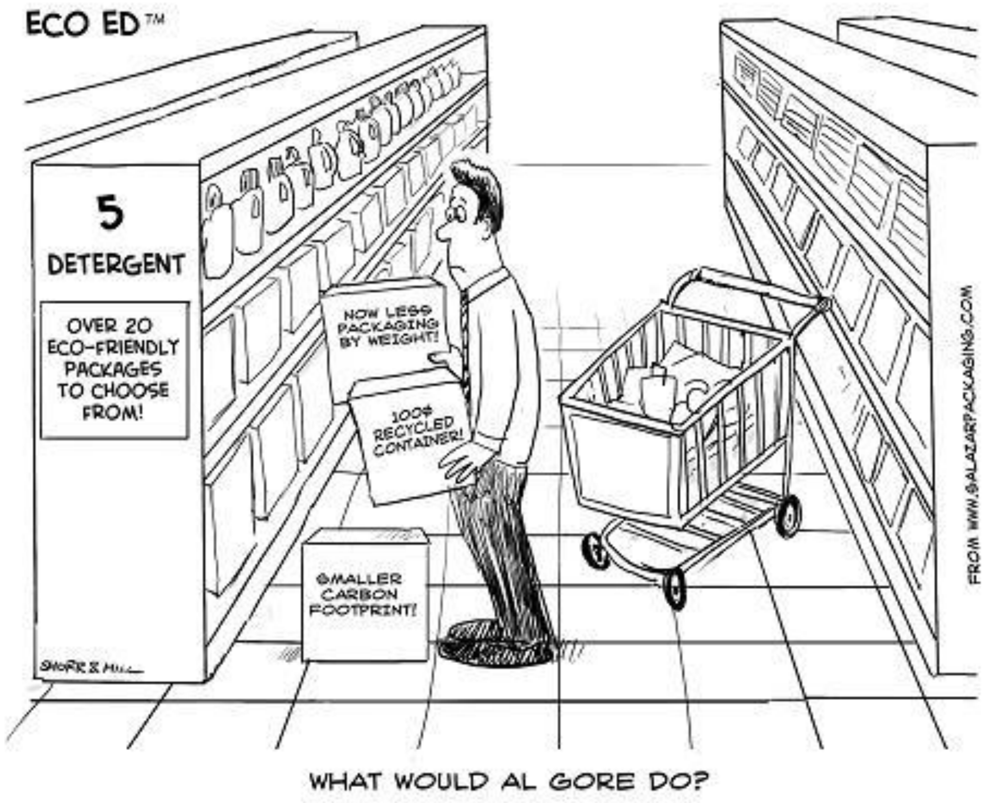
Sustainable Packaging

"European consumers are more and more prepared to buy goods and services which have reduced environmental impact"

European Commission

Packaging Sustainability is a real special topic.
Very often is considered as a marketing tool, i.e. a way of promoting and differentiating a new package or a new packaging material. Packaging Sustainability, however, is a much more serious and complex theme, close to Science and Technology.

Sustainable Packaging



Greenwashing is a form of spin in which green PR or green marketing is deceptively used to promote the perception that an organization's products, aims or policies are environmentally friendly. *Wikipedia*

Sustainable Packaging

What "sustainable packaging" really is and how sustainability can be evaluated is still widely discussed at various levels, and a global agreement has not yet ached.

COMPASS®
COMPARATIVE PACKAGING ASSESSMENT

What is COMPASS?

COMPASS (Comparative Packaging Assessment) is online design software that allows packaging designers and engineers to assess the human and environmental impacts of their package designs using a life cycle approach. COMPASS helps packaging designers make more informed material selections and design decisions by providing quick visual guidance on a common set of environmental indicators.

COMPASS provides consistently modeled data sets for USA, Canada and Europe tailored for materials and processes used for packaging to allow reliable apples to apples comparisons of multiple scenarios. In addition, regionalized solid waste modeling provides a waste profile of each scenario to help understand the end of life (EoL) implications of packaging designs.

SUSTAINABLE PACKAGING
COALITION

SPC is GREENBLUE Project

http://www.sustainablepackaging.org/

GreenBlue *is a nonprofit institute that stimulates the creative redesign of industry by focusing the expertise of professional communities to create practical solutions, resources, and opportunities for implementing sustainability*

Sustainable Packaging

What "sustainable packaging" really is and how sustainability can be evaluated is still widely discussed at various levels, and a global agreement has not yet been reached.

PIQET

Packaging Impact Quick Evaluation Tool

SPA is the global distributor of PIQET, a web based business tool used for rapid packaging environmental impact assessments. PIQET is used to optimise packaging system design from a sustainability perspective in all stages of the product development process.

PIQET is also used for training to build an understanding of the life cycle impacts of packaging and develop business capability to make more sustainable decisions.

PIQET is accessed through a direct license from SPA. Licenses include training, technical support and access to regular updates. Click here to download brochure.

spa

Sustainable Packaging Alliance

An Academic initiative in Australia

http://www.sustainablepack.org/default.aspx

*The **Sustainable Packaging Alliance** is a joint initiative of **Victoria University** of Technology, through its Packaging and Polymer Research Unit, **RMIT University**, through its Centre for Design, and **Birubi Innovation** Pty Ltd*

Sustainable Packaging

A general and widely accepted assumption refers to four main attributes of sustainable packaging: they must be Effective, Efficient, Clean and Cyclic

Effective: the packaging system adds real value to society by effectively containing and protecting products **IT'S USEFUL !**

Efficient: the packaging system is designed to use materials and energy as efficiently as possible throughout the product life cycle. **DON'T WASTE !**

Cyclic: Packaging materials used in the system are cycled continuously, minimizing material degradation
DON'T LITTER !

Clean: packaging components used in the system do not pose any risks to humans or ecosystems. **DON'T CONTAMINATE !**

Sustainable Packaging
facts and figures

Nothing new, actually !! The previous mentioned attributes are almost standard requirements for modern packaging.

Our environment for sure, is not at risk for Packaging

Crude oil consumption

GASOLINE & JET FUEL : Of all the crude oil refined for use, almost **57%** becomes FUELS

DIESEL FUEL AND HOME HEATING: Another **20%** becomes distillate, two-thirds of which is diesel fuel and one-third home heating oil.

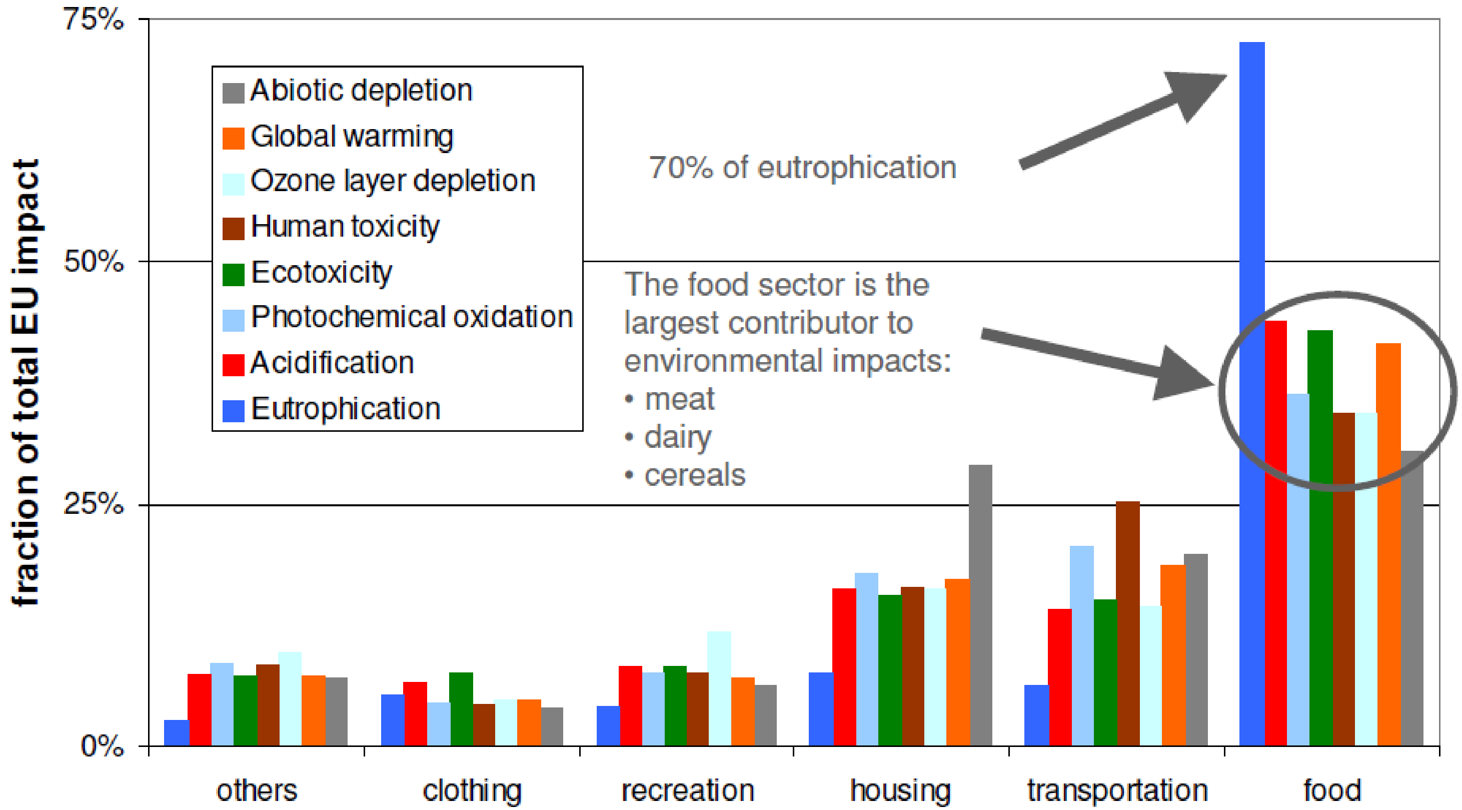
BOILER OIL: Boiler oil, or residual fuel oil, which makes up **7%** of crude oil consumption, is used to produce electricity.

ASPHALT AND OTHER NON-ENERGY FEEDSTOCKS: account for **13%** of crude oil consumption.

PETROCHEMICAL FEEDSTOCKS: products of the refining process, make up the remaining 3% of all crude oil consumption for plastics and chemicals

Sustainable Packaging
facts and figures

Our environment for sure, is not at risk for Packaging

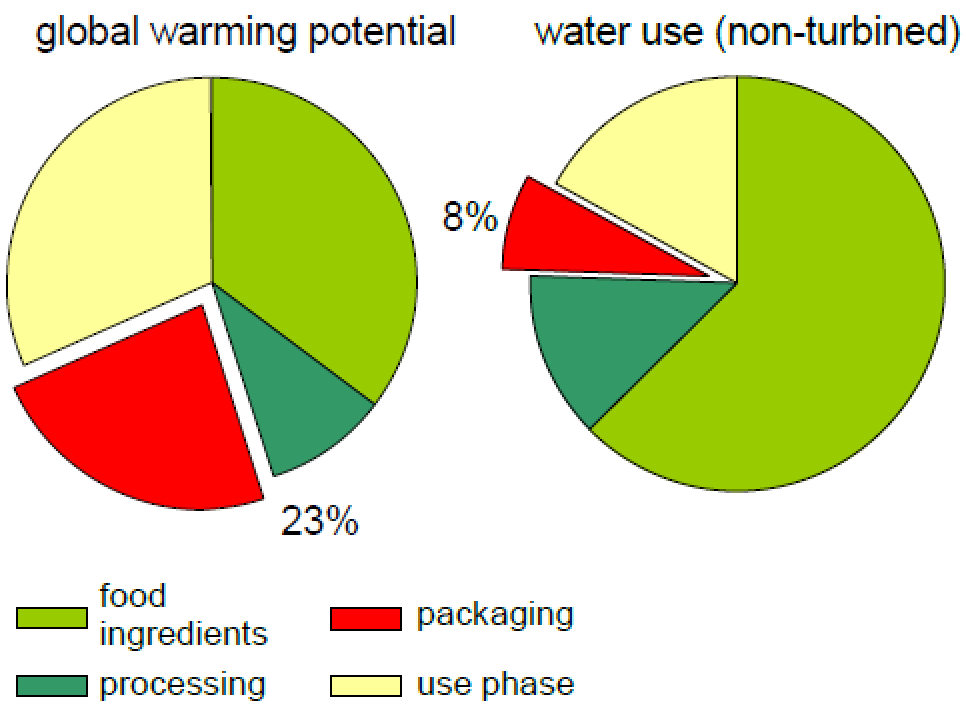


Adapted from: Environmental Impact of Products (EIPRO) - 29.04.05 based on 7 existing studies & own analysis

