Aqueous Dispersions of Poly(lactic acid) Homo- and Copolymers: Toward Sustainable Materials for Diverse Applications

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University of Ferrara

European Advanced Materials Congress
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Polymeric coatings







THE VALUE

Polymeric coatings are ubiquitous. They offer **aesthetics**, **mechanical resistance**, and **protection** (barrier against humidity and corrosion).

THE HIDDEN COST

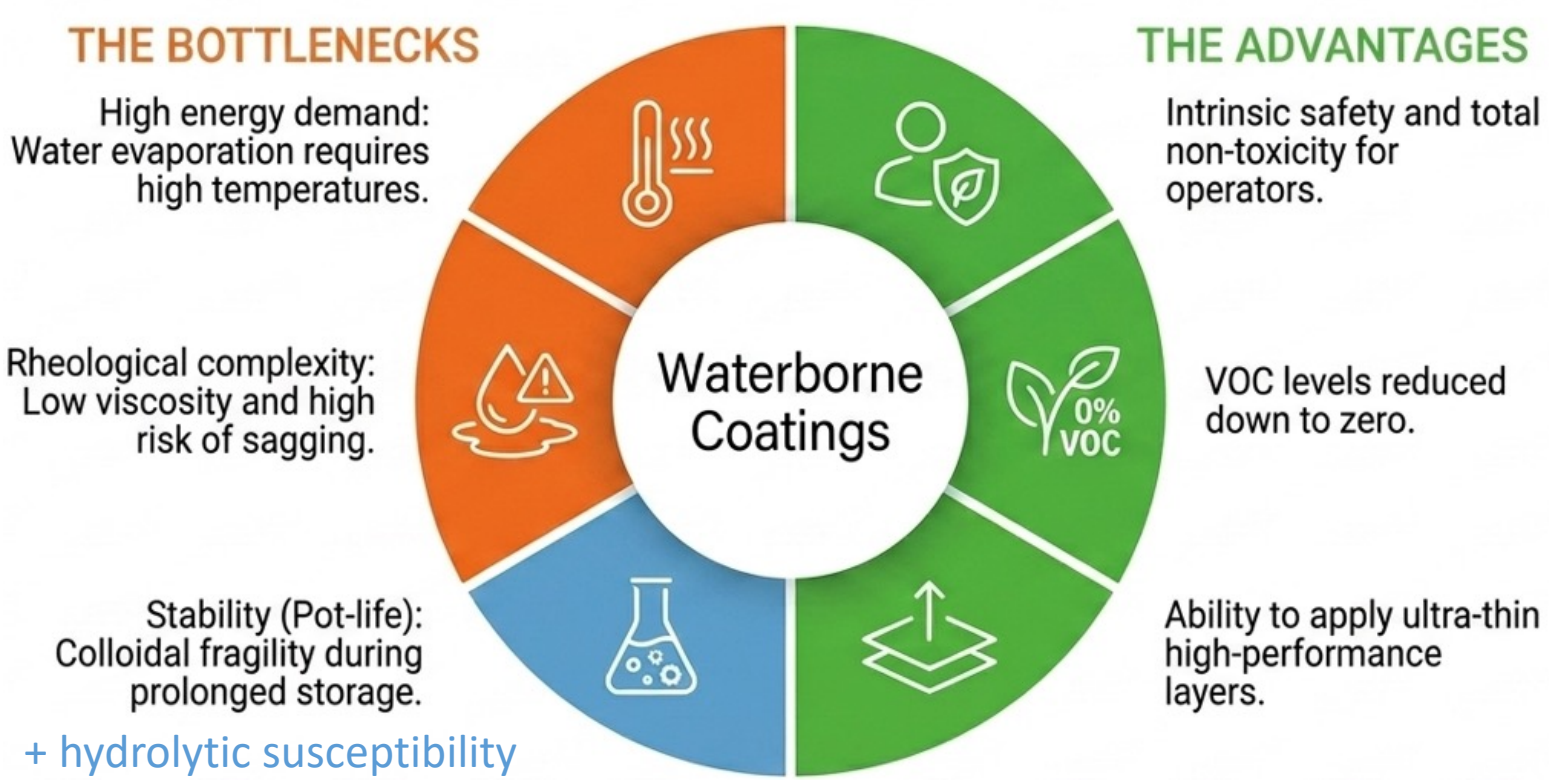
Traditionally, these polymeric coatings require **volatile organic compounds (VOCs)** as a liquid carrier.

Result: high toxic emissions, respiratory health risks, and severe **environmental impact.**



Waterborne coating systems

- **Most polymers, including biopolyesters, are not soluble in water**
- **Water-phase polymerization of monomer to obtain waterborne polymers is not possible for many polymers**



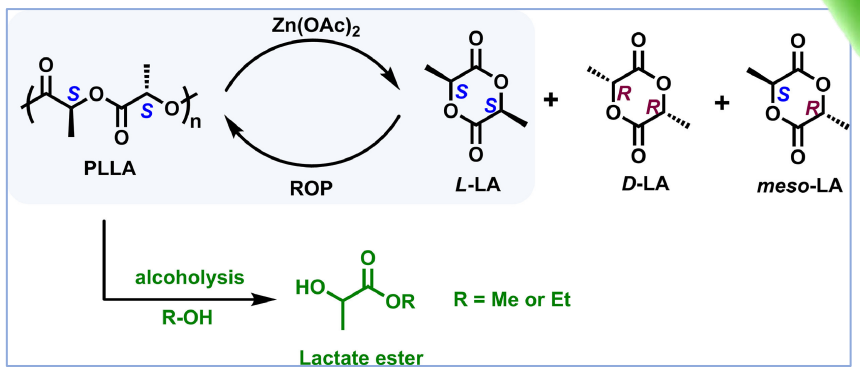
Adapted from RSC Sustainability, 2024, 2, 3704–3729 | 3705

