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10th APS International PharmSci Conference

Greenwich 2019

11 – 13 September 2019

11/09/2019

Lignin-PLA Composites for Additive Manufacturing Applications: A Potential Material for Healthcare Applications

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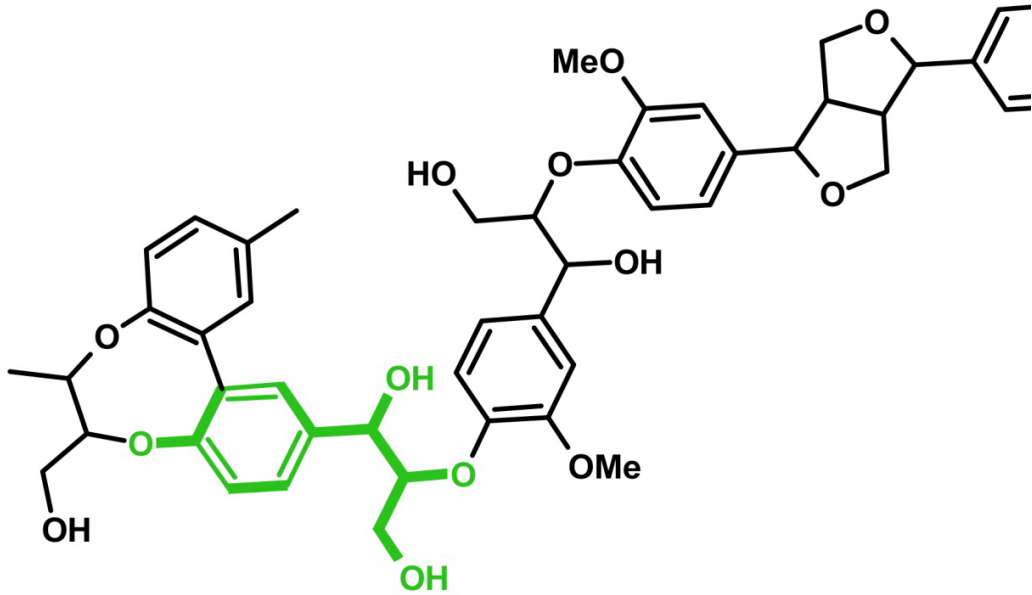
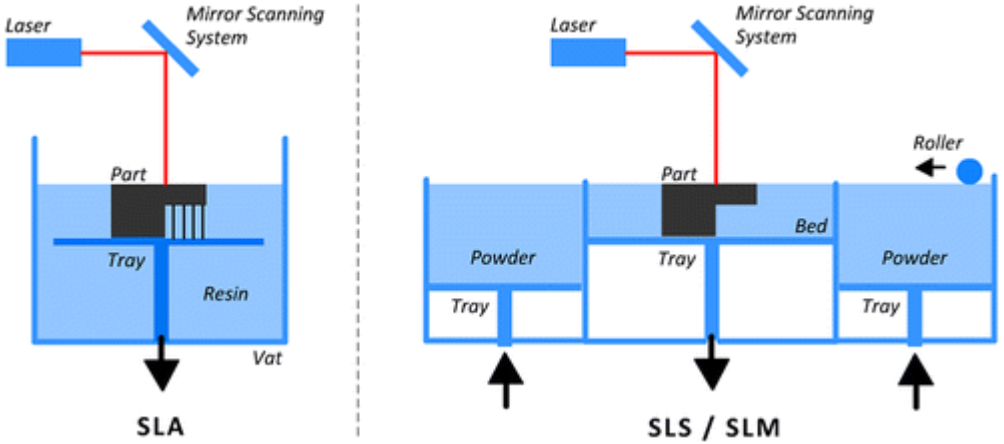
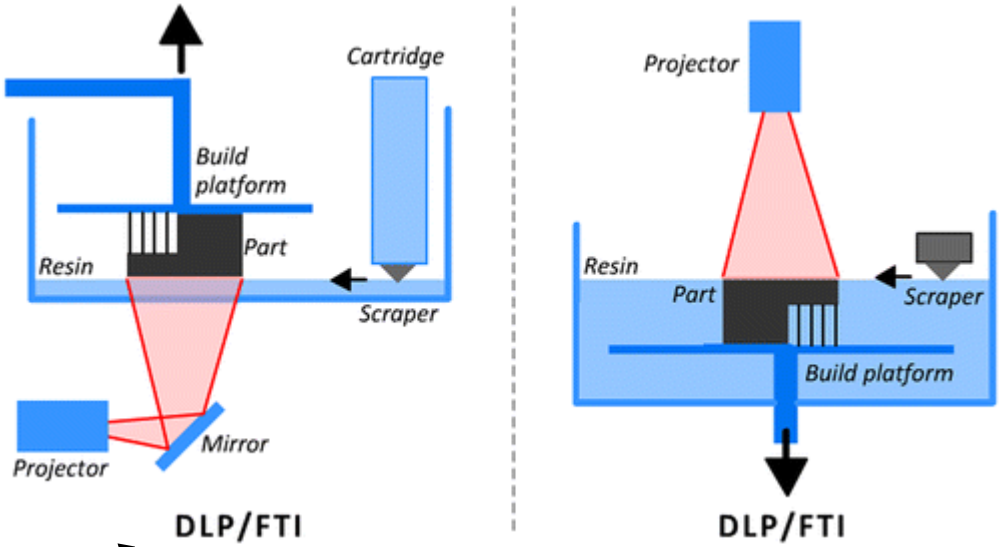