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

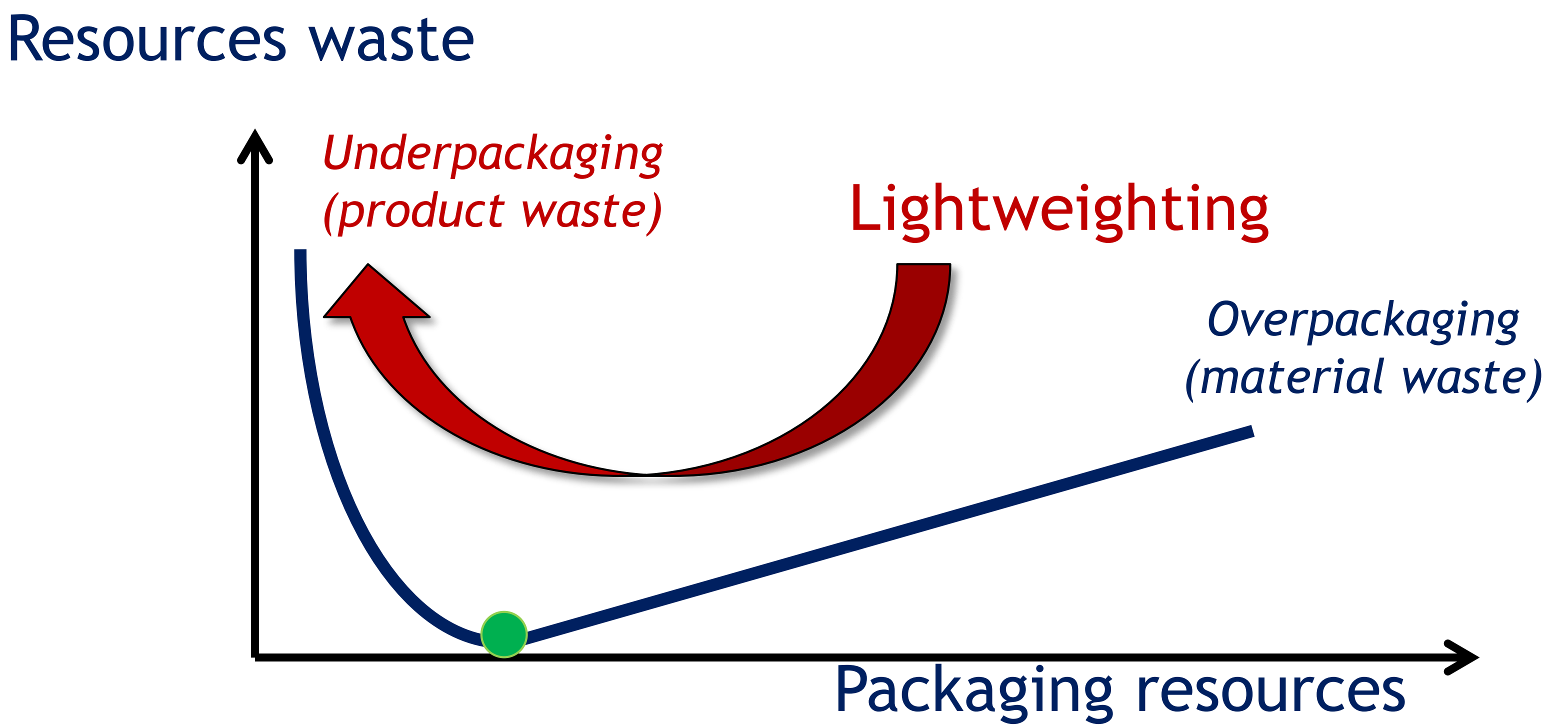
Sustainable Packaging
facts and figures

Our environment for sure, is not at risk for Packaging



Source: conservative estimate based on internal Nestlé screening LCA studies

Sustainable Packaging
Overpackaging



L. Stramare, COREPLA

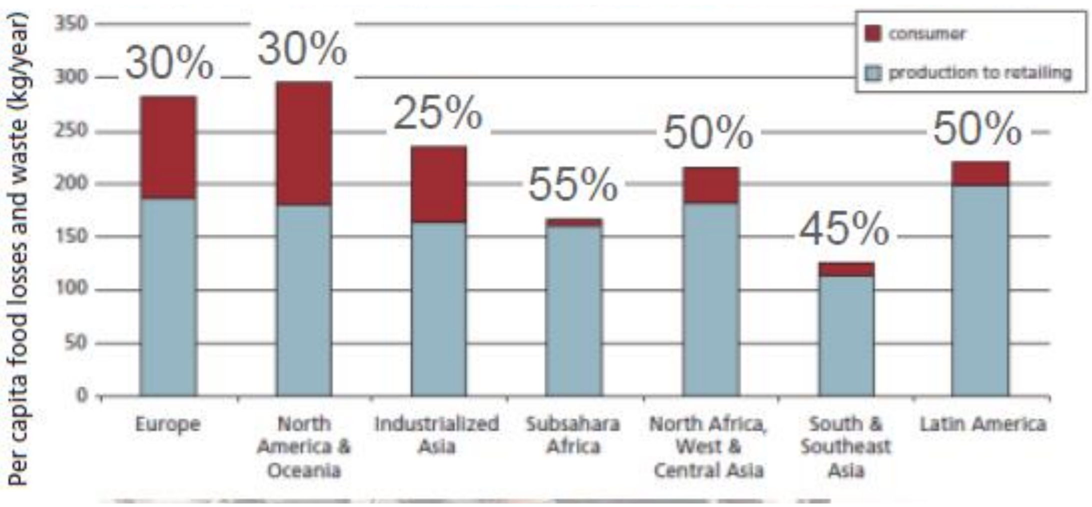
Appropriate packaging saves more waste than it creates. If, due to being badly packed, the contents are spoiled, ten times more waste occurs than that generated by the production of appropriate packaging

Kooijman, J. 1996. Environmental Impact of Packaging Performance in the Food Supply System, Journal of Waste Management and Resource Recovery, Vol. 3, Nr. 2,

Sustainable Packaging

Overpackaging

"Appropriate packaging" … might mean a correct balance between environmental expectations and high protective performance



Packaging serves to protect the food it contains. Packaging design oriented only towards packaging reduction fails to identify opportunities to a green and sustainable economy

Bio-based materials

A green and sustainable economy needs a revolutionary change in the use of raw materials, it needs to overcome today's dependency on fossil fuels and to bring about a shift towards processes and products based on natural resources.

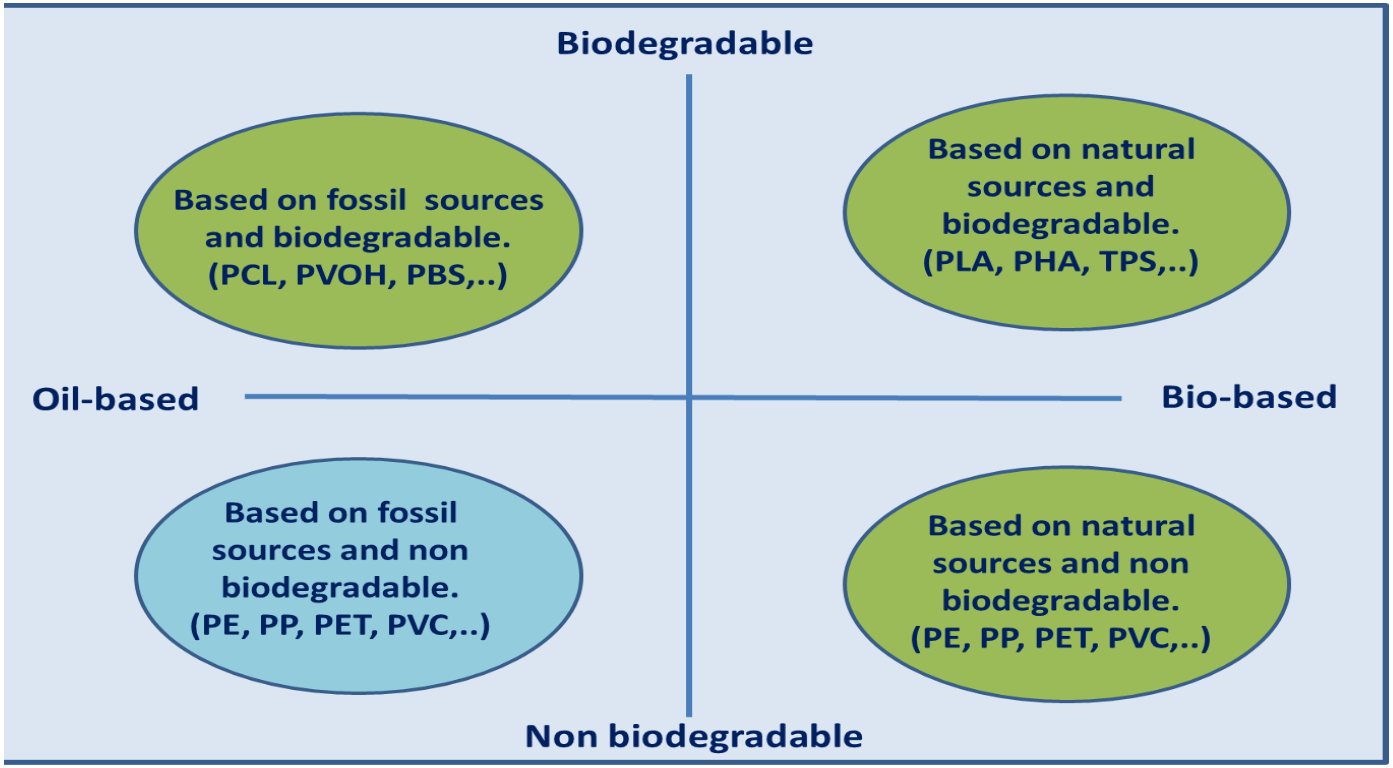
Within the energy supply sector, the change will be solar and wind power, within the materials sector, very likely, it will be Bio-based materials and their composites.

M. Carus, L. Scholz Report on Bio-based Plastics and Composites ISSN 1867-1217, Edition 7, April 2010

Bio-plastics

Bio-plastics are not a single kind of polymer but rather a family of materials that can vary considerably from one another.

The term bio-plastics encompasses materials which are bio-based, biodegradable, or both.



Thus, there are three groups in the bio-plastics family, each with its own individual characteristics

http://en.european-bioplastics.org

Bio-plastics

Poly(hydroxyalkanoates) (PHAs), Thermoplastic Starch (TPS), Polylactic acid (PLA),……..
Bio-based and biodegradable

Polyethylene and Polyester from renewable resources (BioPE,HD-LD; Bio PET),……..
Bio-based and Non-biodegradable

Polycaprolactone (PCL), Poly(vinyl alcohol) (PVOH), Poly(butylene succinate) (PBS), Polyglycolic acid (PGA),…..
Non-renewable and biodegradable

The Research on BBMs at Packlab

The combination of novel bio-based materials with conventional flexible packaging can be also a good way to accelerate the movement towards a sustainable bio-economy, in order to…. "not throw out the baby with the bath water"…

That's why we are focusing mainly on "coating technology"

L. Piergiovanni, F. Li, S. Farris. 2013. Coatings of Bio-based materials on flexible food packaging: opportunities for problem solving and innovations. In IJEB Special Issue on New Developments in Biotechnology, Guest Editors- RS Singh, Ashok Pandey, CG Dussap & L Piergiovanni, Indian Journal of Experimental Biology, 51(11), 867-1048 (2013) ISSN: 0019-5189 New Delhi

The Research on BBMs at Packlab

Coatings are thin layers of functional material deposited on a substrate, mainly as liquid solutions

From tenths of nm to few µm, generally much thinner than the substrate beneath

S. Farris, L. Piergiovanni . 2012 Advances in coating technologies for food and beverage packaging materials. In: Emerging Food Packaging Technologies (2012),K. Yam and D.S. Lee (Eds.). Woodhead Publishing Ltd, Oxford, UK. pp. 274

The Research on BBMs at Packlab

Coatings applications

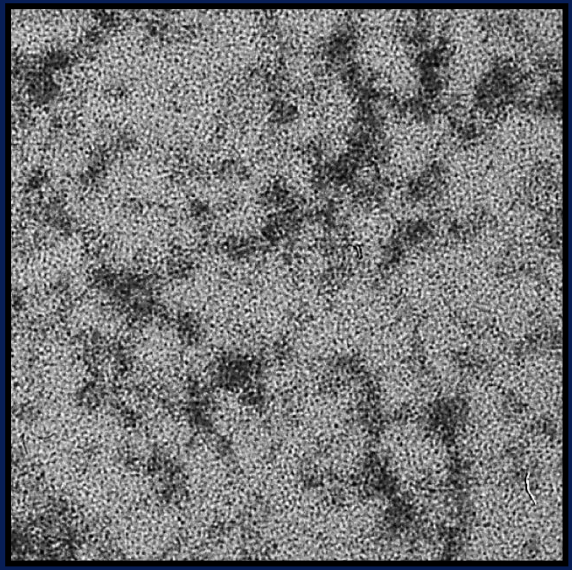
Laboratory scale

Pilot scale

Industrial level

The Research on BBMs at Packlab

Self-assembled Pullulan/Silica hybrid Coatings as Oxygen Barrier at high RH

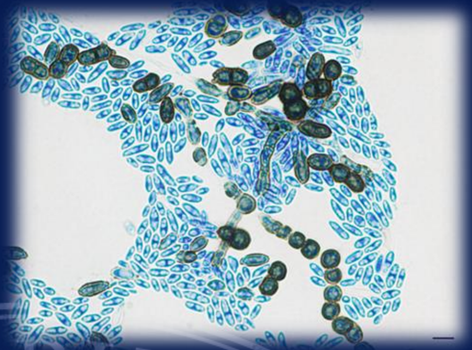


S. Farris, L. Introzzi, J.M. Fuentes-Alventosa, N. Santo, R. Rocca, L. Piergiovanni 2012
Journal of Agricultural and Food Chemistry, 60 (3): 782–790