Poly(lactic acid) and biopolyesters

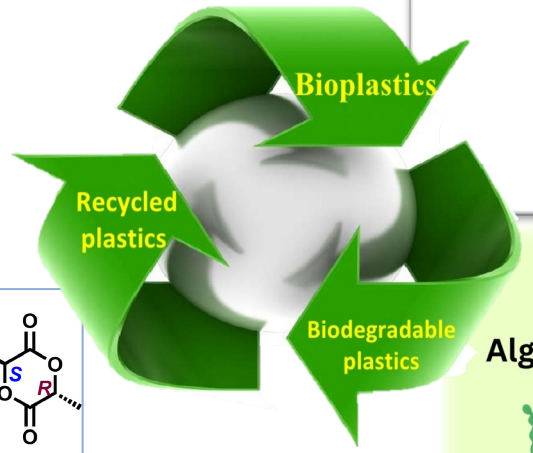


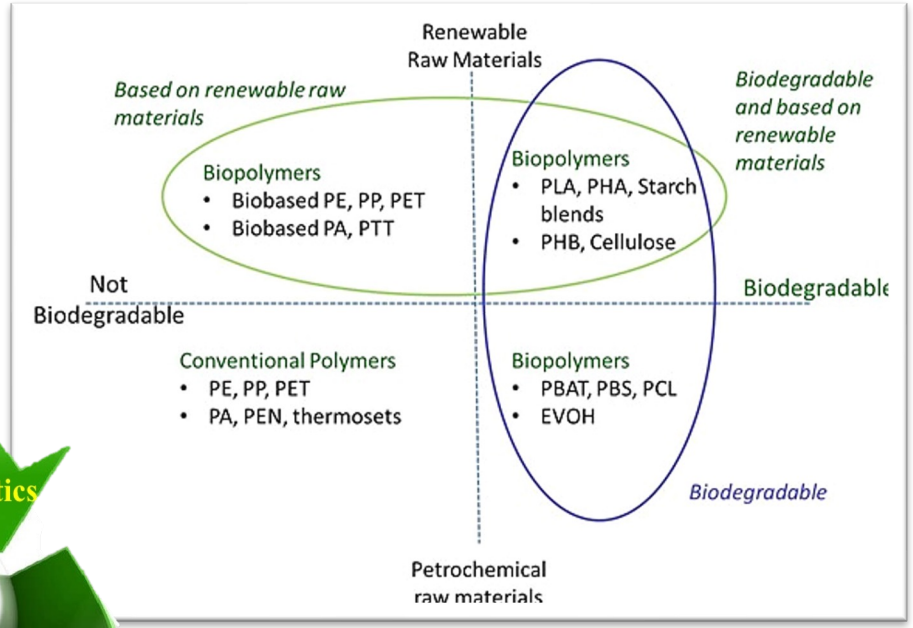
https://wastelessfuture.com

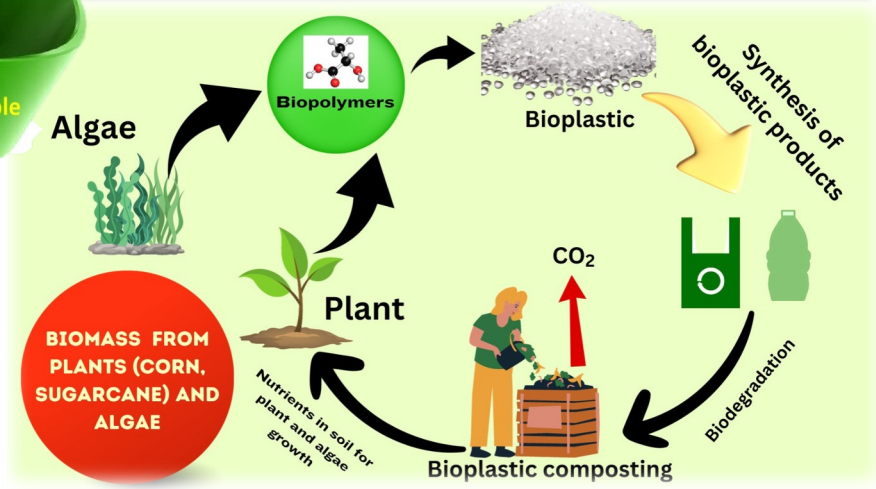
Mechanically and chemically recyclable



S. Wang, J. Li, X. Li et al. Fundamental Research 5 (2025) 935–950



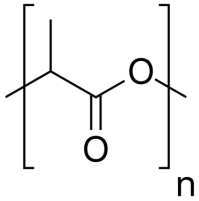




Ali, S.; Isha; Chang, Y.-C. Processes **2023**, 11, 3445.

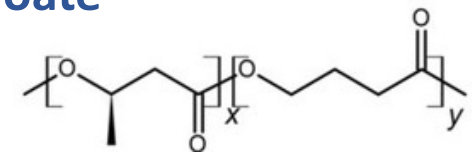
Polymers

Poly(lactic acid) -PLA-



- Produced at **industrial scale**
- Derived from **renewable resources**
- Available in **amorphous and semi-crystalline grades**
- **Industrially compostable** under controlled conditions

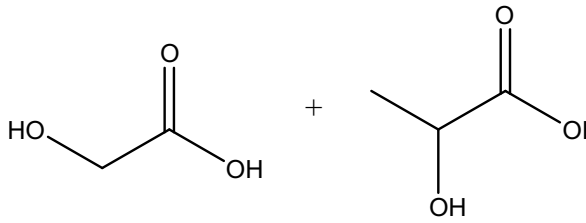
Polyhydroxyalkanoate -PHA-



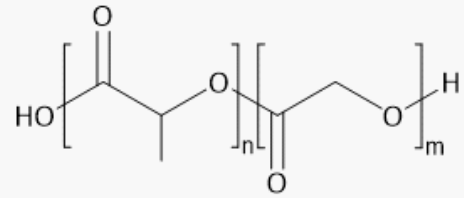
- Produced at industrial scale
- Derived from **renewable feedstocks through microbial fermentation**
- Available in amorphous to highly crystalline grades
- Biodegradable and compostable under many conditions

PLGA

HICCUPS
Co-funded by the European Union
Circular Bio-based Europe Joint Undertaking
Bio-based Industries Consortium



Glycolic acid **from atmospheric CO_2** + Lactic acid



Poly(lactic-co-glycolic) acid (PLGA)

- Experimental polymer
- Derived fully from **renewable resources**
- Crystallinity depends on the co-monomer ratio
- Biodegradable and compostable under many conditions

Tested copolymers:

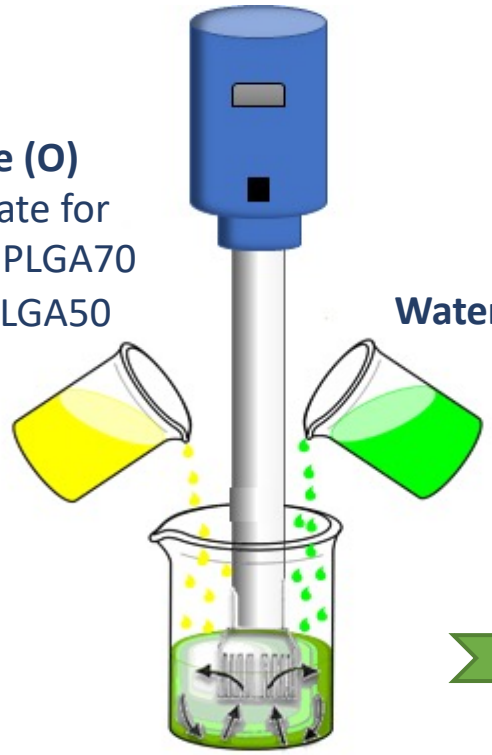
- 50% LA (PLGA50)
- 70% LA (PLGA70)

Preparation of biopolyester dispersions

Organic phase (O)

- Ethyl Acetate for PLA, PHA, PLGA70
- DCM for PLGA50

Water phase (W)



Oil-in-water emulsion

Solvent evaporation /recovery



Dispersion in water

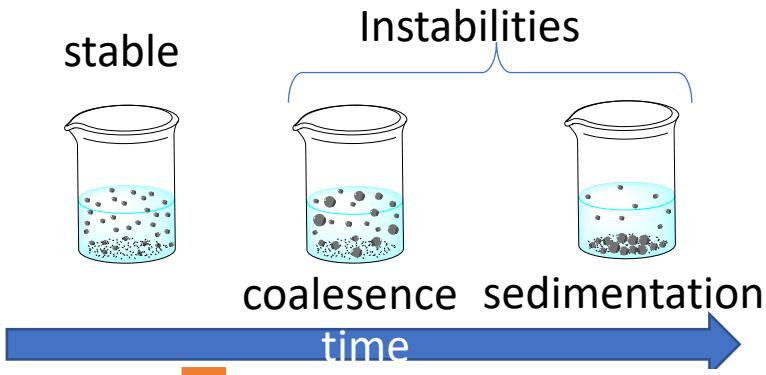
Several parameters must be optimized :

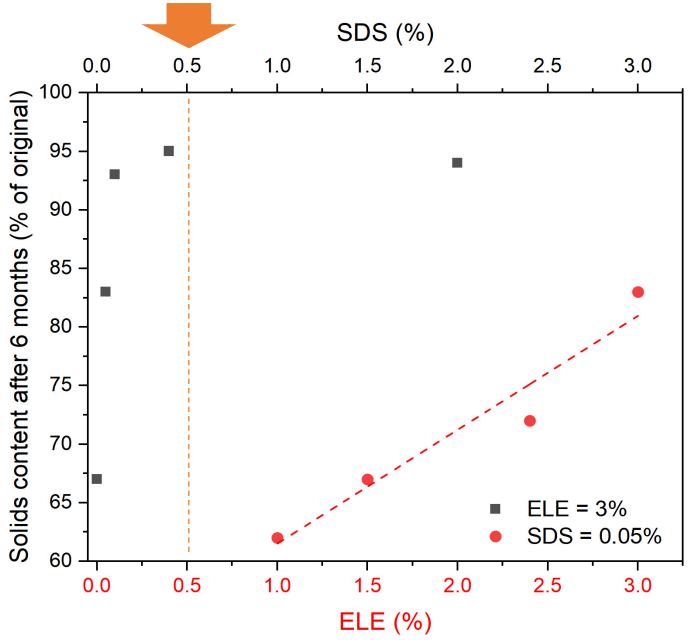
- ✓ Polymer grade
- ✓ Organic solvent
- ✓ Polymer concentration
- ✓ Surfactants and stabilizer
- ✓ Mixing method
- ✓ Dry matter content