Additive Manufacturing (AM)

Laser technologies

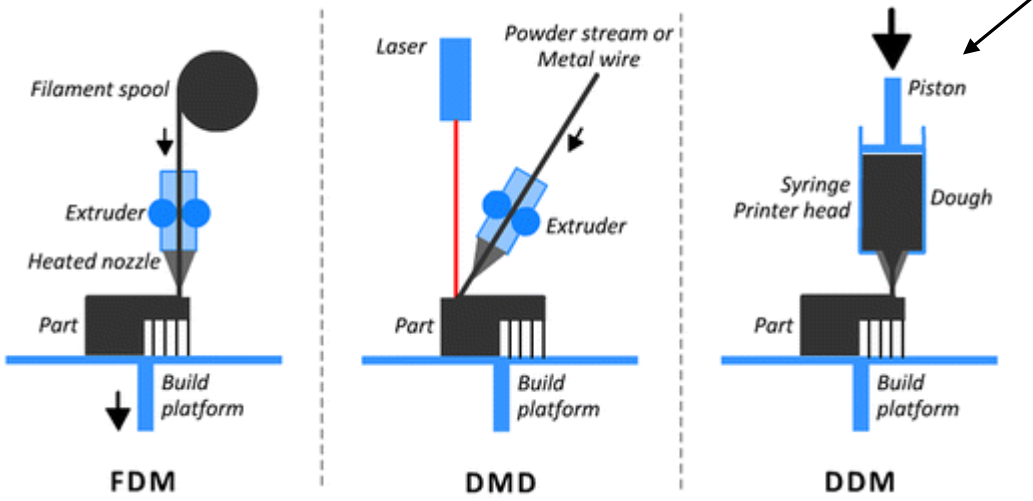


Flash technologies

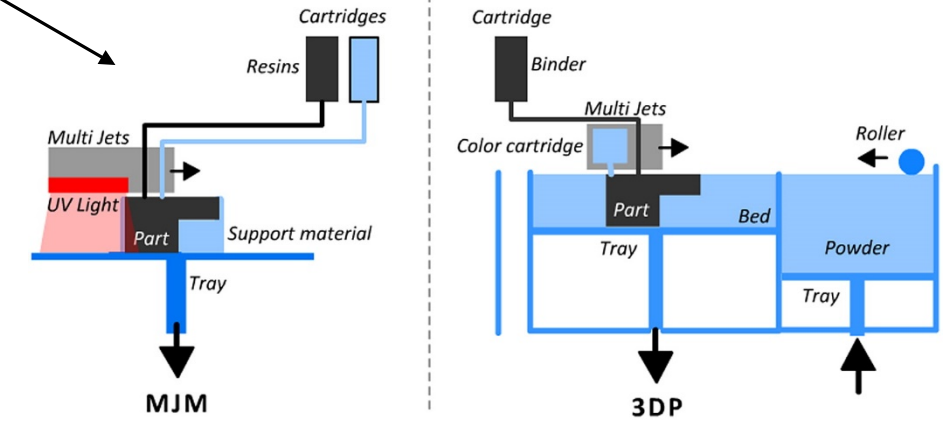


Main AM Technologies

Extrusion technologies



Jet technologies



Gardan. Internaional Journal of Production Research 2016, 54(10), 3118-3132.