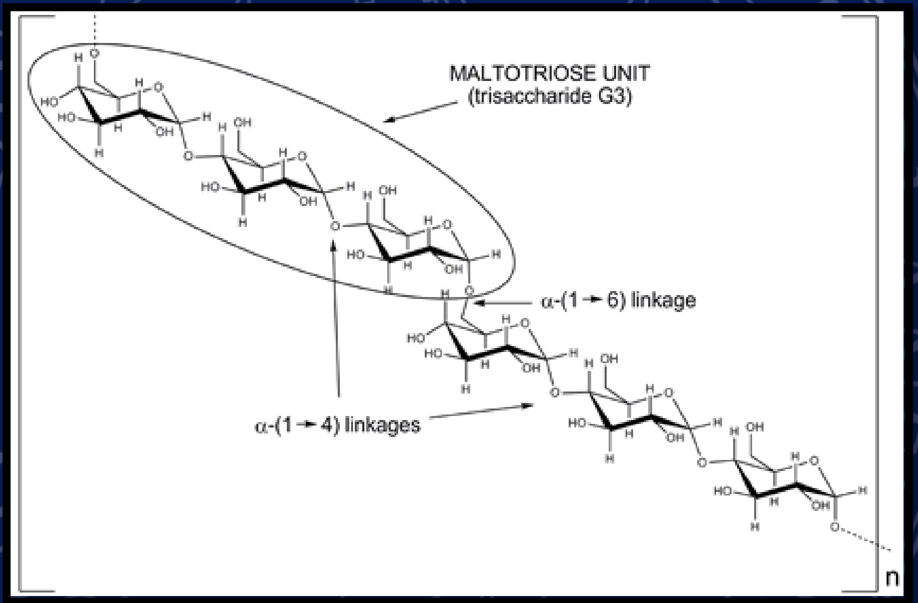
Materials

Pullulan

Exopolysaccharide produced aerobically by a yeast-like fungus *A. pullulans*.



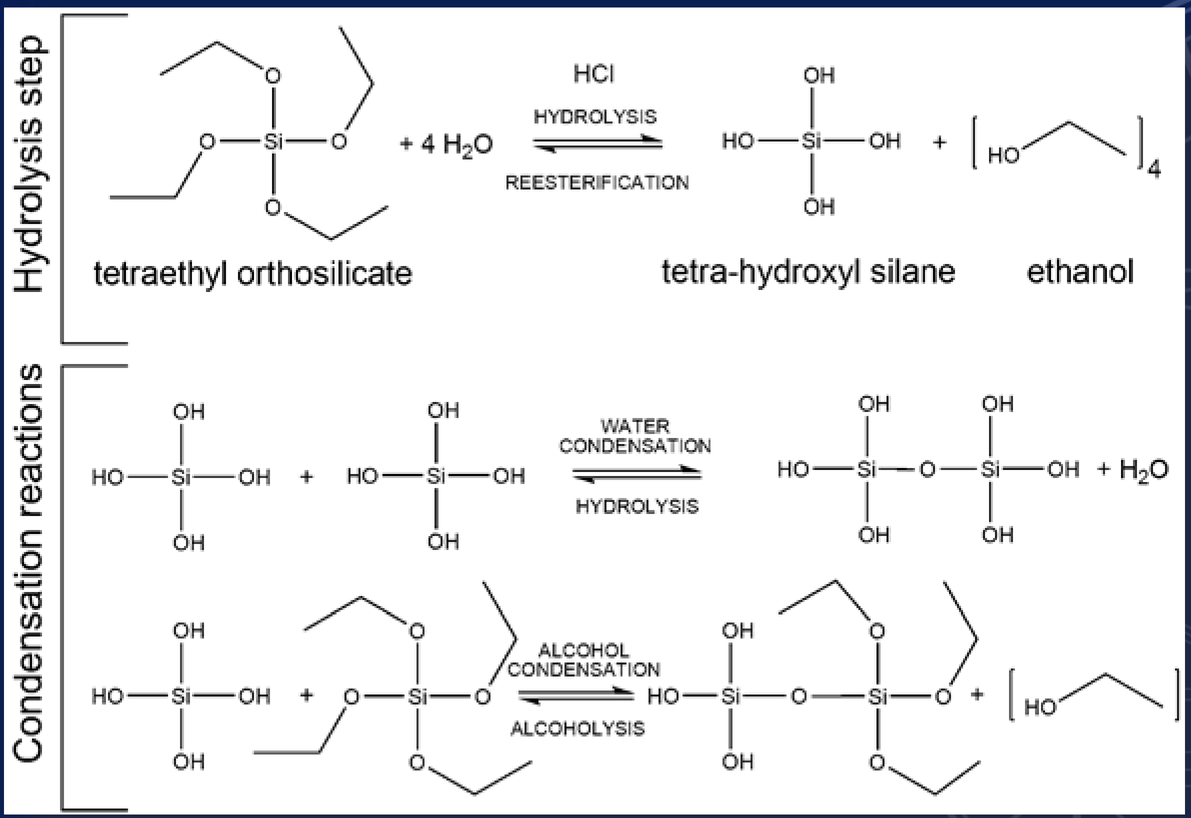
- High chain flexibility
- Low viscosity at high concentation
- Film-forming properties
- Highly transparent
- Rich in hydroxyl groups
- Similar to PVOH
- High moisture sensitivity
- High price (~ 20 €/kg)



Materials

Tetraethyl orthosilicate (TEOS)

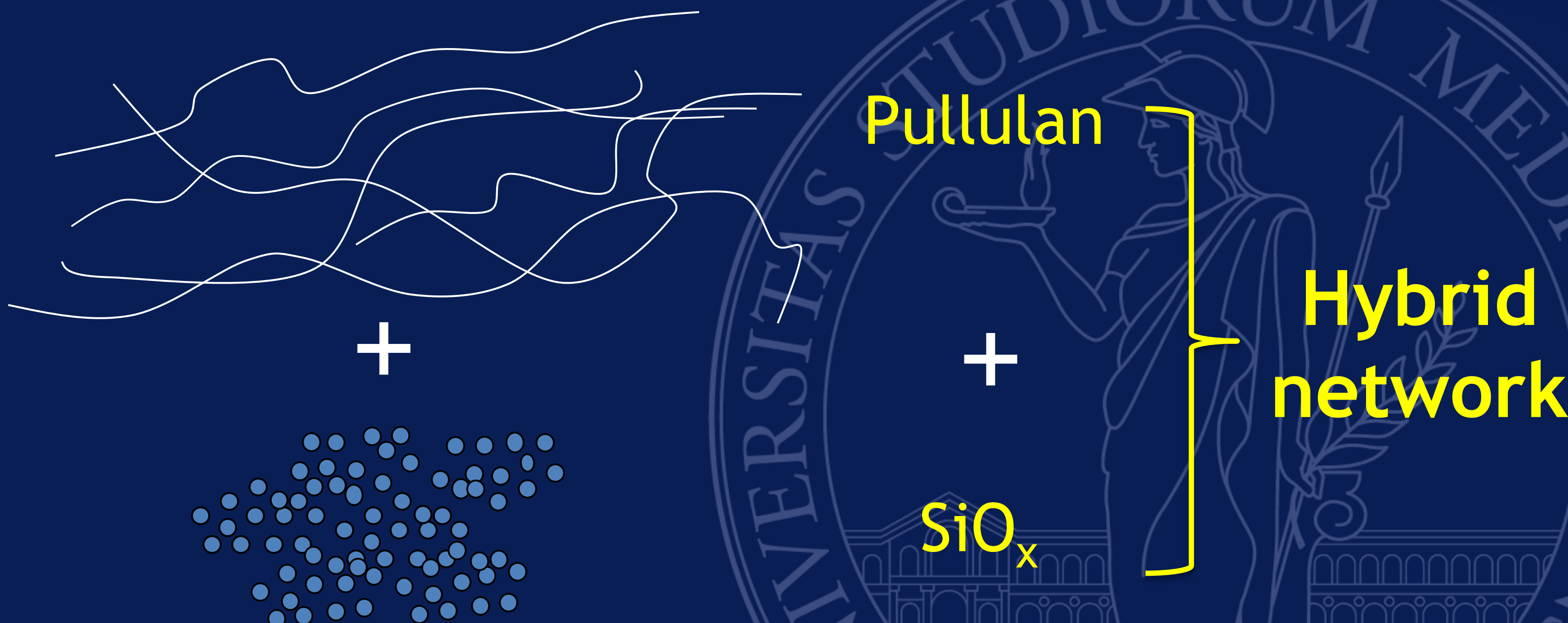
Widely used in the **sol-gel** processes as a precursor of both orthosilic acid [$Si(OH)_4$] and silicon dioxide (SiO_2).



→ Glass-like features

Rationale

Combining the features of the individual phases (i.e. organic and inorganic) can be useful to obtain **a hybrid network** for the production of coatings with high oxygen barrier properties even at high relative humidity values



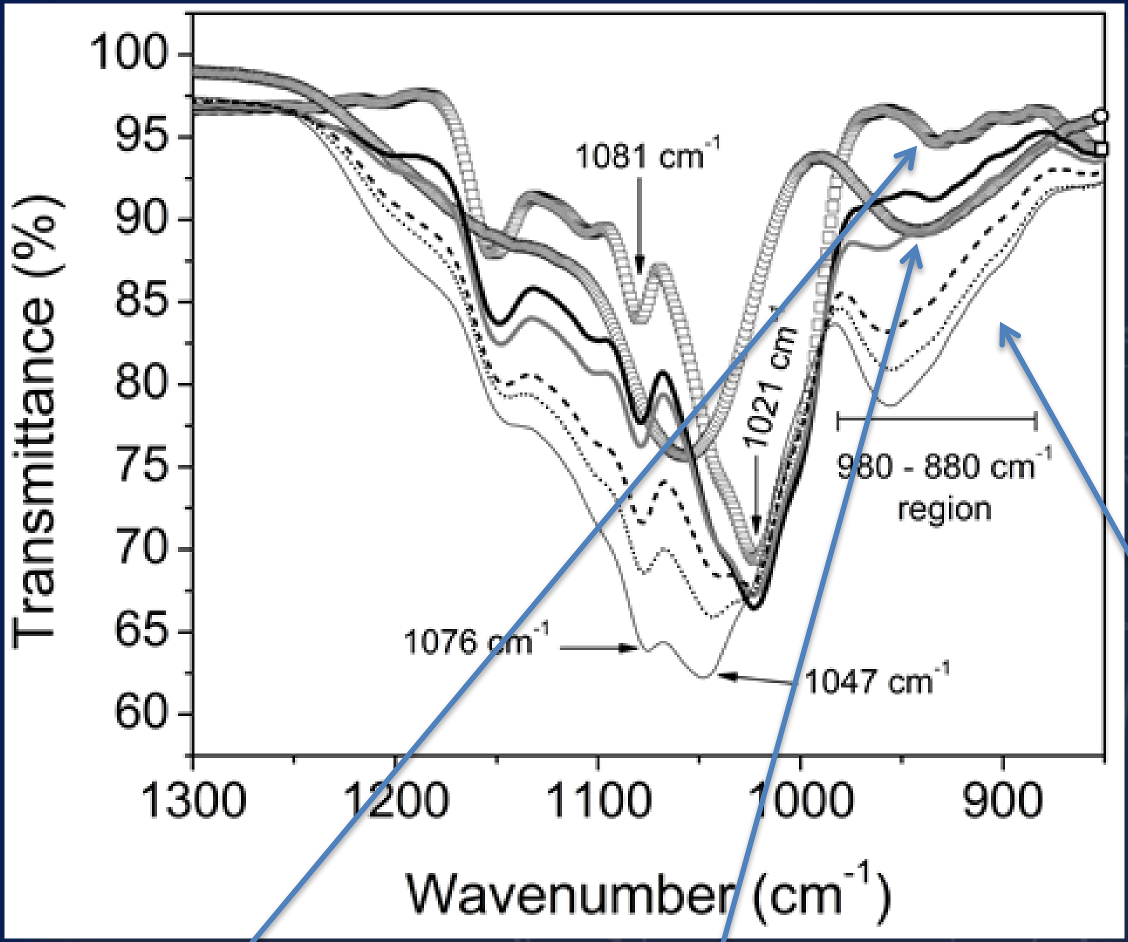
Procedures

Coating formulations tested

Exp. n°	Coded name	Pullulan (wt-%)	$Si(OH)_4$ (wt-%)	(O/I*) ratio	Coating thickness (μm)
1	H_0	10	0	/	1.27 ± 0.12
2	H_3	7.5	2.5	3	1.37 ± 0.18
3	H_2	6.66	3.33	2	1.31 ± 0.07
4	H_1	5	5	1	1.26 ± 0.14
5	$H_{0.75}$	4.3	5.7	0.75	1.19 ± 0.08
6	$H_{0.5}$	3.33	6.66	0.5	1.15 ± 0.09