Bertoldo, M. et alt. *Polymers* **2021**, *13*(16), 2767

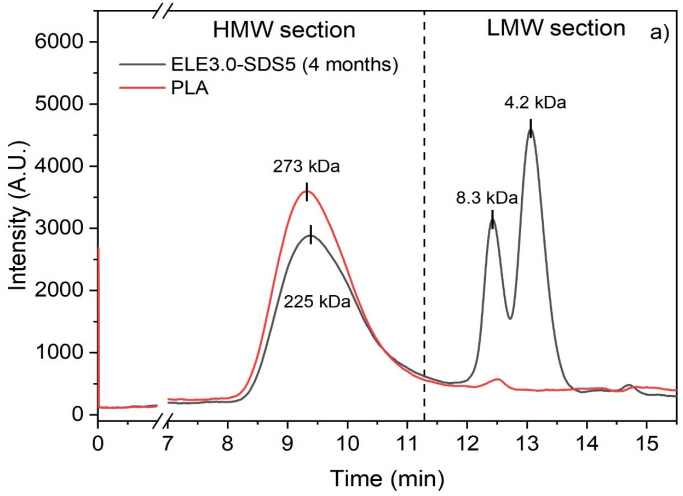
Bertoldo, M. et alt. *Progress in Organic Coatings*, **2024,** 193, 108541

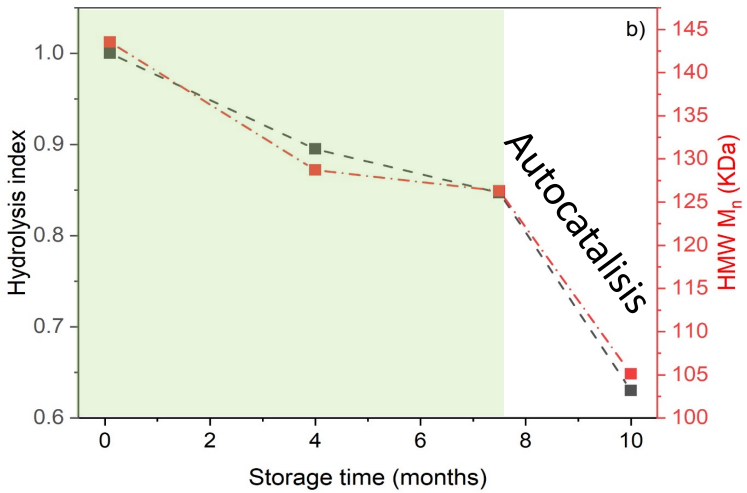
Stability



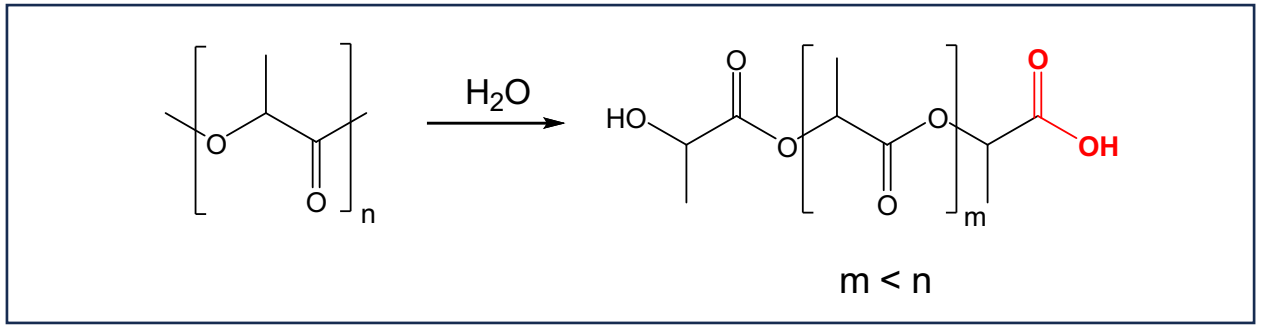


SEC





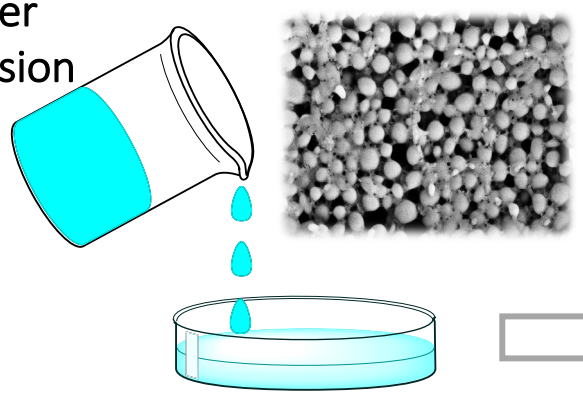
Hydrolysis index: $$HI = \frac{A_{HMW,t}/(A_{HMW,t}+A_{LMW,t})}{A_{HMW,0}/(A_{HMW,0}+A_{LMW,0})}$$