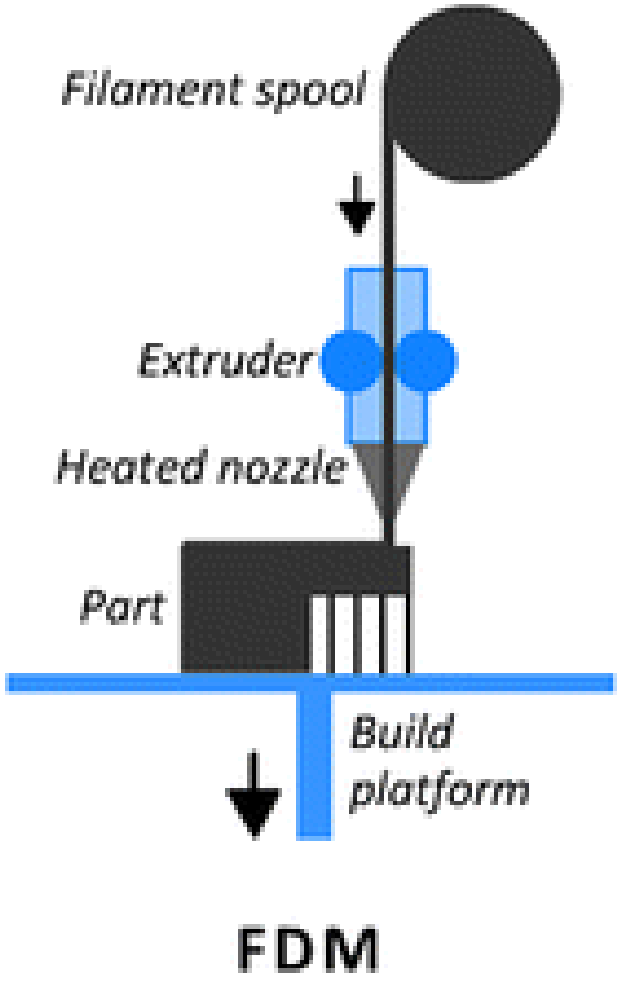
FDM: Fused Deposition Modeling

- ✓ Layer-by-layer appearance
- ✓ Poor surface quality
- ✓ Limited number of materials