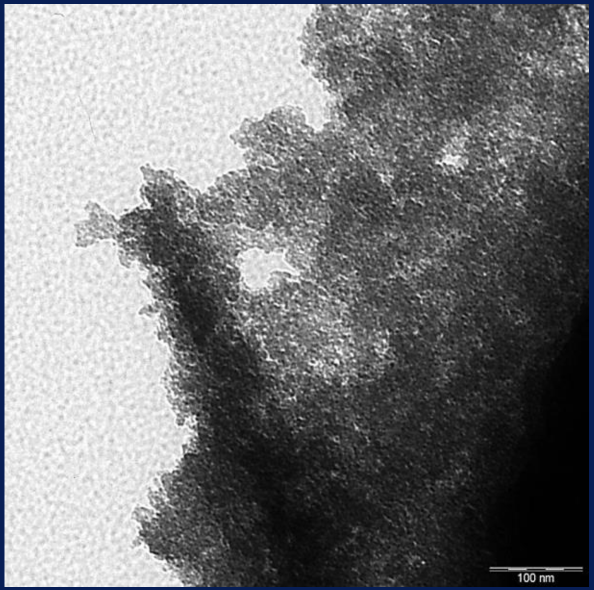
* "O/I" is Organic/Inorganic Ratio; "I" refers to the silanol form, $Si(OH)_4$, calculated by the initial TEOS content and assuming the completion of the hydrolysis reaction;

Results by ATR-FTIR

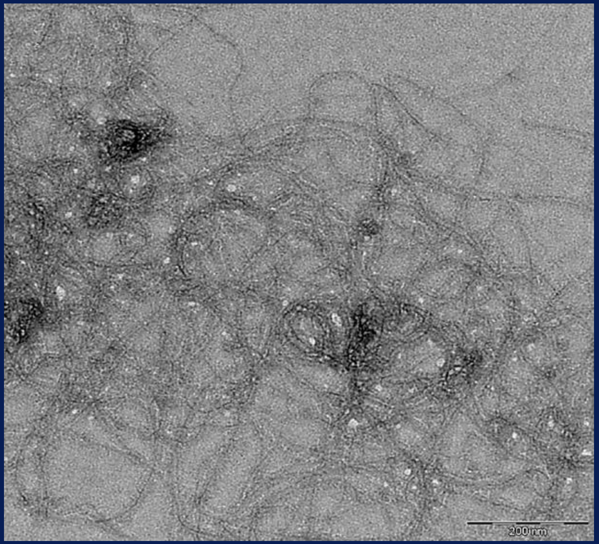


Spectra of pullulan (□), reacted TEOS (○) and hybrid coatings $H_{0.5}$ (——), $H_{0.75}$ (••••••), H_1 (- - - -), H_2 (——), H_3 (——) within 1300 cm^{-1} – 850 cm^{-1} (d) spectral range

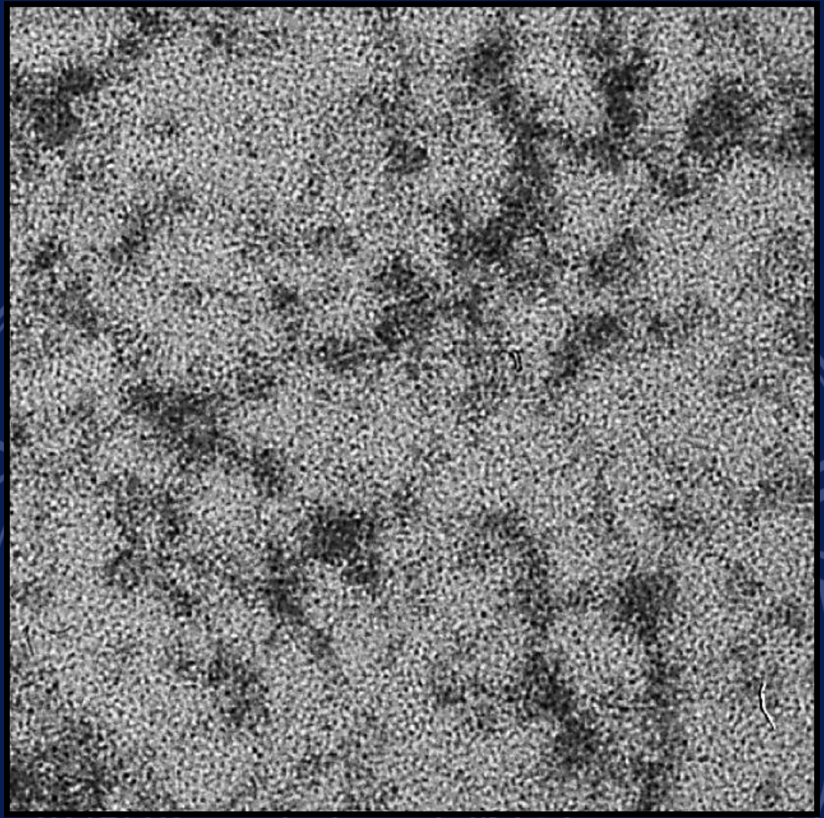
Results by TEM



SiO_2 network after hydrolysis and condensation of the metal alkoxide precursor

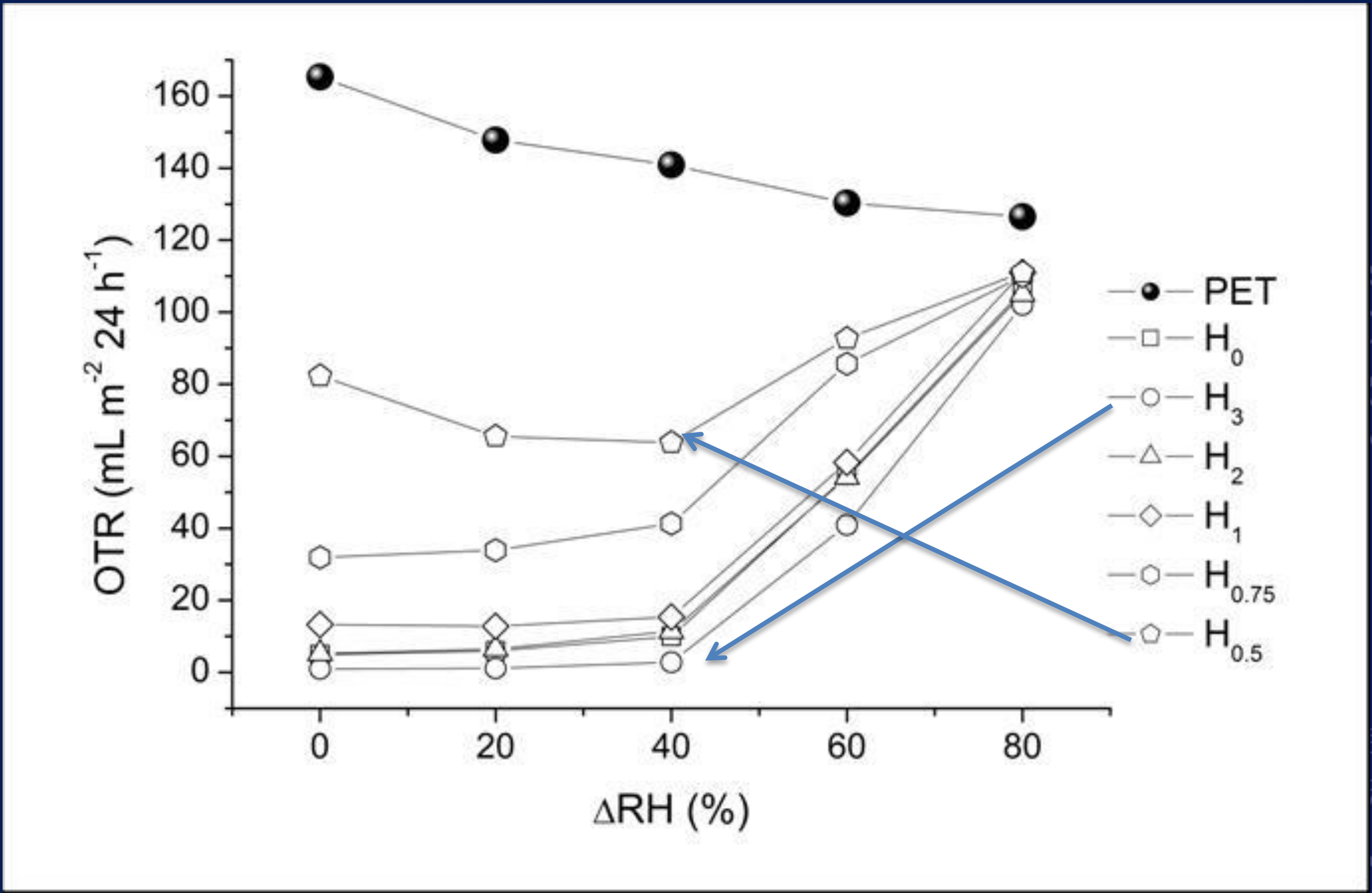


Pullulan chains with high extent of entanglement



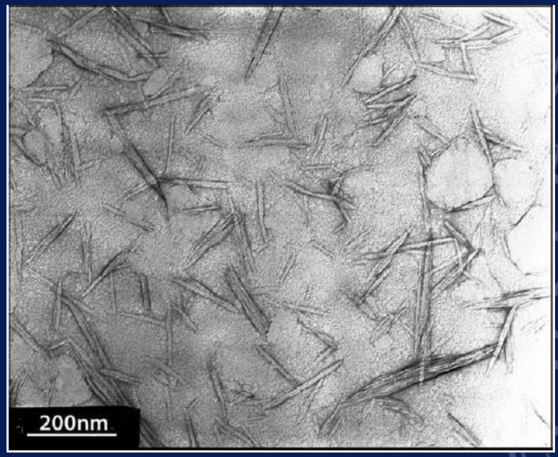
Pullulan/SiO_2 (1:1) hybrid network

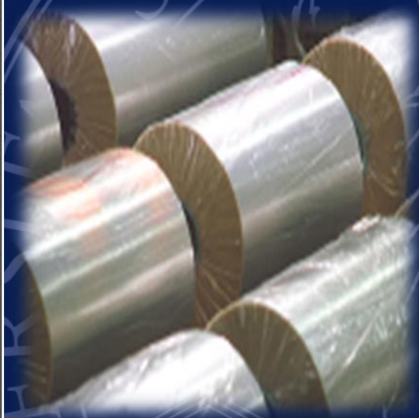
Results by OTR measures

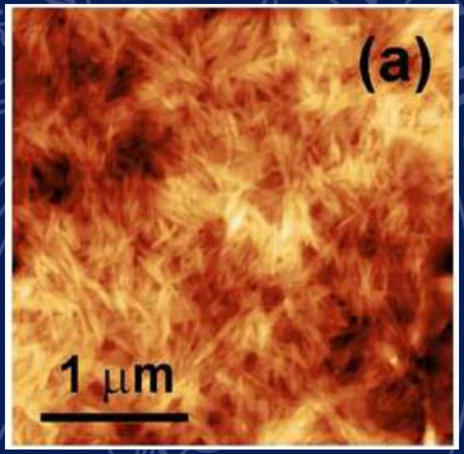


The Research on BBMs at Packlab

Multi-functional Coating of Cellulose Nanocrystals for Flexible Packaging Applications



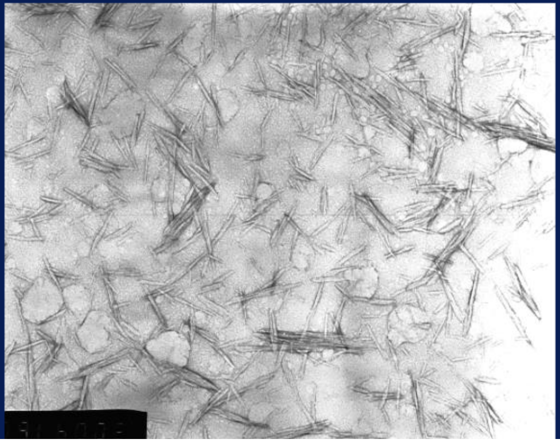


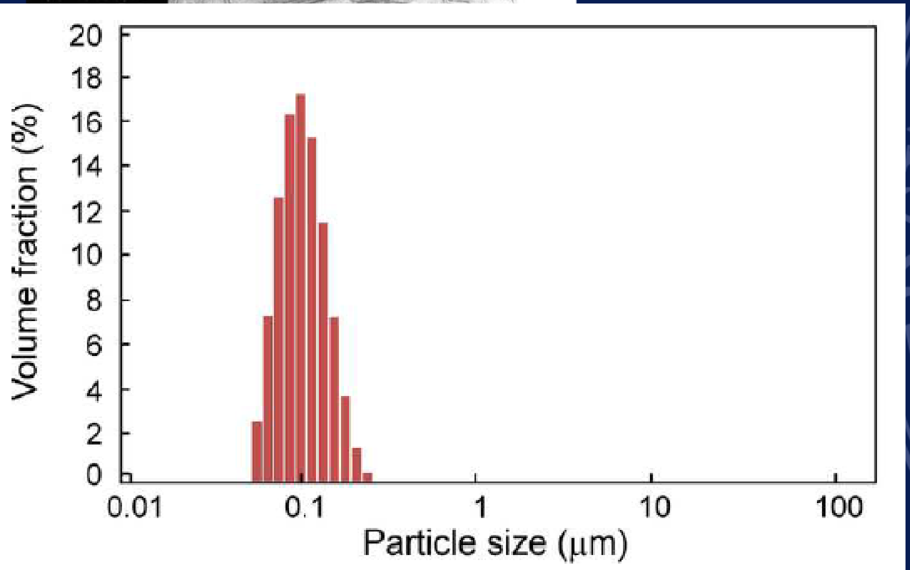


F. Li, P. Biagioni, M. Bollani, A. Maccagnan, L. Piergiovanni. 2013 Multi-functional coating of cellulose nanocrystals for flexible packaging applications *Cellulose 20* (5): 2491-2504