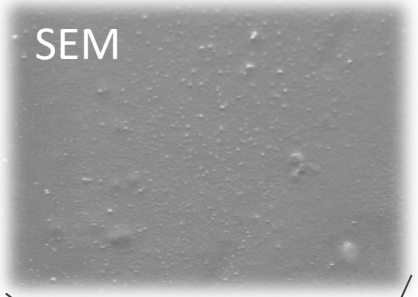


Bertoldo, M. et alt. *Progress in Organic Coatings*, **2024,** 193, 108541

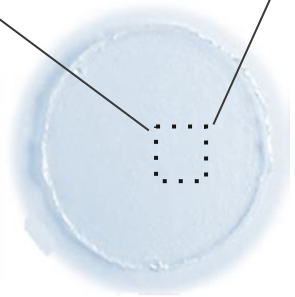
Film formation

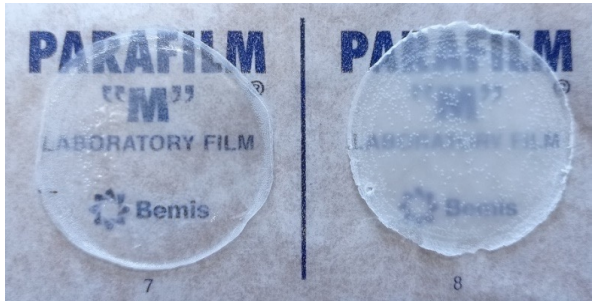
Polymer dispersion





Drying



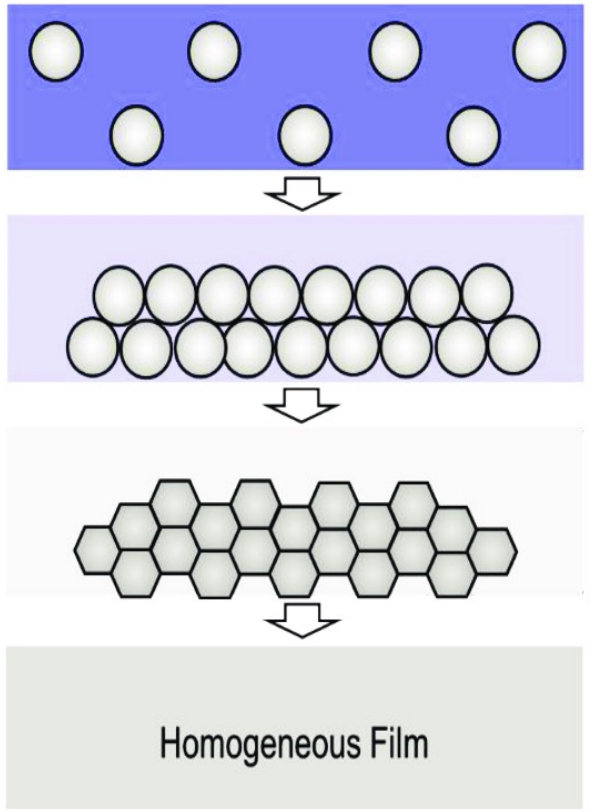


PLA_1 PLA_2

- ✓ **Thickness** between 130-250 µm
- ✓ **UV-VIS Transmission**

  PLA_1 transmittance 4%
  PLA_2 transmittance 55%

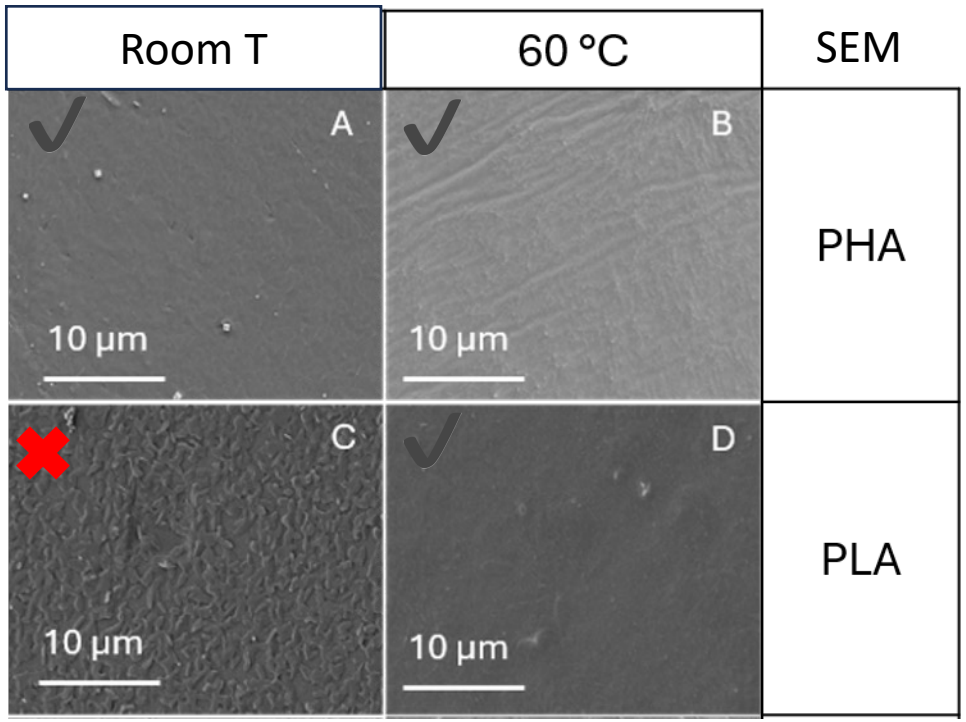
Film formation mechanism



MFFT: minimum film formation temperature

Minimum film formation temperature

Biopolyester	T_g (°C) by DSC
PLA	54
PHA	-19



MFFT depends on the glass transition temperature (T_g)

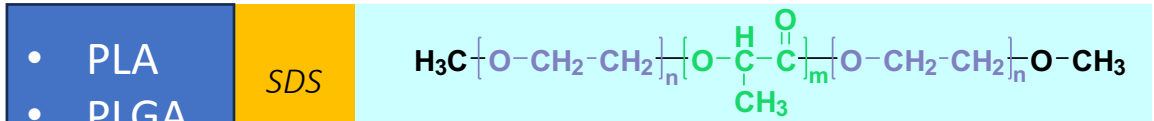
Viscosity depends on solid content

Polymer

- PLA
- PLGA

SDS

Surfactants/stabilisers



ELE

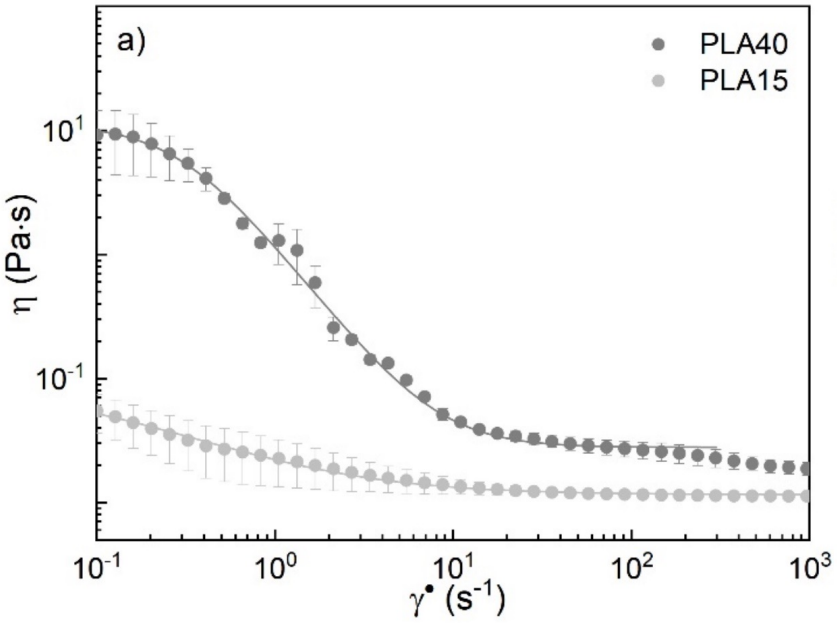


As prepared, solid content ~ 15 %

Water evaporation



solid content ~ **40 %**



Bertoldo, M. et alt. *Progress in Organic Coatings*, **2024,** 193, 108541

Xanthan gum, a natural polysaccharide, as rheological modifier

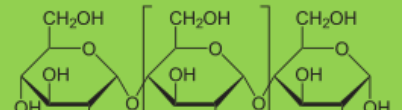
Polymer

Surfactants/stabilisers

PLA

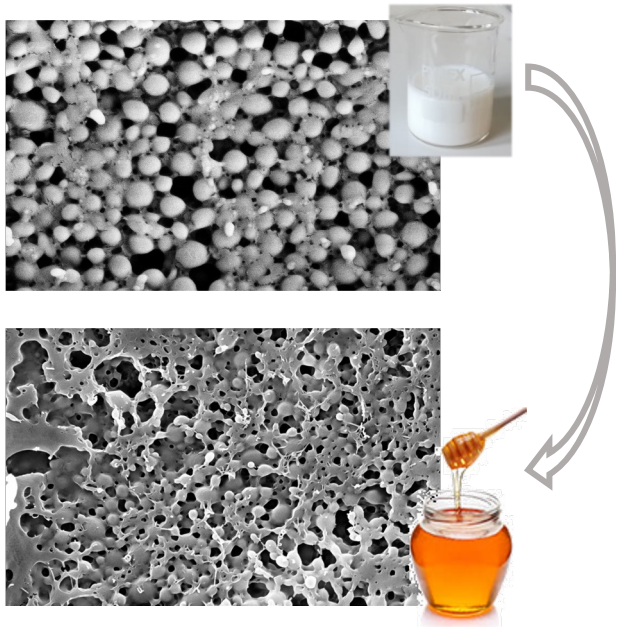


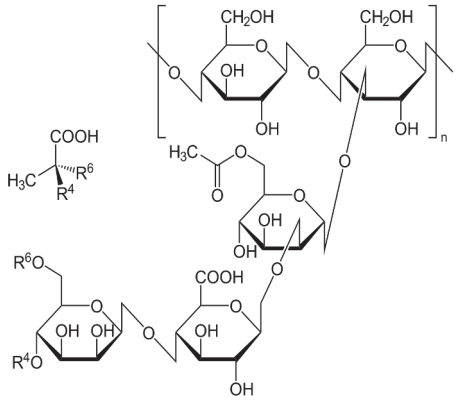
Sodium dodecyl sulfate (SDS)