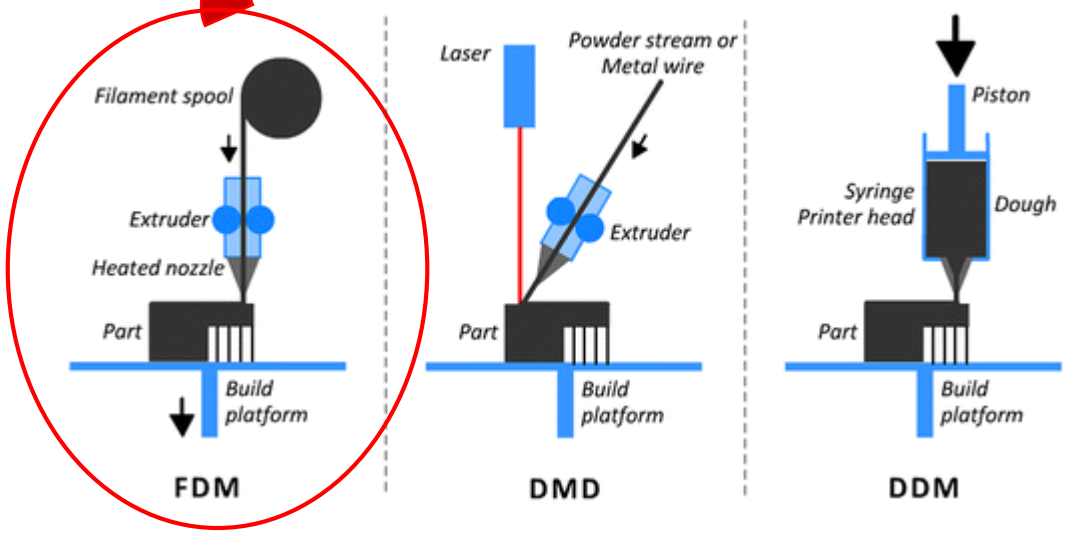
☹

- ✓ Low cost
- ✓ High speed
- ✓ Simplicity of the process

☺



Extrusion technologies



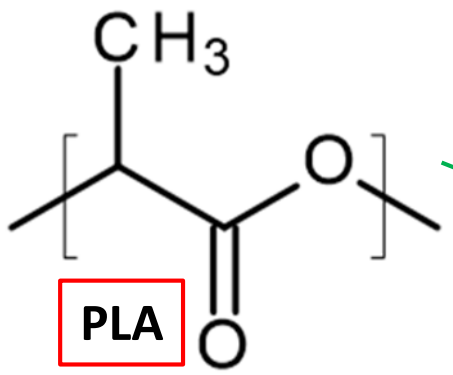
Gardan. Internaional Journal of Production Research 2016, 54(10), 3118-3132.