Materials

Cellulose nanocrystals (CNCs)

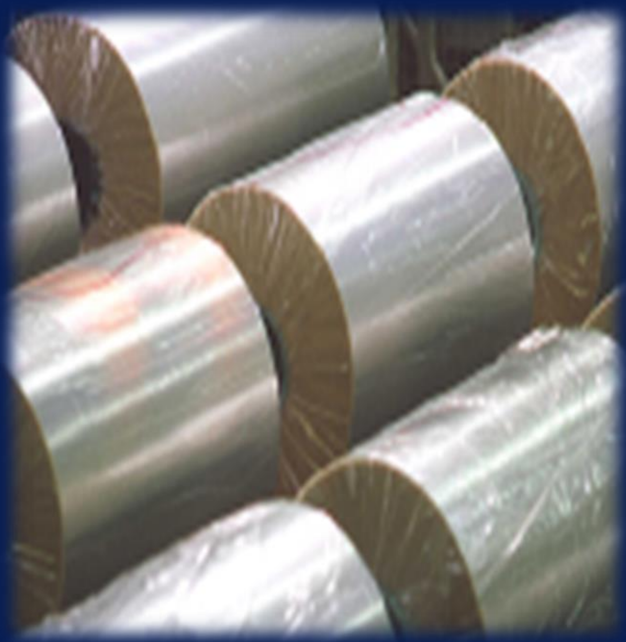




Milled cotton linters were hydrolyzed by 64 wt% sulfuric acid at 45 ° C for 45 minutes to obtain 1 wt% Cellulose nanocrystals dispersion. After further purification the suspension was sonicated, adjusted to pH ~7, freeze-dried and used to prepare a given concentration of cellulose nanocrystals for coating operations

Materials

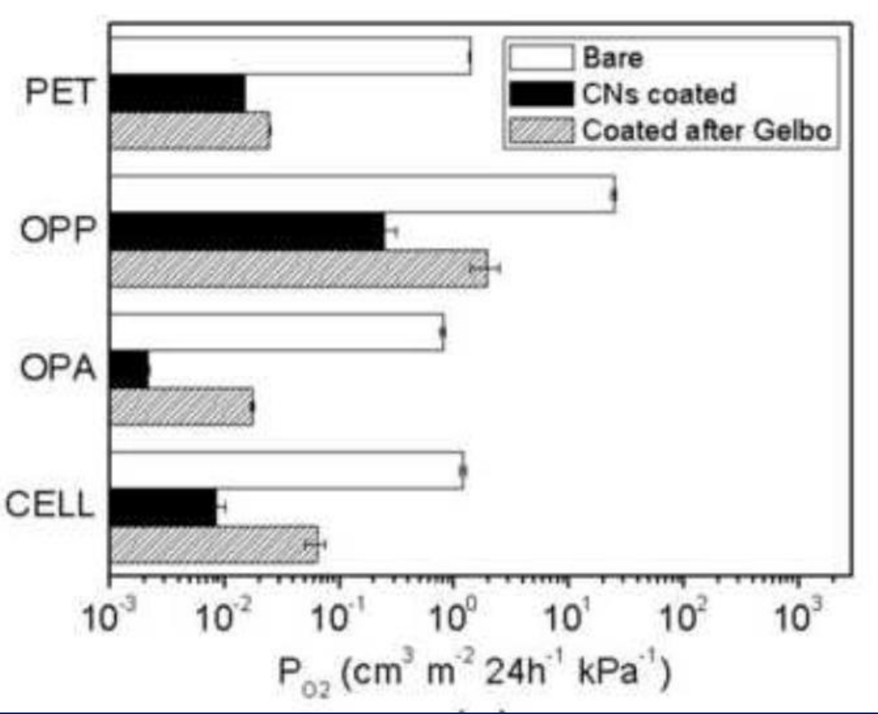
Poly(ethylene terephthalate (**PET,** 12μm), oriented polypropylene (**OPP,** 20μm), oriented polyamide (**OPA**, 12μm), and cellophane (**CELL**,12m).

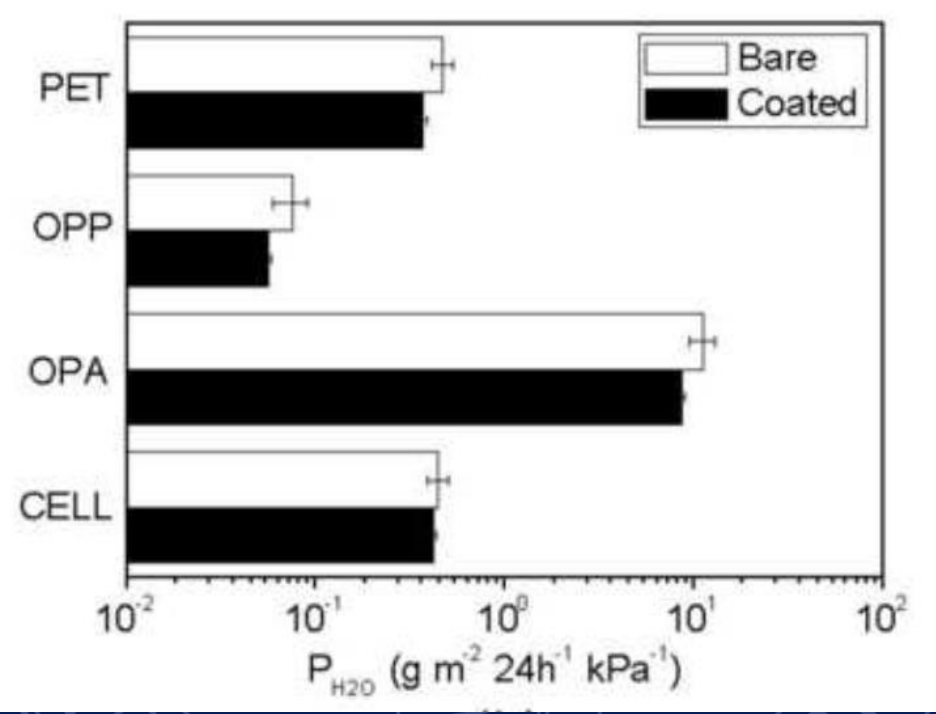


According to ASTM standard the corona-treated sides of the 4 different plastic films were coated by an automatic film applicator at a constant speed

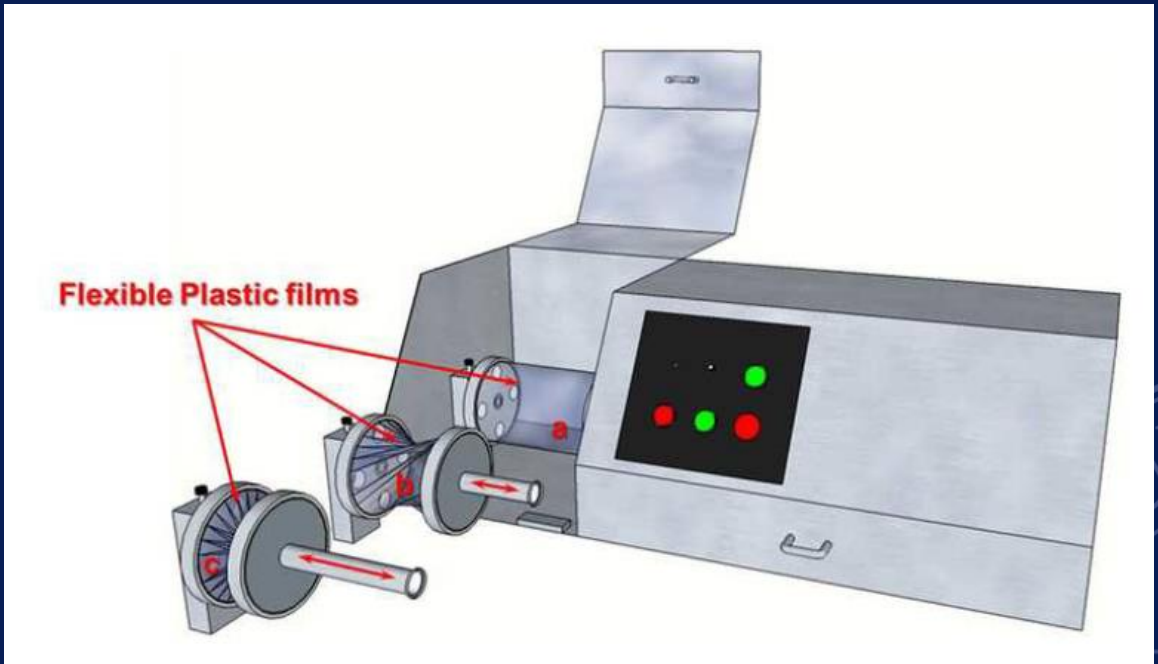
Rationale

To produce a multi-functional coating, by means of a dispersion of CNCs as coating material, in order to enhance the coefficient of friction, anti-fog, optical, oxygen barrier and water vapor barrier properties of various substrates films



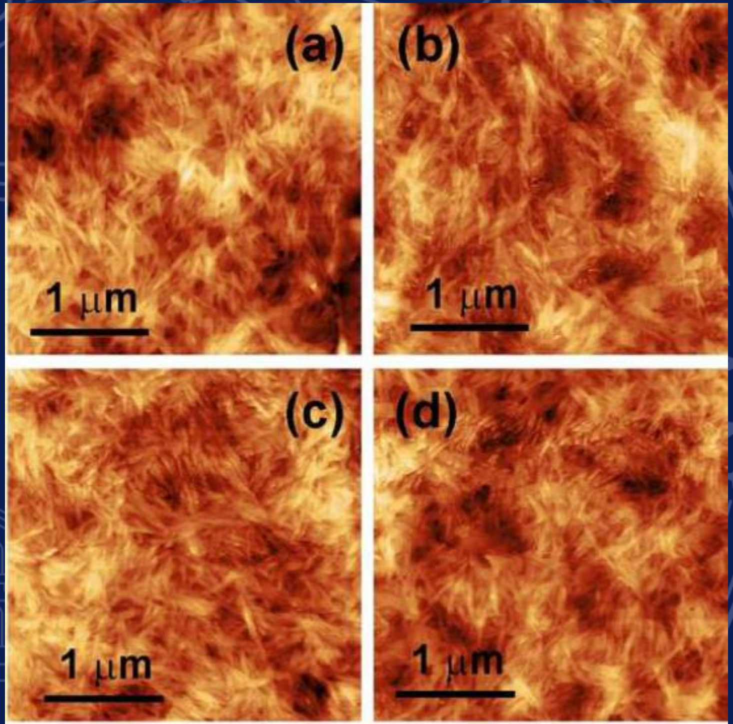


Procedures



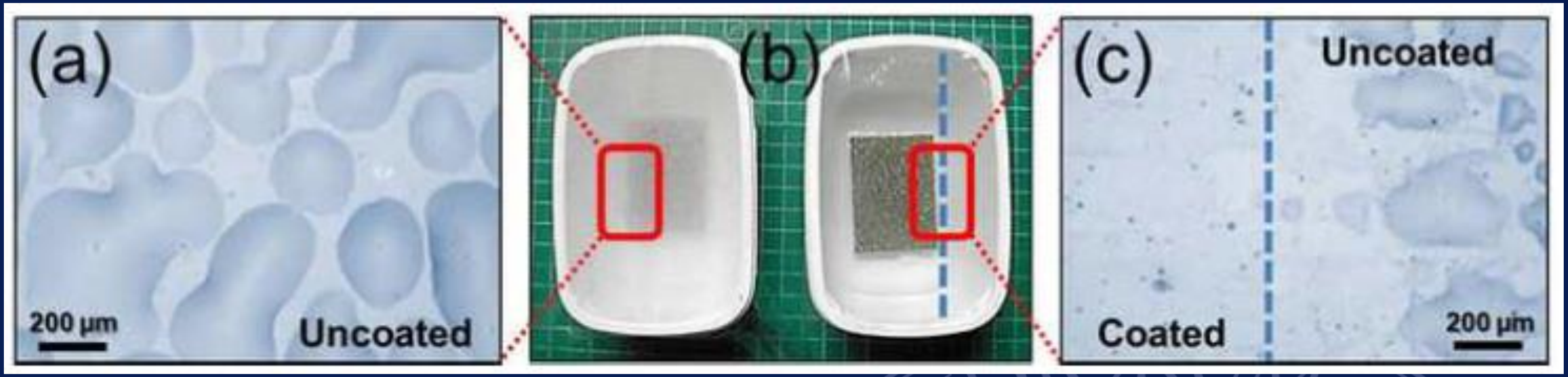
GELBO FLEX testing machine

The CNCs network onto the 4 films



Both practical or empirical tests and scientific investigations were carried out in order to understand the real feasibility of such bio-based coatings