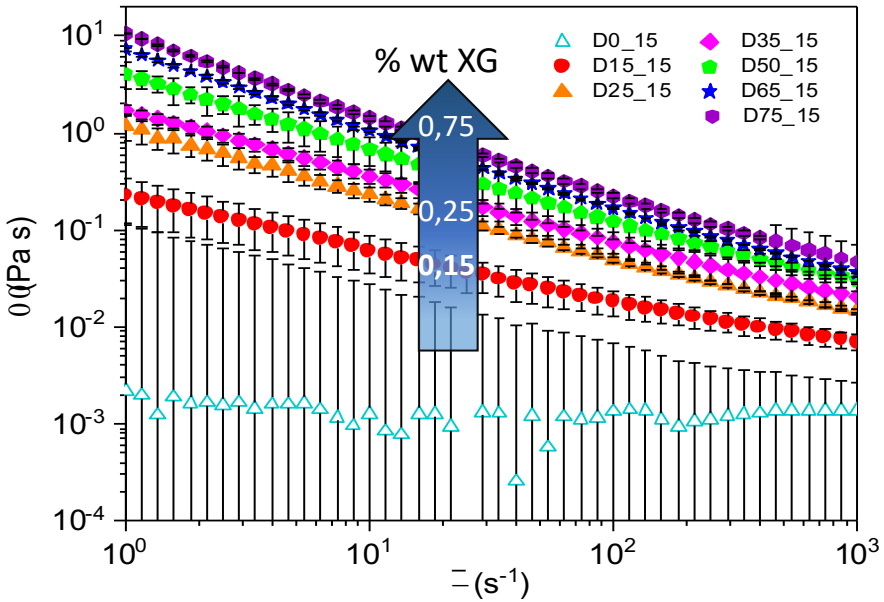
starch

solid content 13-16 %





Xanthan gum (XG)