Poly(lactic acid) (PLA): the most common material used for **FDM technology**

Renewable

Good processability for extrusion applications

Biodegradable



High mechanical strength

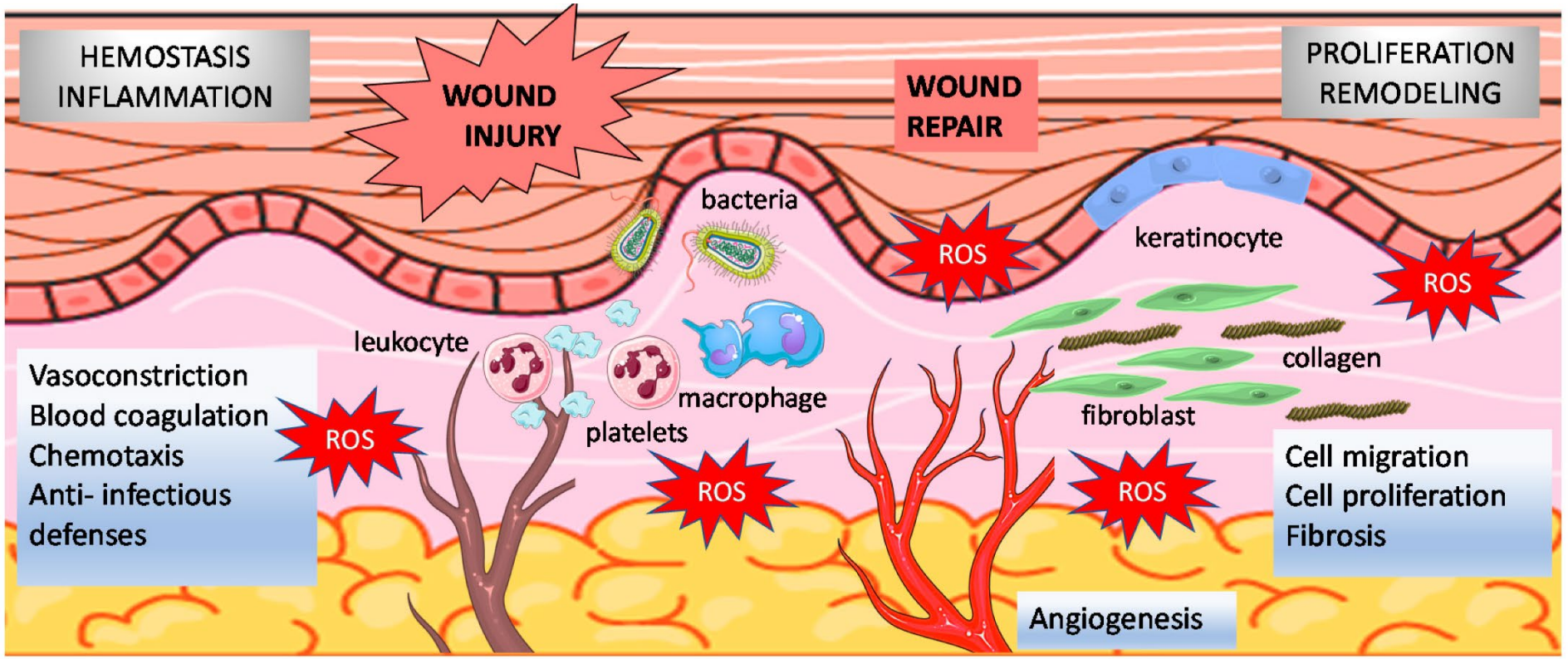
Biocompatible

Low coefficient of thermal expansion

Pharmaceutical and biomedical applications

+ Antioxidant properties

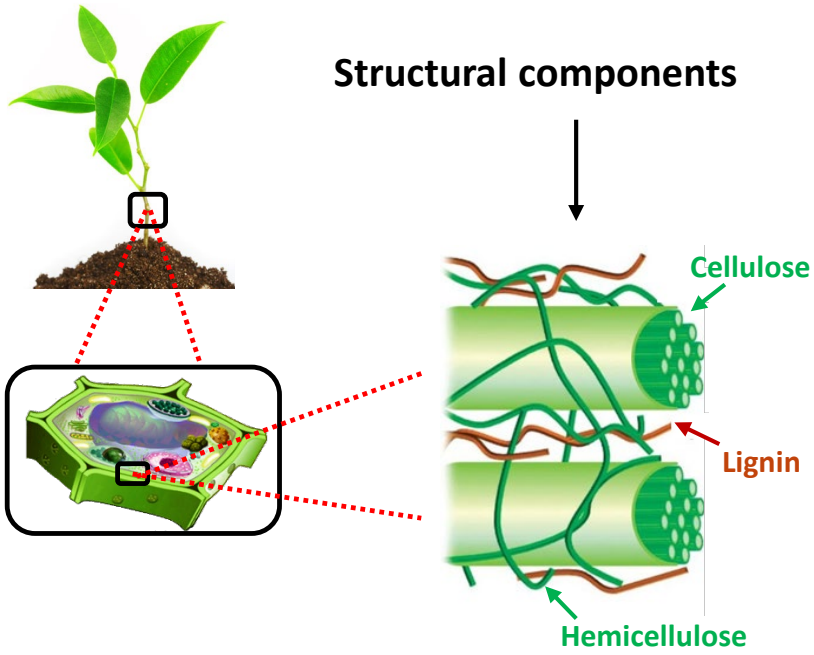
The importance of antioxidants properties



Cano Sanchez *et al*. Antioxidants 2018, 7(8), 98.

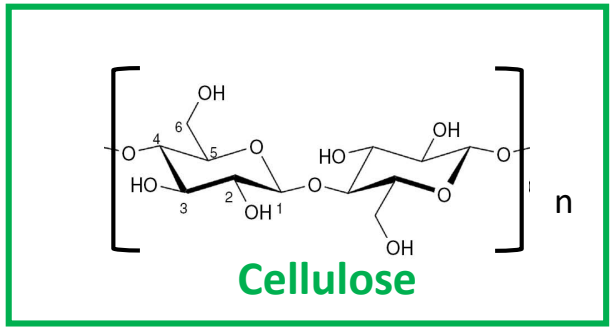
- Free radicals and ROS → Rheumatoid arthritis, atherosclerosis, cancer.
- Antioxidant materials → Reduce these compounds (free radicals and ROS).
- Excess of ROS prevents wound healing.
- **Antioxidants → A way to control oxidative stress in wounds to accelerate their healing**