Procedures/Results



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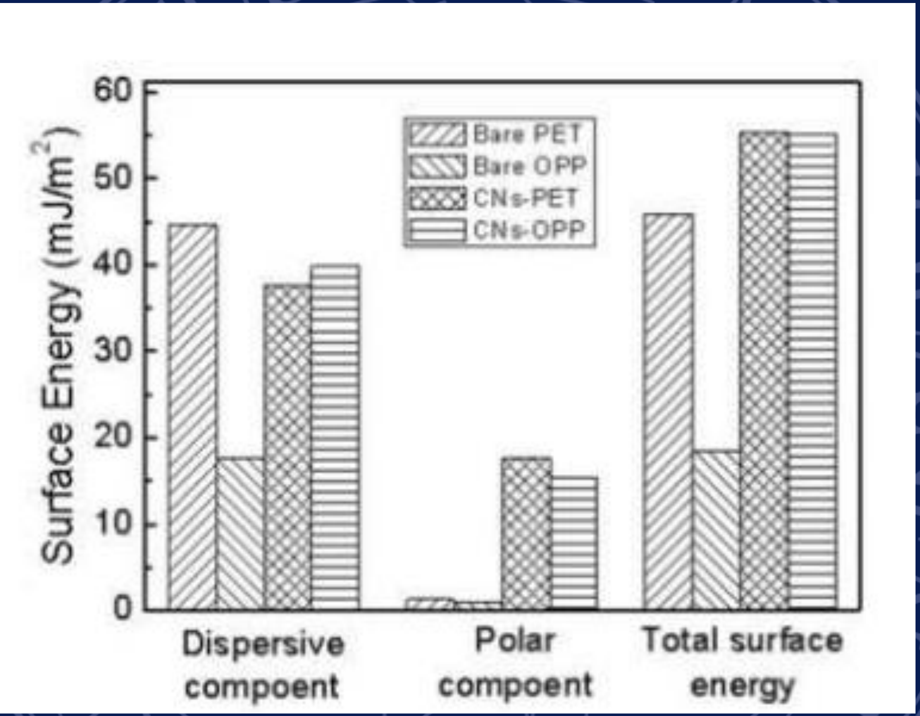


Results

Multi-functional Coating of Cellulose Nanocrystals for Flexible Packaging Applications

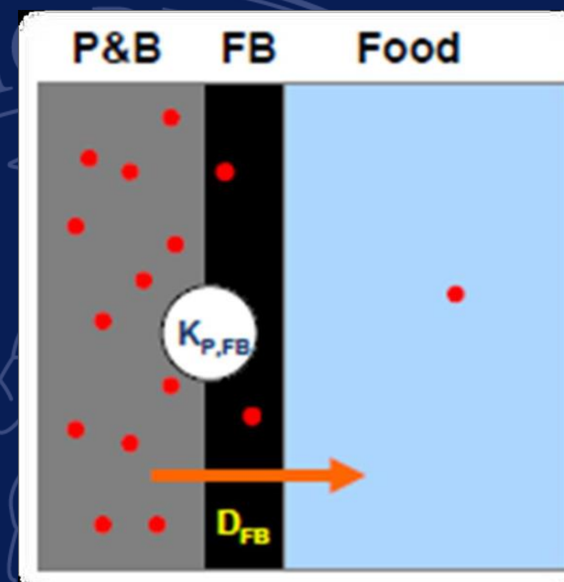
	T%	Haze	OTR	WVTR	Antifog	COF
PET	↑	↕	↓ ↓	↓ ↕	↑ ↑ ↑	↓ ↓
OPP	↓	↑	↓	↓ ↕	↑ ↑ ↑	↕
OPA	↕	↑	↓ ↓	↓ ↕	◆	↓ ↓
Cell	↑	↑	↓ ↓	↓ ↕	◆	↓ ↓

The Research on BBMs at Packlab

Bio-based coatings as potential barrier to chemical contaminants from recycled paper and board packaging

Packlab

Fraunhofer IVV



V. Guazzotti, S. Limbo, L. Piergiovanni, R. Fengler; D. Fiedler, L. Gruber 2014. A study into the potential barrier properties against mineral oils of starch-based coatings on paperboard for food packaging **submitted to** Food Packaging and Shelf Life

Rationale

Paper and Paperboard, if produced using recycled cellulosic materials, can be contaminated by **MOSH** (Mineral Oil Saturated Hydrocarbons) **and MOAH** (Mineral Oil Aromatic Hydrocarbons); a bio-based coating can provide a **functional barrier** to reduce the possible contamination below a threshold of concern.

Description	Thickness (mm)	Name	MOSH (µg/g)
Fully coated white lined chipboard with kraft back suitable for dry food, 320g/m²	0,405	paperboard recycled	**484,4**
Fully coated white lined chipboard with manilla back suitable for dry food, 320g/m²	0,425	paperboard recycled	**486,5**
Paperboard with kraft back suitable for dry food, 135g/m²	0,300	paperboard 100% virgin	**-**
One side machined glazed white paper suitable for dry food, 50g/m²	0,060	paper	**84,9**
One side machined glazed kraft paper suitable for dry food, 50g/m²	0,060	paper raw	**91,6**

Materials

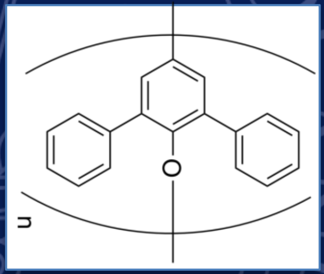
Starch coated on a virgin paper as FB

1. Maize Cationic waxy starch
2. Maize Cationic starch
3. Cationic starch mixture with high amylose content

Spiked Paper as donor

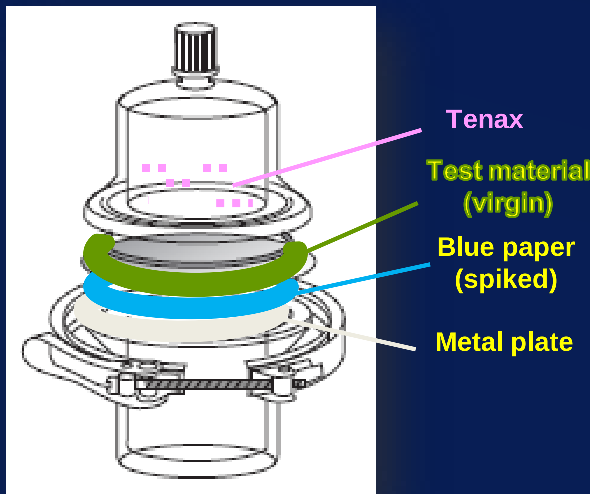
Industrial towel, 60 g/m², spiked with 100µL of a mixture of all even n-alkanes from C10 to C40, 50 mg/L in n-heptane each and allowed to dry

Poly(2,6-diphenyl-p-phenylene oxide) (PPPO) - TENAX as acceptor



For regenerating Tenax, ASE 300 DIONEX was used. As solvent Ethanol and a mixture of Hexane/Ethyl Acetate 56:44.

Procedures

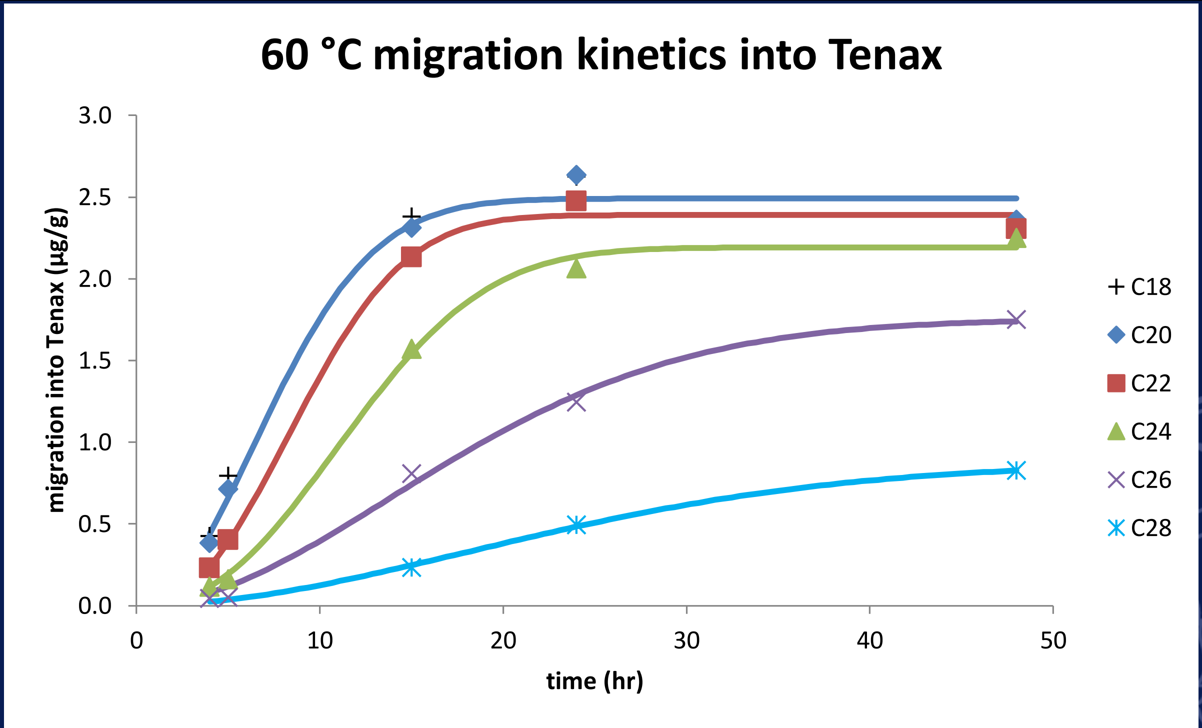


Fraunhofer IVV

Each test material (neat or coated paperboard) were sandwiched between a glass Migration Cell (MIGRACELL - Fabes)

After conditioning in thermostatic hoven, both blue paper and Tenax were extracted following the BfR methodology for quantification of alkane's residue or migration, respectively in the donor and receptor. Extracts were analysed by online normal phase HPLC-GC-FID.

Results



Weibull parameters			
	C_∞	τ	β
C20	2,49	9,05	2,00
C22	2,39	10,56	2,31
C24	2,19	13,79	2,35
C26	1,75	20,64	1,88
C28	0,87	26,79	1,89

Their shape of migration curves is well represented by the **Weibull model** (Pocas M 2011. *Food Control* 22 (2011), 303-312)..

The **Weibull kinetic model** was fit to the experimental data.

$$\frac{C(t)}{C_\infty} = 1 - \exp\left[-\left(\frac{t}{\tau}\right)^\beta\right]$$

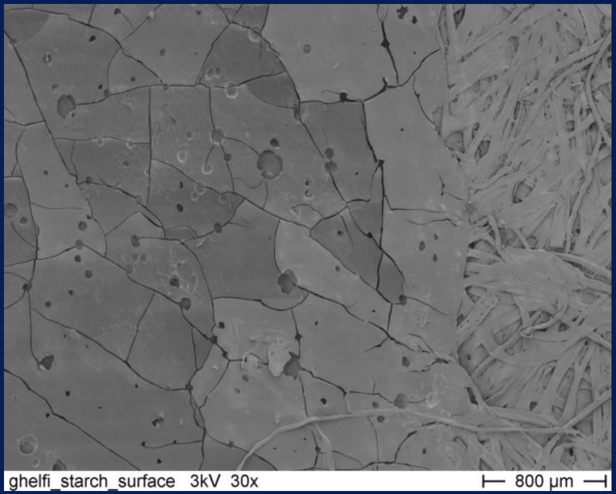
The fitting function was applied to the experimental data using the software Table Curve 2D (Jandel Scientific).