M. Bertoldo et al, *ACS Omega,* **2022,** 12536-1248.

Coating on paper

Pros and cons of paper packaging

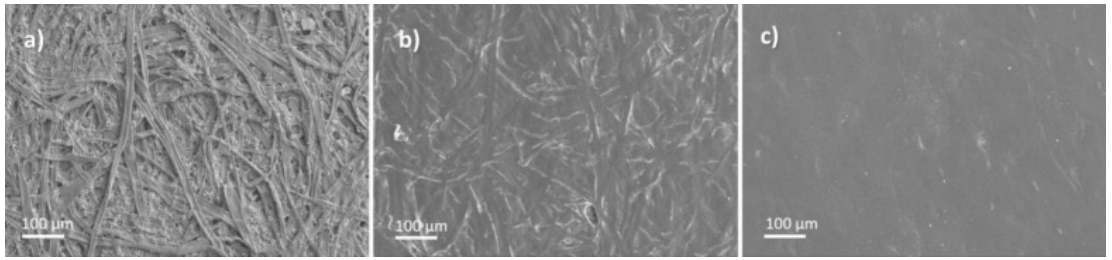


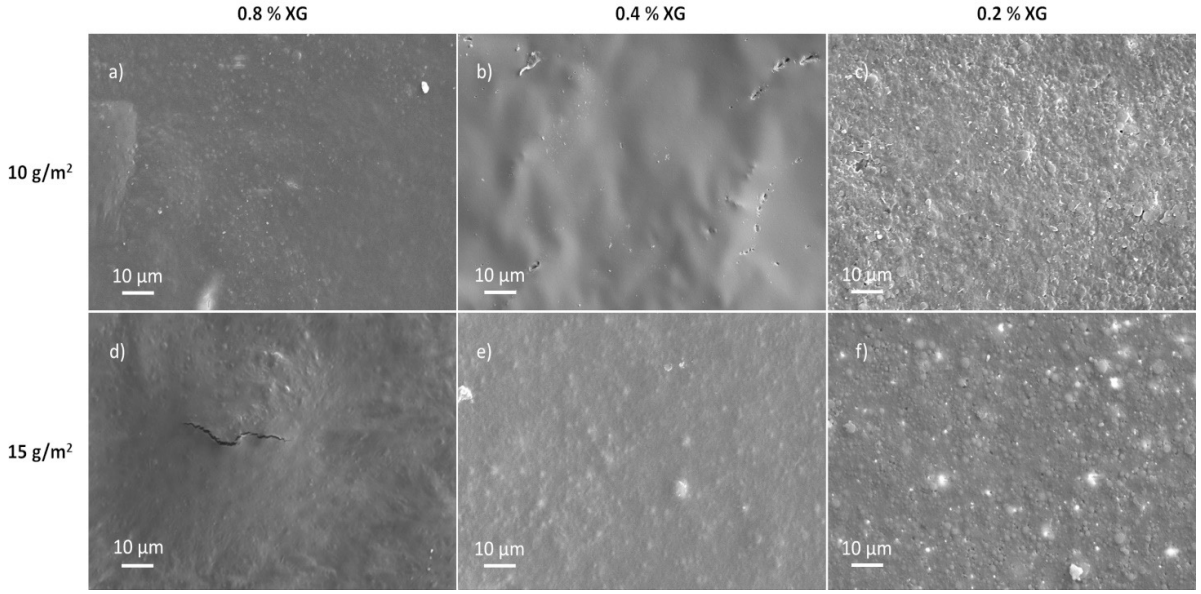
- ☑ Recyclability
- ☑ Compostability

- ? Barrier properties
- ? Water resistance



Uncoated | Single layered | Double layered

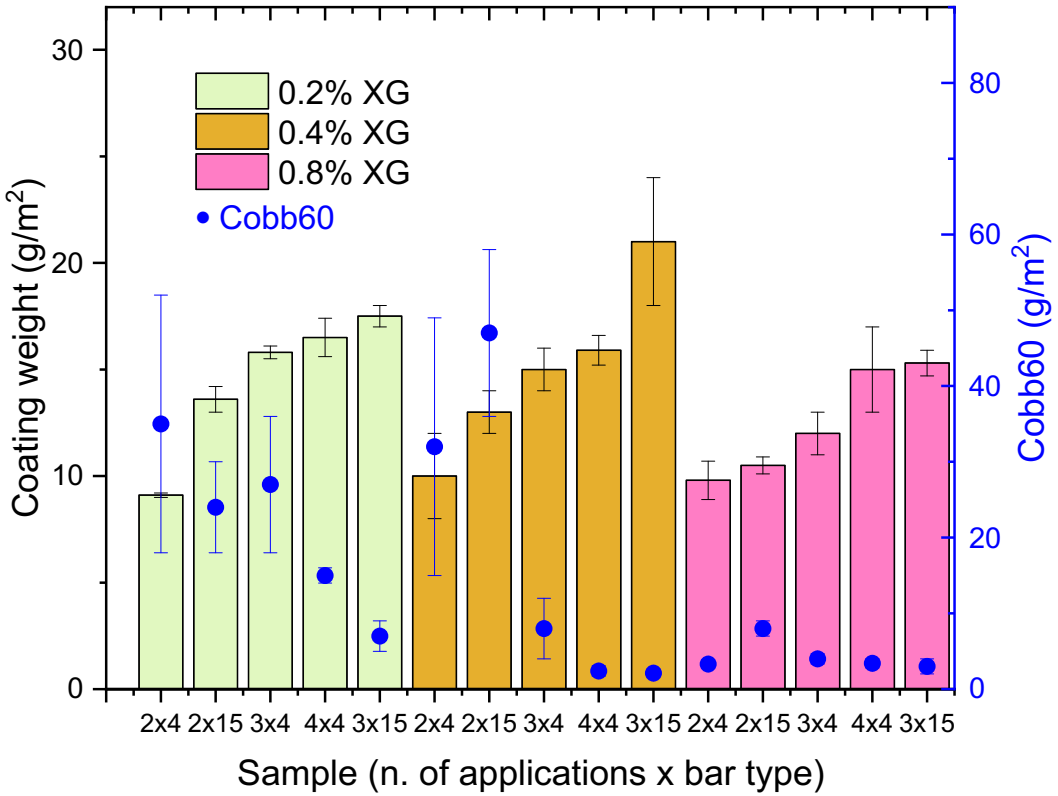




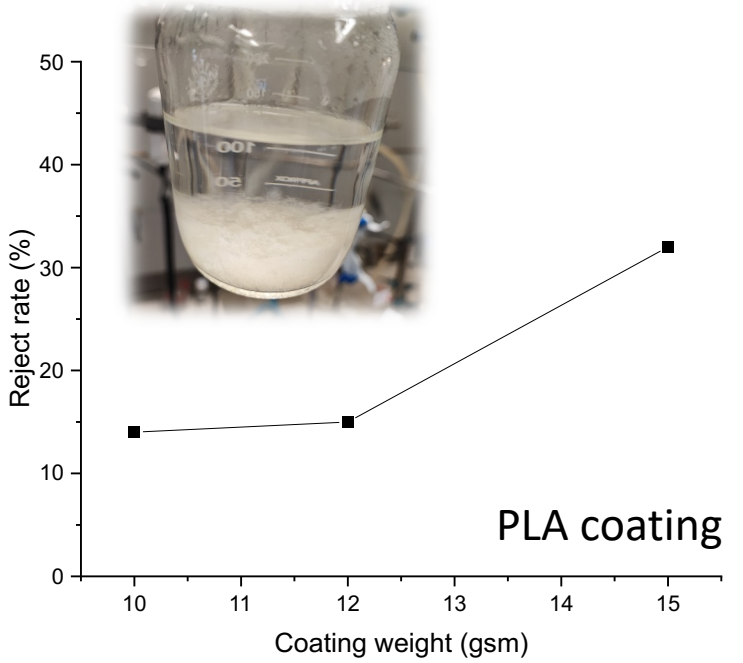
Fiber covering depends on number of depositated layers and viscosity

Bertoldo, M. et alt. *Progress in Organic Coatings*, **2024,** 193, 108541

Control over coating thickness



Recyclability (2h repulping, 50°C)

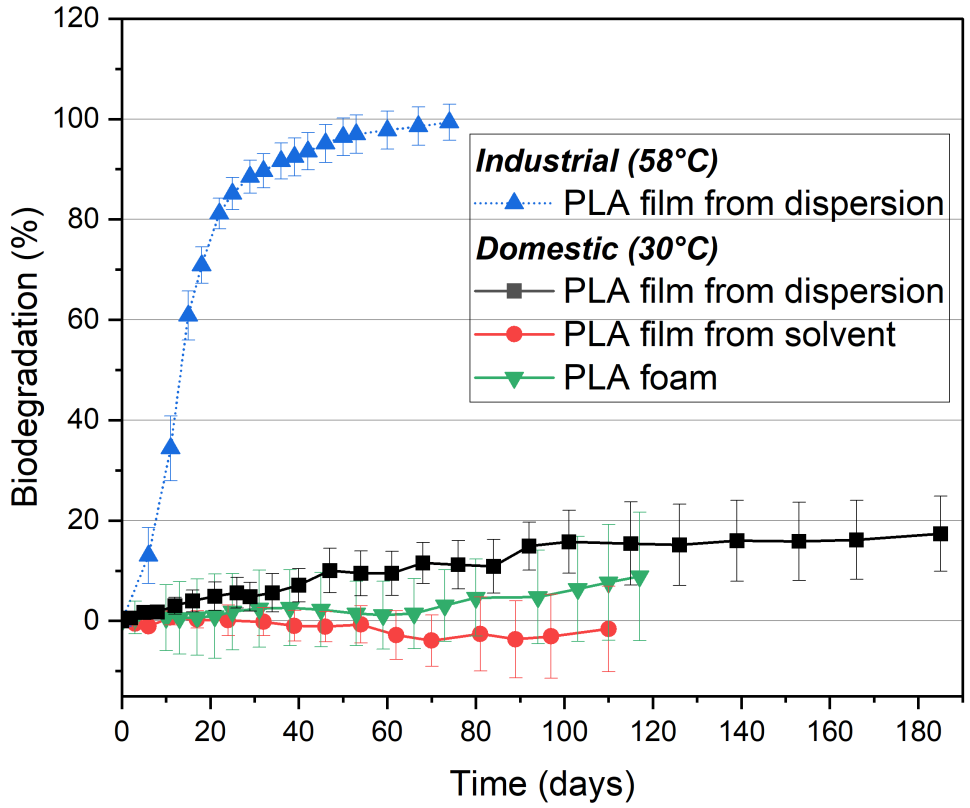


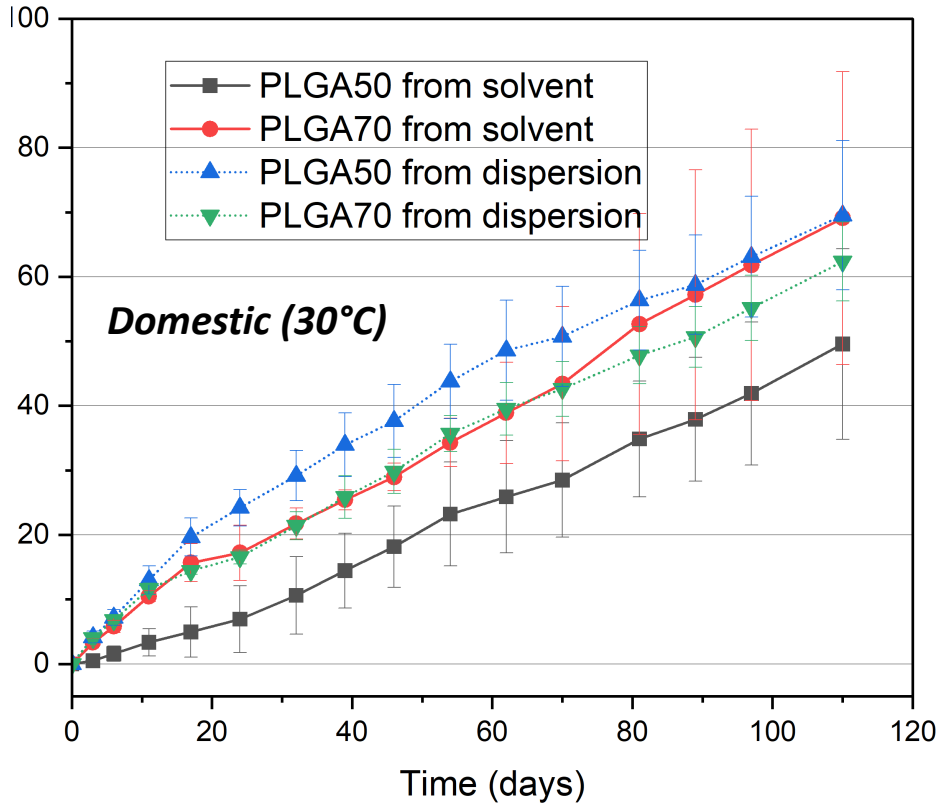
Good repulpability below 15 g/m²

Biodegradation



Respirometric method





Easy preparation of functional coatings



Additive in solution



polymer dispersion
solid content
~ 15 % wt

CASTING
OVEN 60 °C



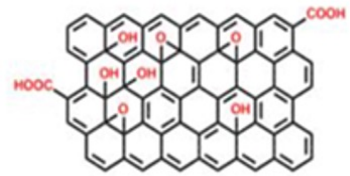
1. Osteogenic and angiogenic peptides
   - BMP-2
   - Preptin
   - VEGF

Calosi M., et al., submitted

J. M. Wozney, *Mol Reprod Dev* **1992**, *32*, 160–167.
M.-C. Ungureanu, et alt.., *Metabolites* **2023**, *13*, 991.
K. D. Hankenson, K. Gagne, M. Shaughnessy, *Adv Drug Deliv Rev* **2015**, *94*, 3–12.