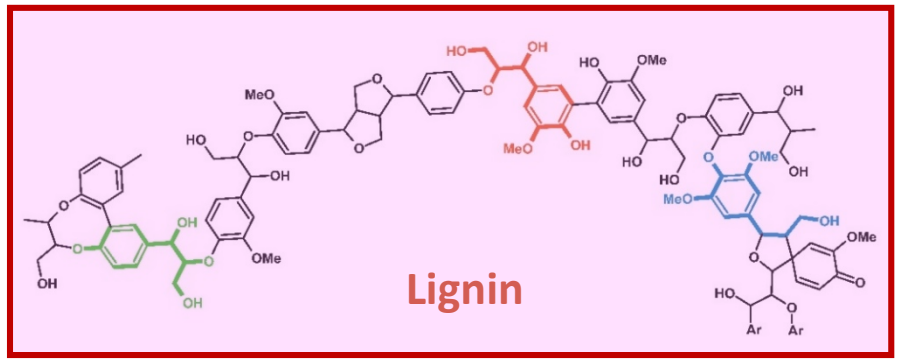
Lignocellulosic biomass components



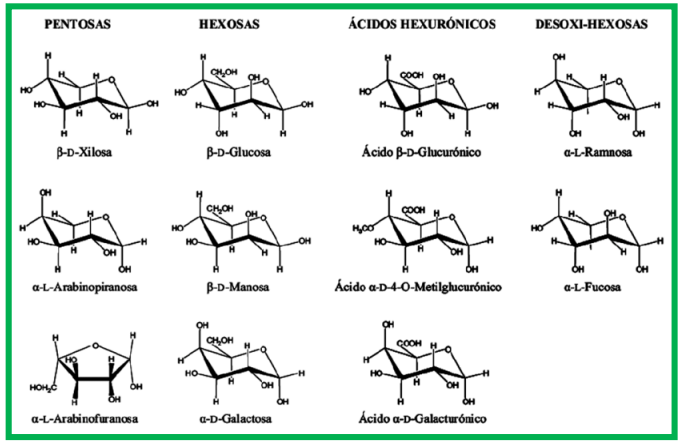
Minority components

- Ashes
- Pectin
- Extractables
- Proteins





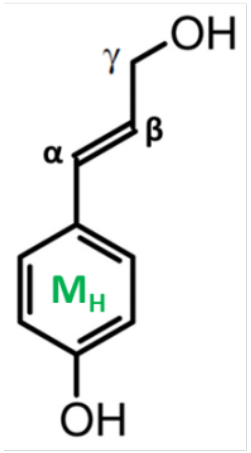
An interesting renewable and natural compound with antioxidant and antimicrobial properties is lignin