The model has two parameters:

τ the system time constant, associated to the process rate and related to the **diffusion coefficient** and the material **thickness**

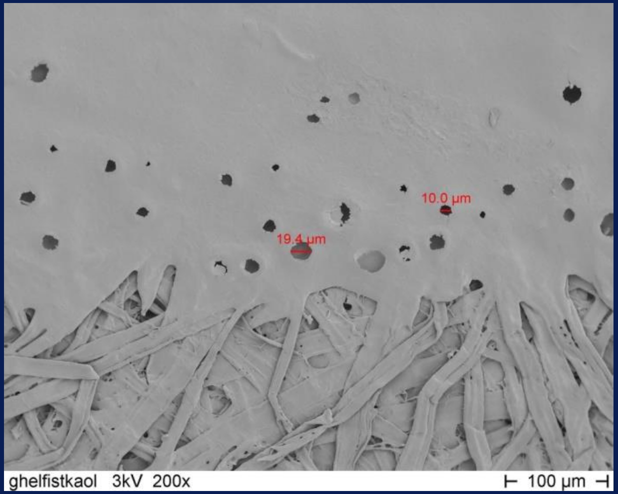
β the shape parameter, related to **the initial rate of the process**

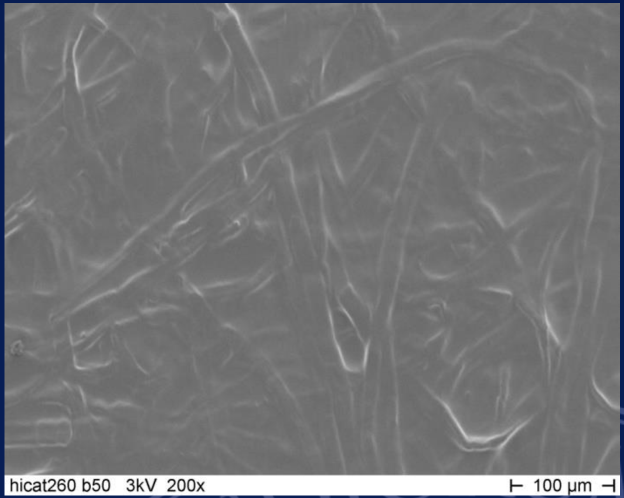
Results



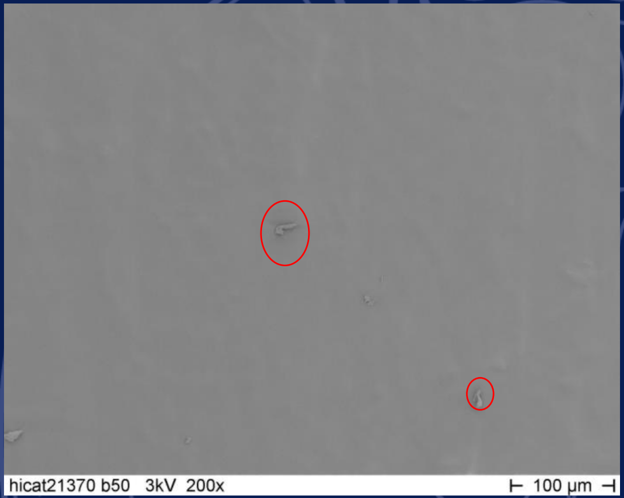
Coated paperboard (pilot scale made):

- **fractures zones**
- **pinholes homogenously distributed**





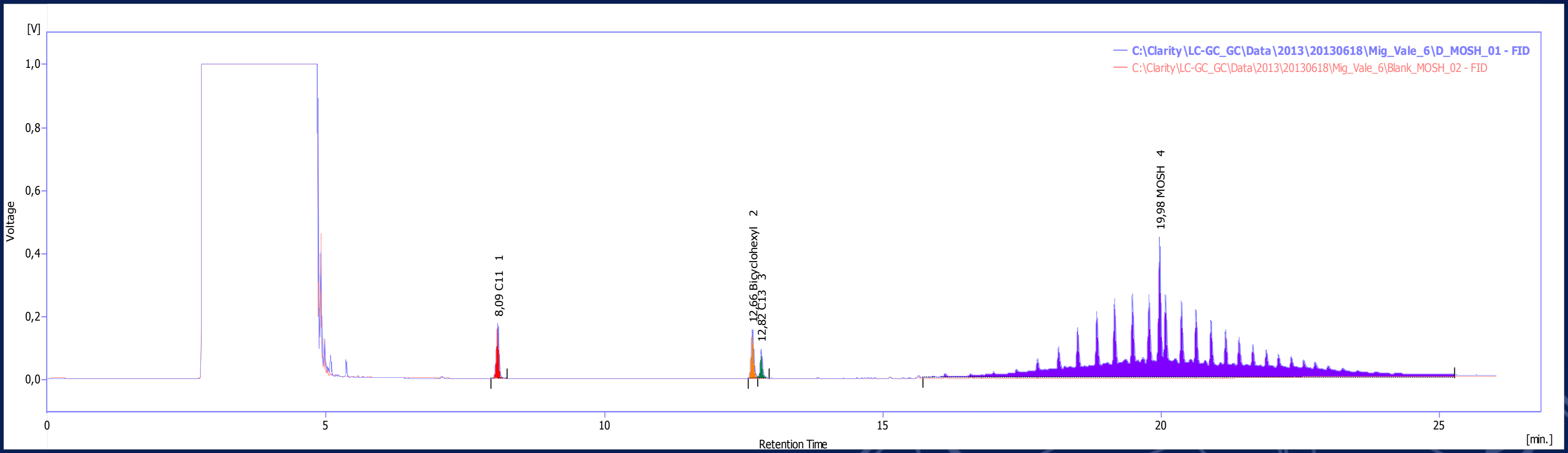
Coated (A= cationic starch) paperboard, lab scale



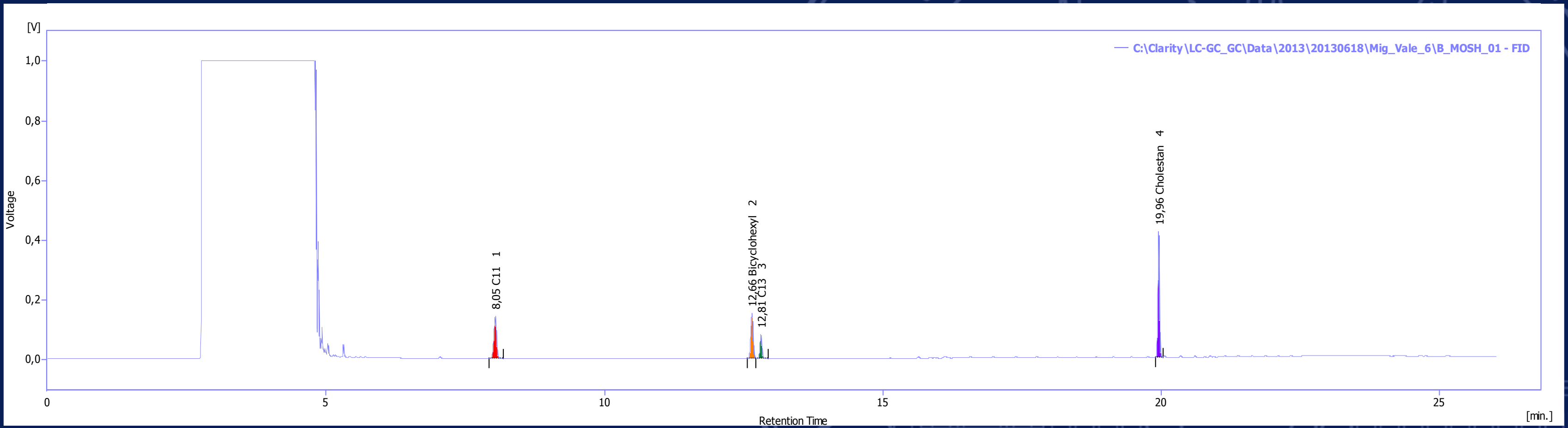
Coated (B = cationic waxy starch) paperboard, lab scale

Only bio-coated paperboard lab scale made could be considered for further investigations of the barrier properties against mineral oil components. The bonds between anionic fibres and cationic starch are very strong with virtually total fixation of the starch to the fibres.

Results

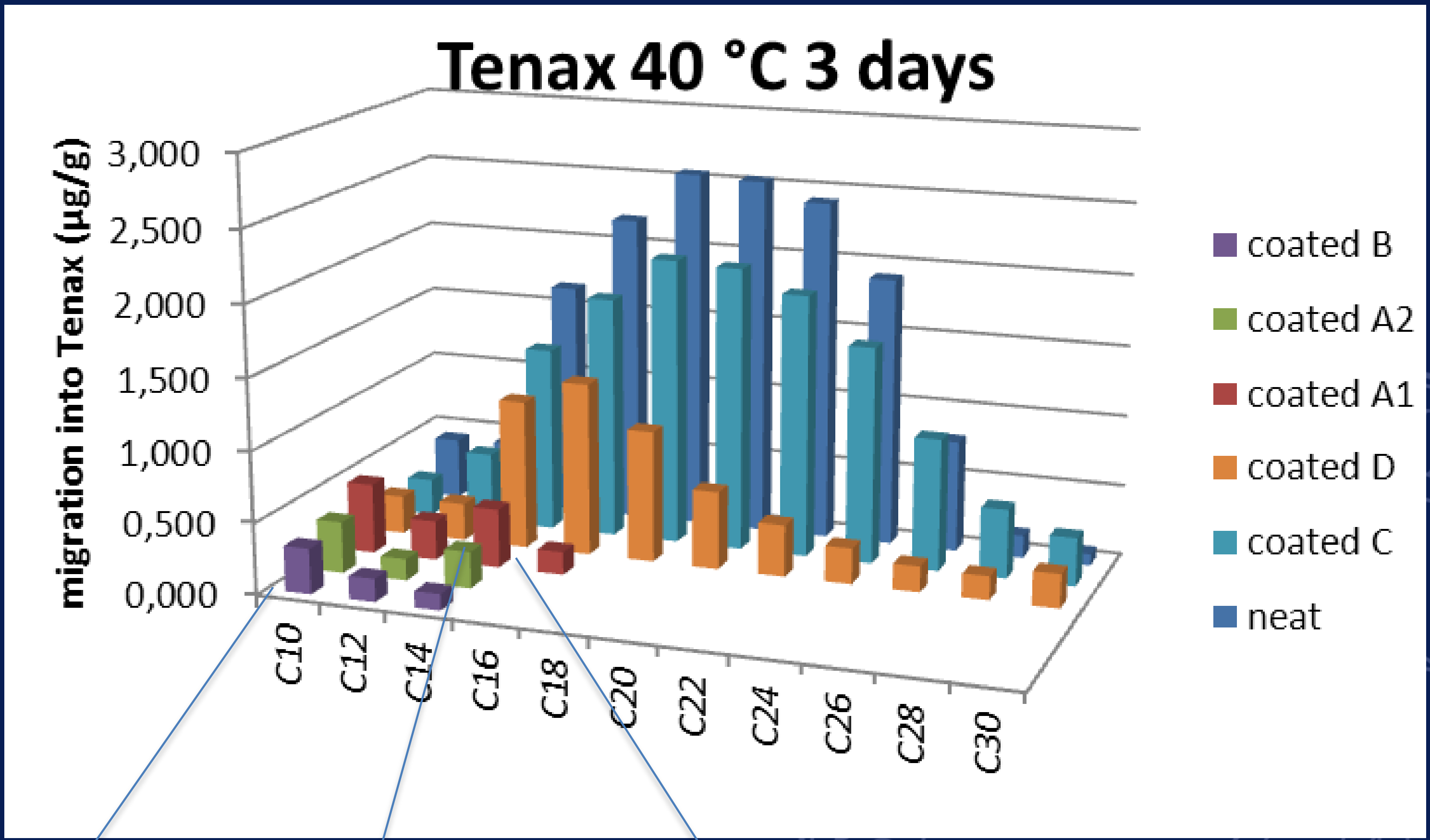


Coated paperboard (pilot scale made)



Coated (B = cationic waxy starch) paperboard, lab scale

Results



Coated paperboard (pilot scale made) with defects

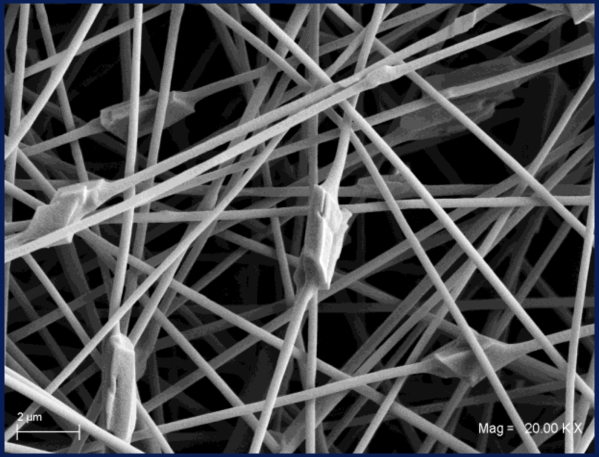
Starch with high amylose content

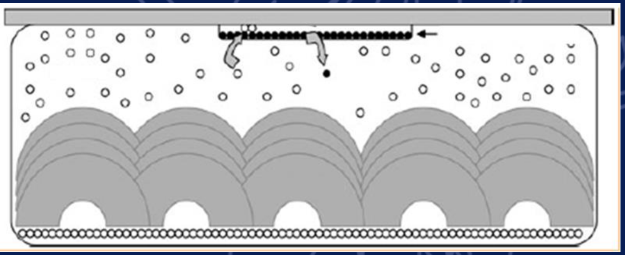
Normal Starch

Starch with high amylopectin content

The Research on BBMs at Packlab

Encapsulation of natural antimicrobial & antioxidants for a Bio-based Active Packaging device





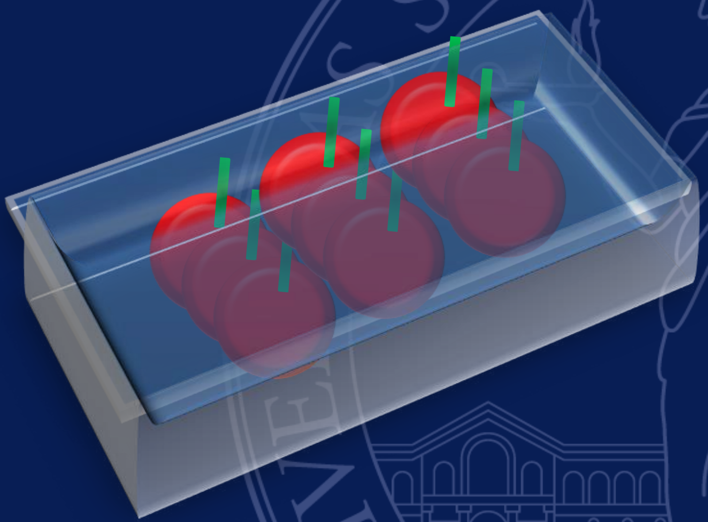
E. Mascheroni, C. Feunmajor, S. Cosio, G. DiSilvestro, L. Piergiovanni, S. Mannino, A. Schiraldi. 2013 ***Encapsulation of volatiles in nanofibrous polysaccaryde membranes for humidity-triggered release***. *Carbohydrate Polymers. 2013:*