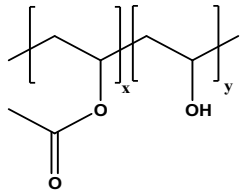
2. **GRAPHENE OXIDE**

GO



Scidà, A. et al., *Advanced* Materials (2026): e74487

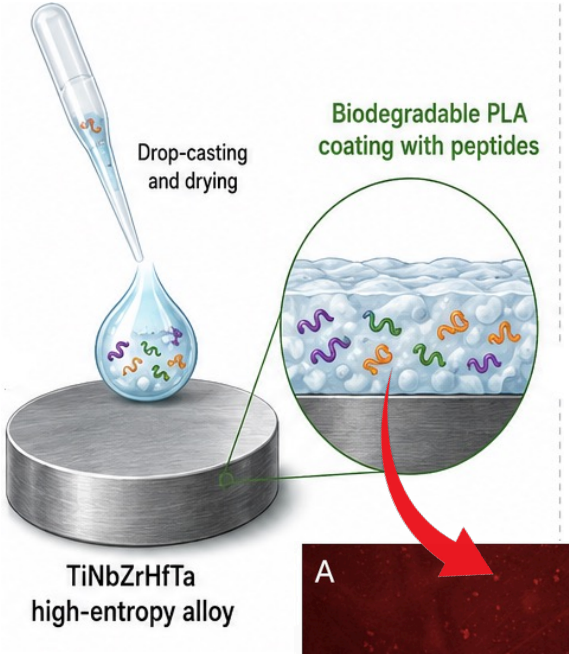
3. **Water soluble polymer**

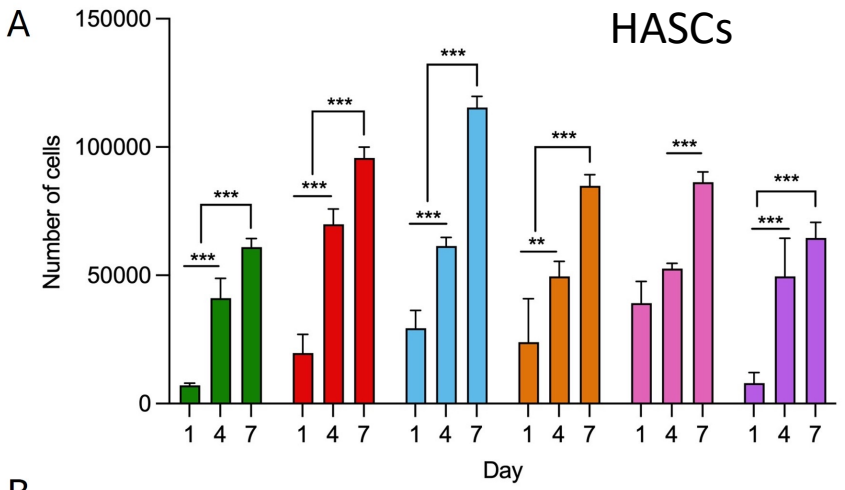


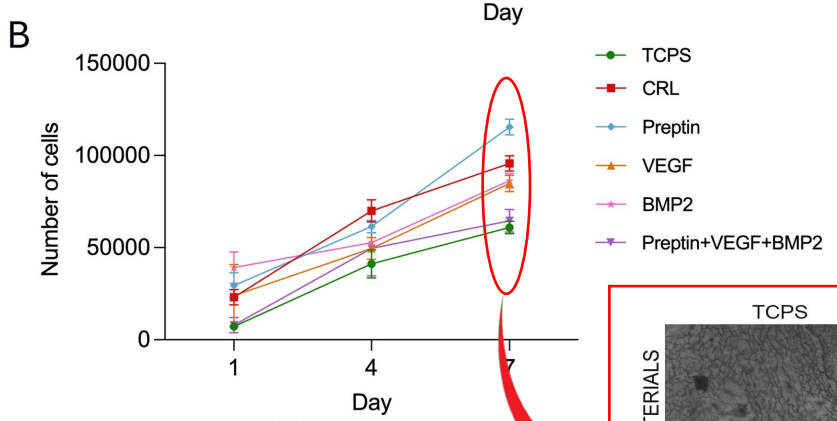
Poly(vinyl alcohol) **(PVA)**

Bertoldo, M. et al. *Macromol. Mat. Eng.* 309 (1), art. no. 2300237, 2024

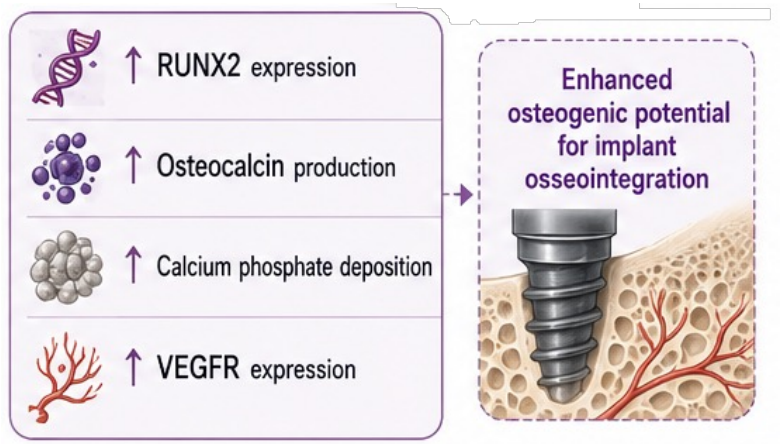
Bioactive Peptides as additives

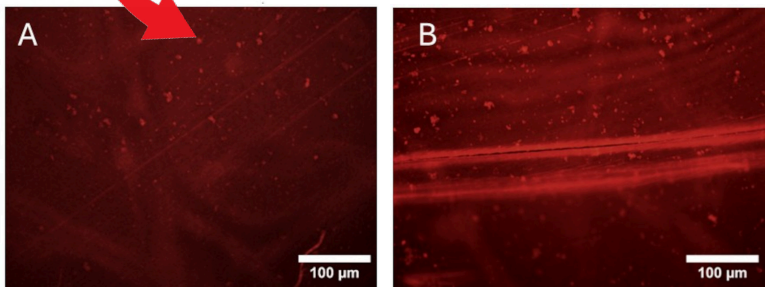


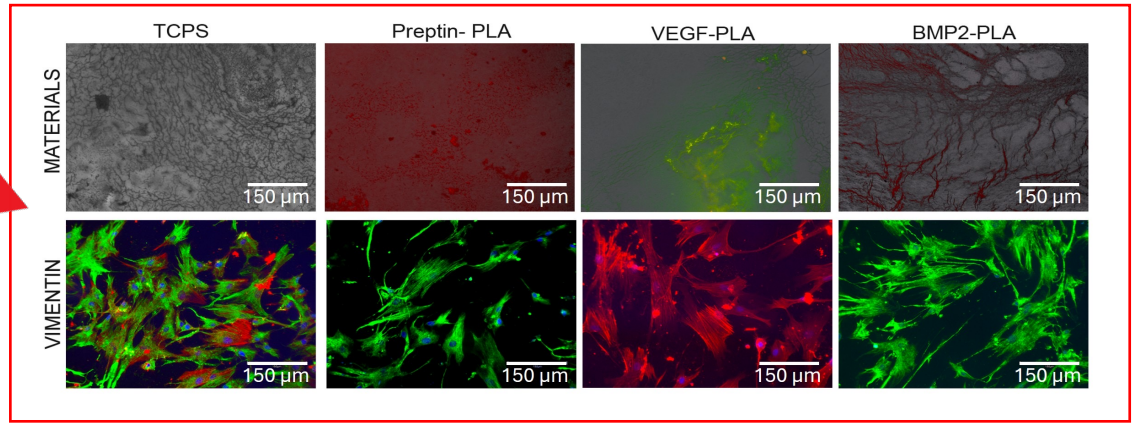




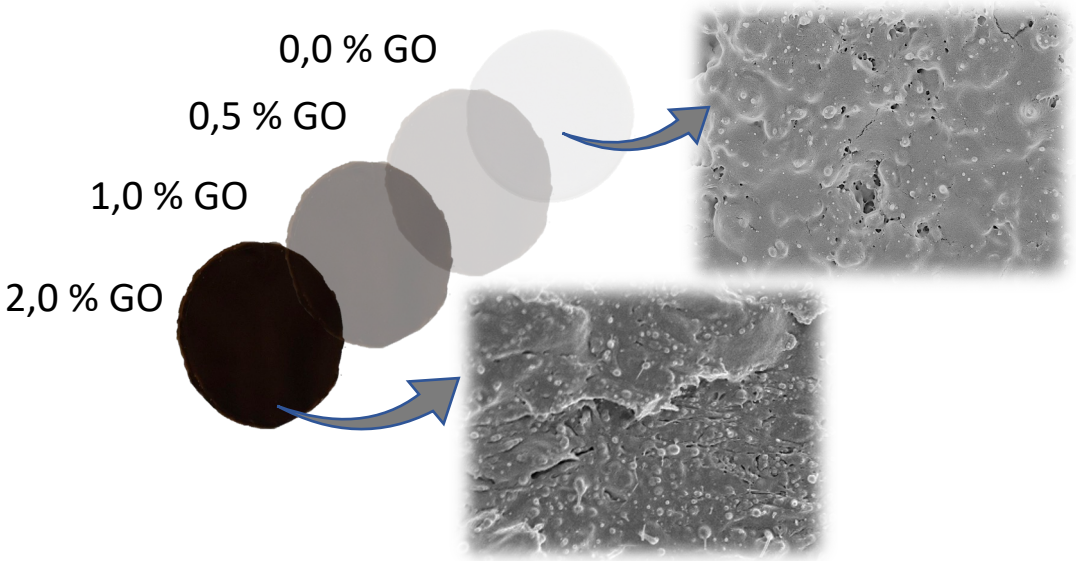
Bertoldo, M. et alt., submitted



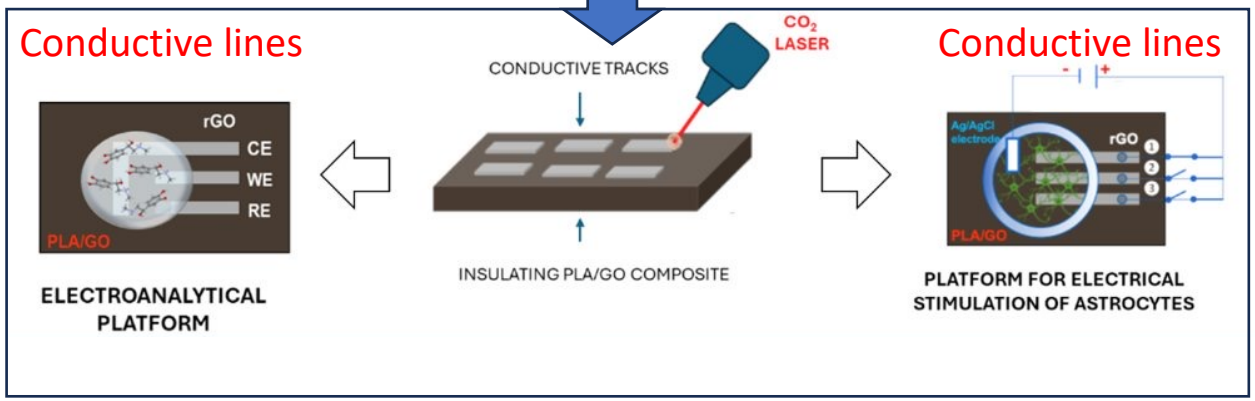




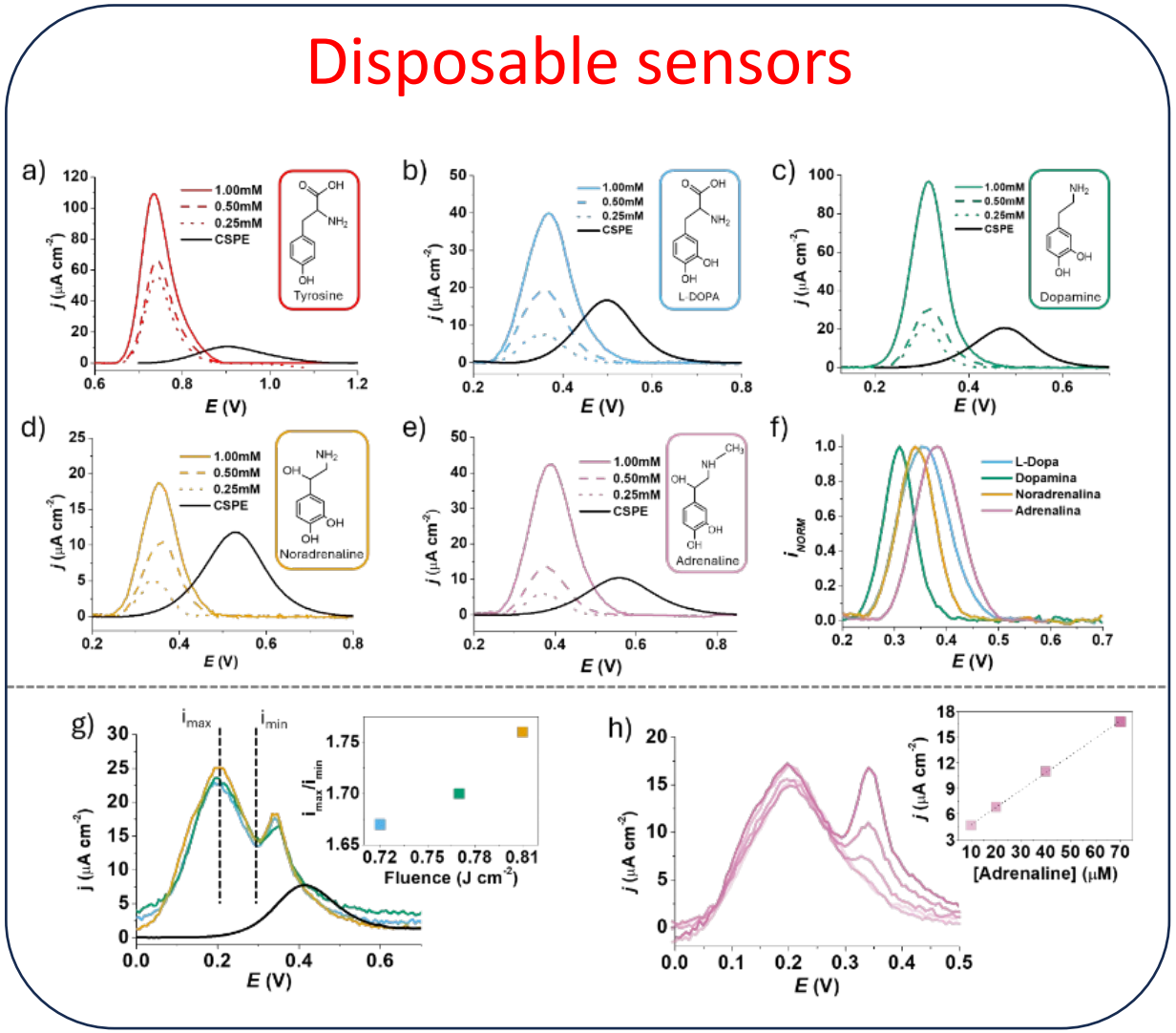
GO as additive



Laser ablation



Disposable sensors



Scidà, A. et al., *Advanced* Materials (2026): e74487

Conclusion



Stable water dispersion of biopolyesters

- Different biopolyesters can be used to formulate stable dispersions.
- These dispersions can be applied as thin coating layers and dried at an appropriate temperature.
- The viscosity can be tailored by increasing the dry matter content and/or by adding natural polymers as rheological modifiers.
- The resulting coatings can be used to:
  - Impart water-barrier properties to paper.
  - Produce coating films for biomedical applications
  - Fabricate disposable sensors in combination with GO.
  - Prepare blends with water-soluble polymers.

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NatureWorks

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HICCUPS

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Circular Bio-based Europe Joint Undertaking

sherpack

Bio-based Industries Consortium

Thank you for your attention

Università
degli Studi
di Ferrara