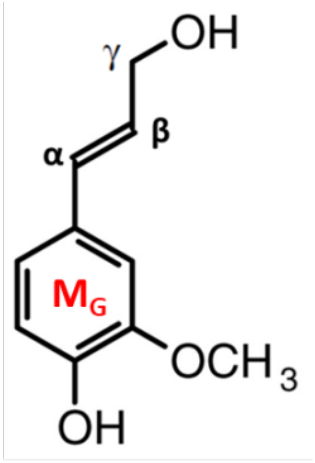
Hemicellulose

Lignin structure

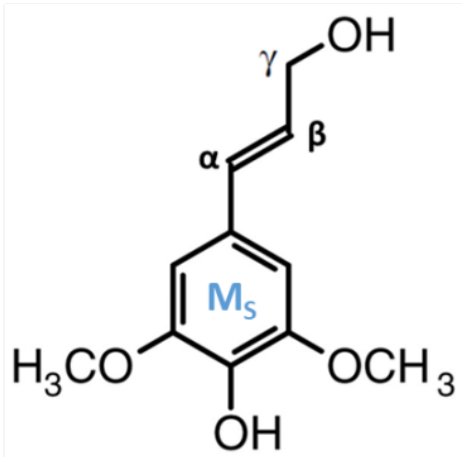
_p_-Coumaryl alcohol



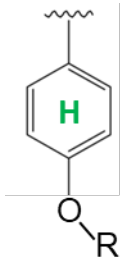
Coniferyl alcohol



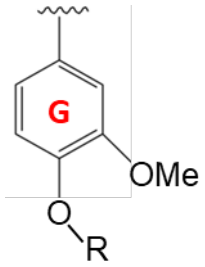
Sinapyl alcohol



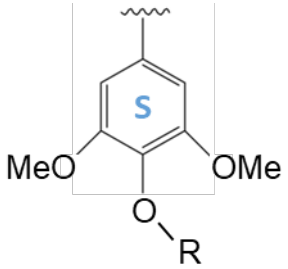
_p_-hydroxyphenyl



Guaiacyl

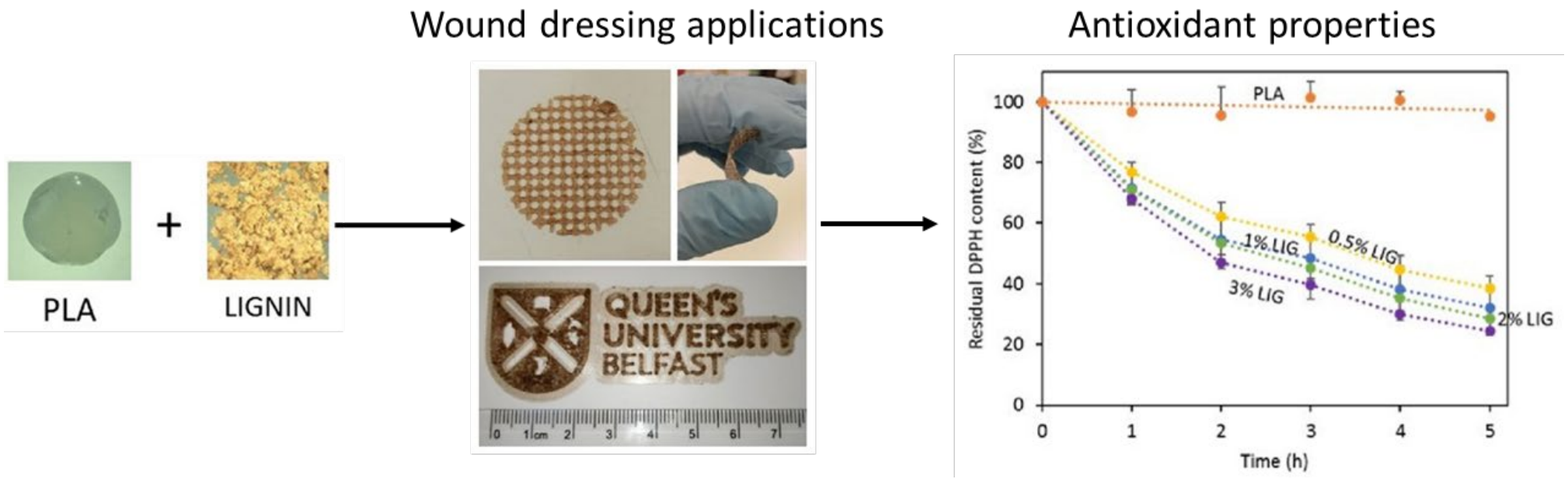


Syringyl



- **Lignin is the second most abundant natural polymer after cellulose.**
- **Lignin is found in most terrestrial plants in the approximate range of 15 to 40% dry weight.**
- **Only 2% of total lignin produced is reused for specialty products.**
- **Due to its high availability and its antimicrobial and antioxidant properties, lignin has a potential for biomedical applications.**

Antioxidant PLA Composites Containing Lignin for 3D Printing Applications: A Potential Material for Healthcare Applications