Rationale

To set up an active packaging device, for fresh foods, triggered by product's moisture and using antioxidant and antimicrobial essential oils (Perilla, propolis, limonene) encapsulated in a Bio-based material

Increase of the shelf life of fresh products by active protection against microbial degradation

Release of volatile compounds during production and storage

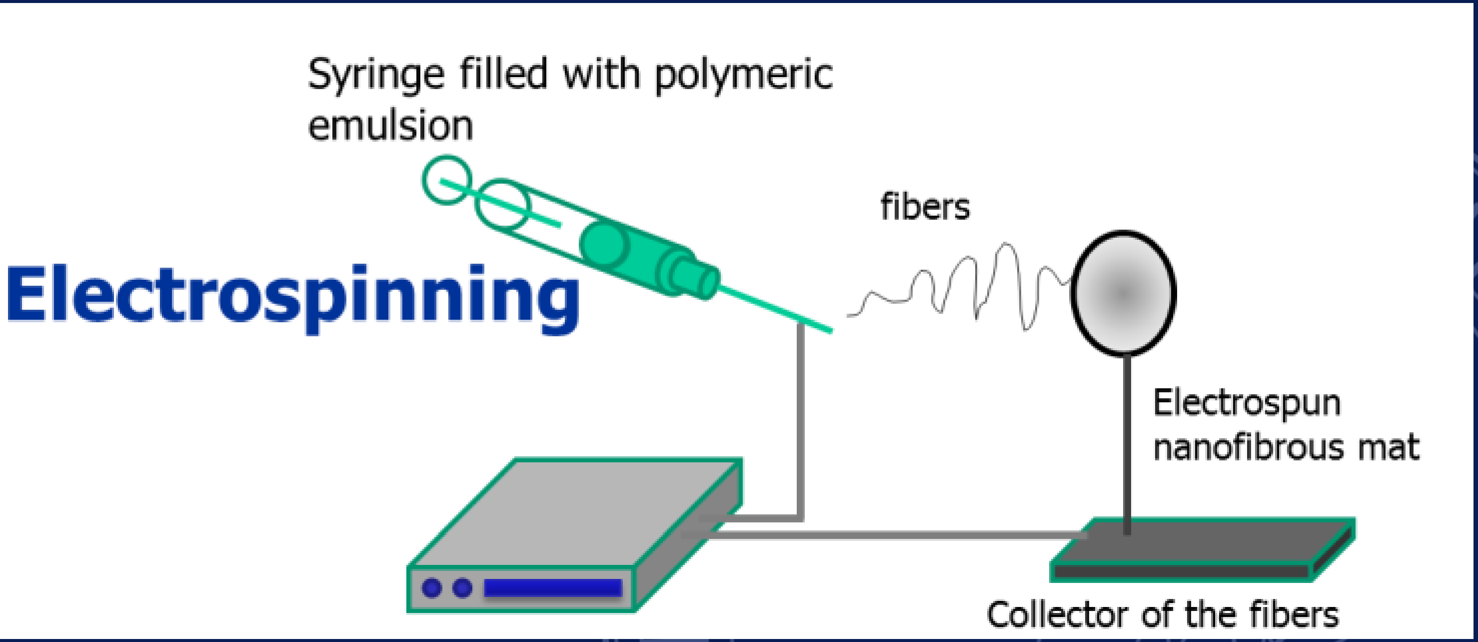


The release is mainly governed by concentration-dependent passive diffusion

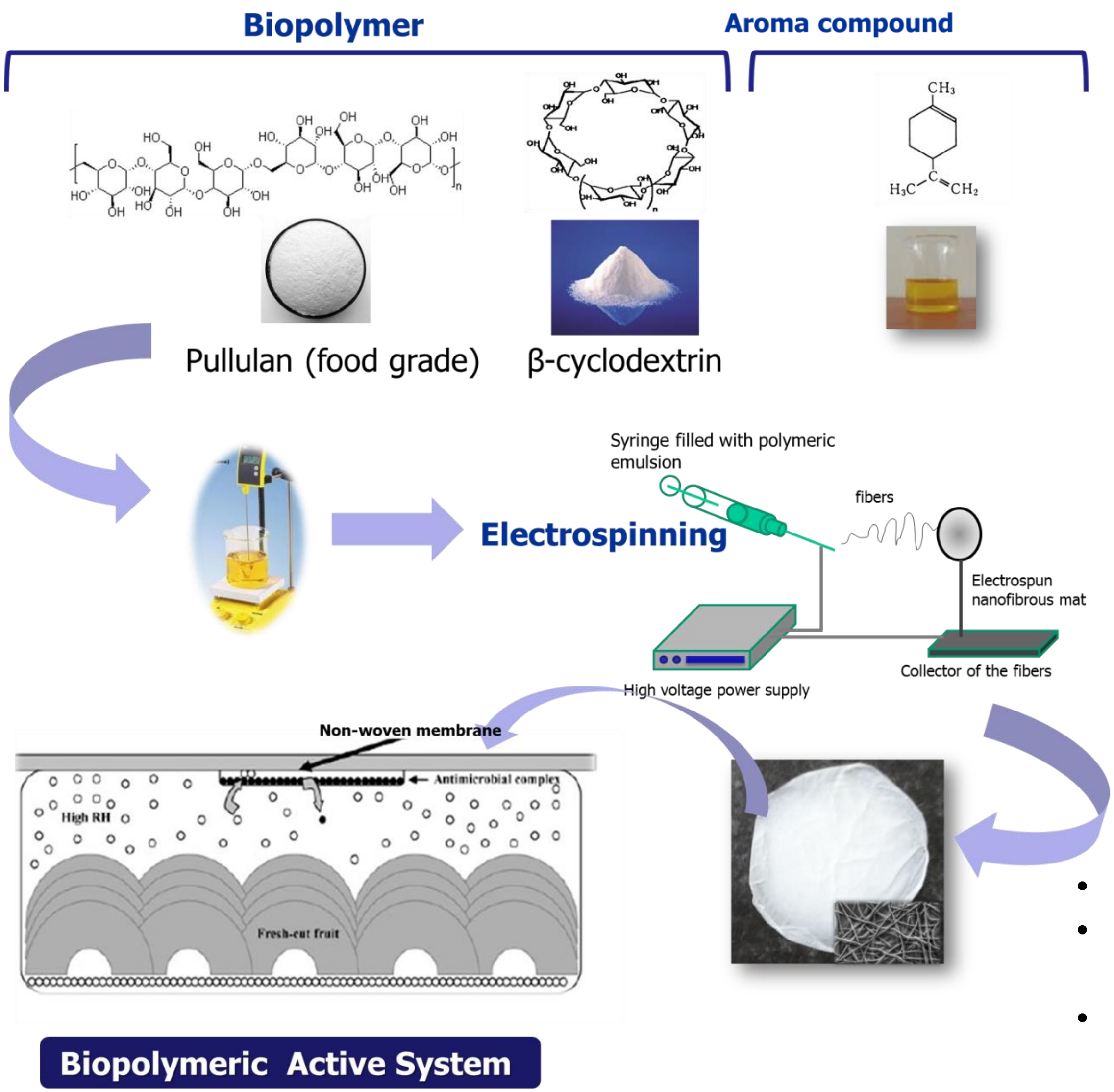
Rationale

To have, in a single step, the formation of both the inclusion complex (ß-cyclodextrine) and the active device (the releasing membrane)

by Electrospinning of Pullulan nanofibers



Procedures

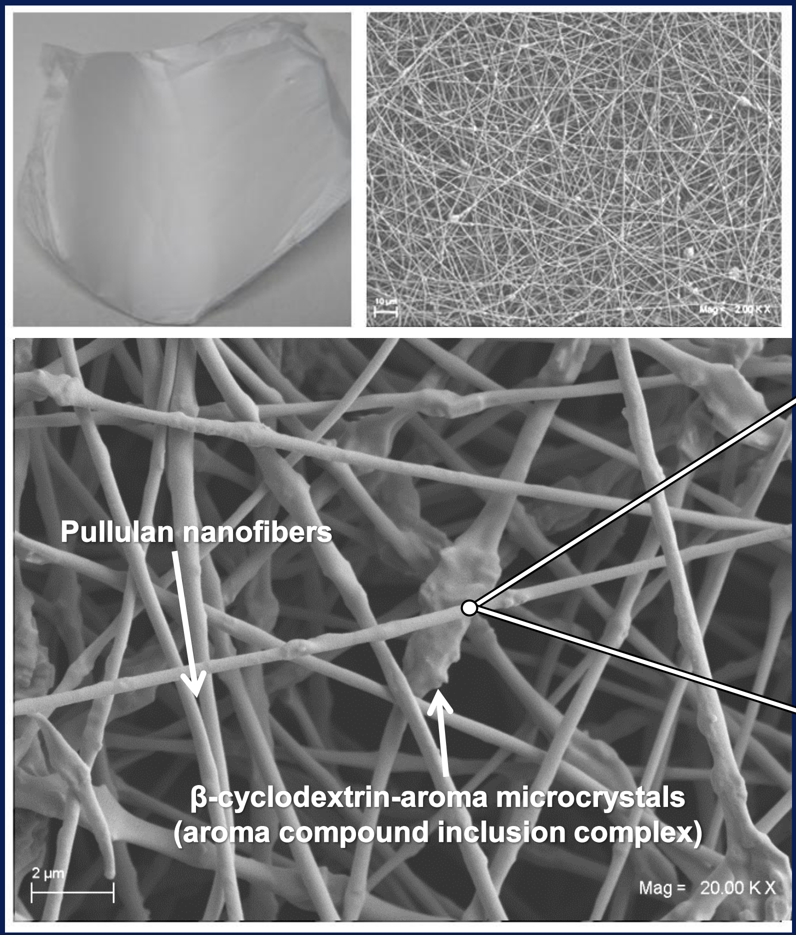


Release under specific conditions

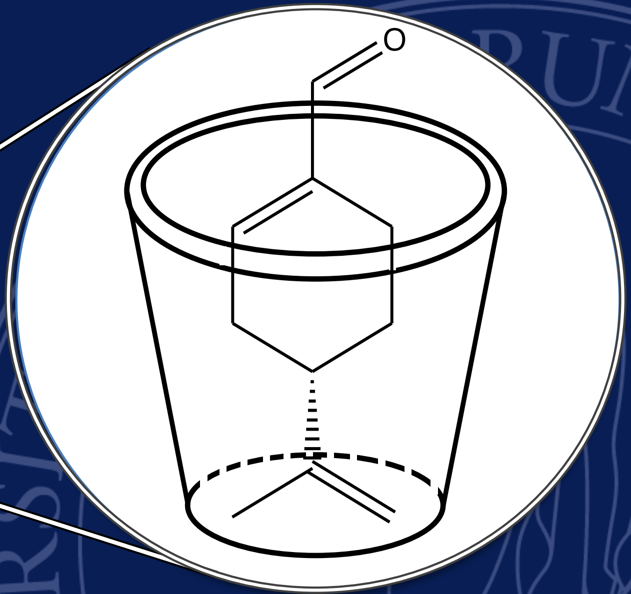
- **Time**
- **Temp.**
- **Relative humidity**

- Morphology
- Aroma retentive capacity
- Thermal properties

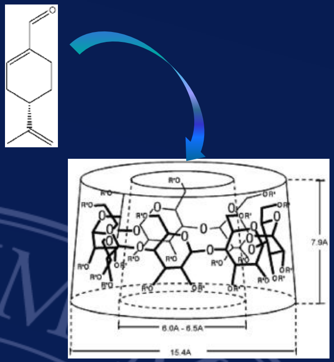
Morphology of the encapsulation membranes

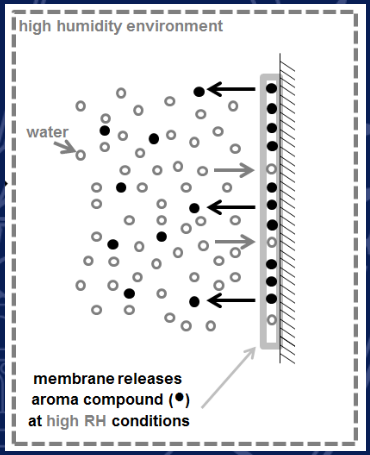


optimal parameters for obtaining pure pullulan nanofibers. 20 wt% pullulan solution, 0.5 mL/h flow rate, 15kV applied voltage and 12 cm tip-to-collector distance.



β-cyclodextrin molecules carrying bioactive aroma (volatile) compound





General Conclusions

Coating technology can be really useful in implementing new and improved properties on flexible packaging materials.

Bio-based materials, derived from renewable sources largely available particularly in underdeveloped countries, can contribute significantly to these achievements

The combination of novel bio-based materials with conventional flexible packaging can be a good way to accelerate the movement towards a sustainable bio-economy,

The PACKLAB

Thanks for your attention !

DEPARTMENT OF
FOOD, ENVIRONMENTAL AND
NUTRITIONAL SCIENCES