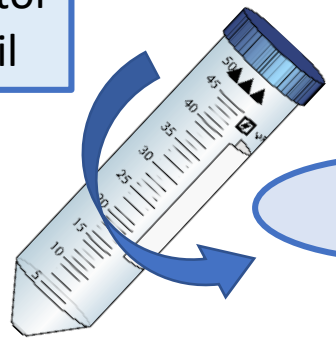
Experimental section

Materials production and characterization

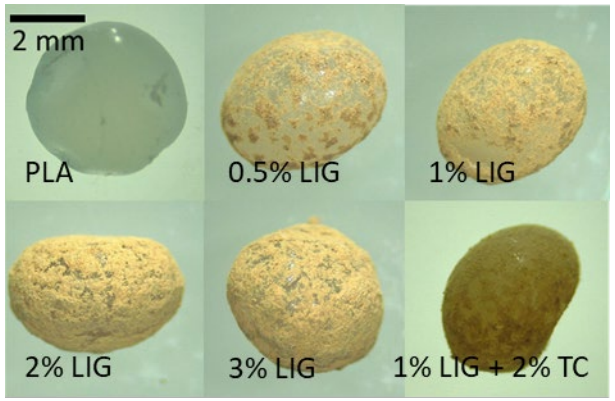
PLA + Lignin + Tetracycline

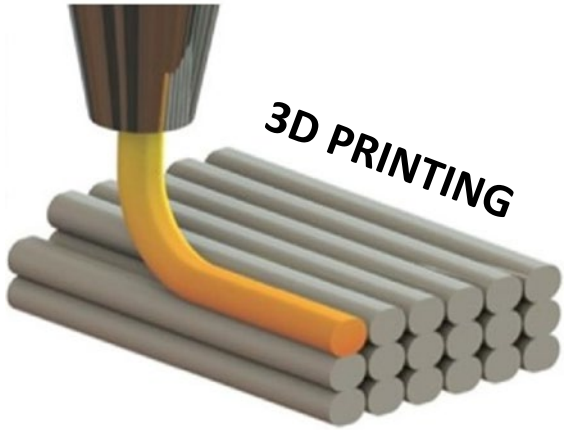
PLA + Castor oil

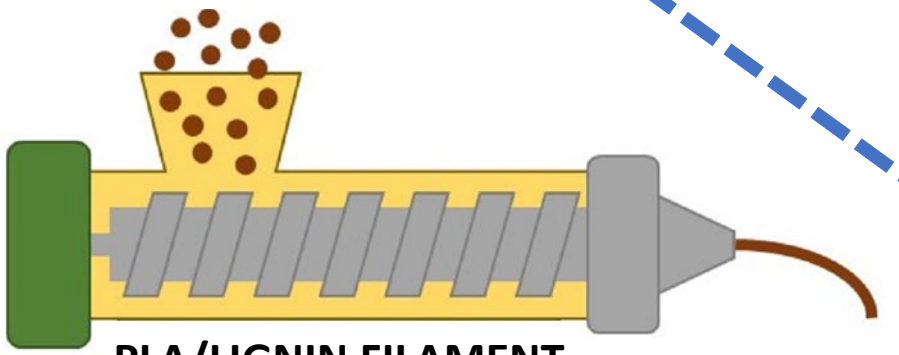
Coating process



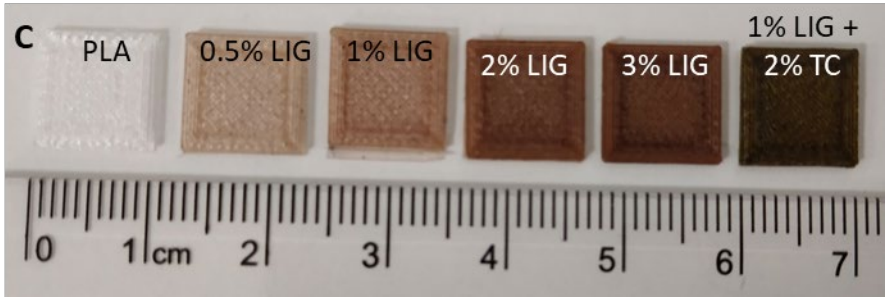
Vortex



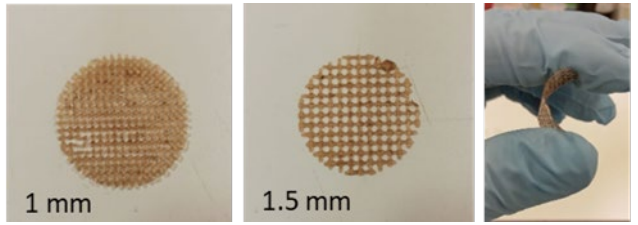




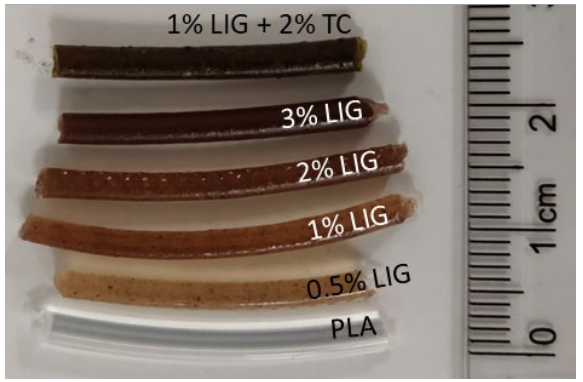
3D printed materials



3D printed meshes



Filaments

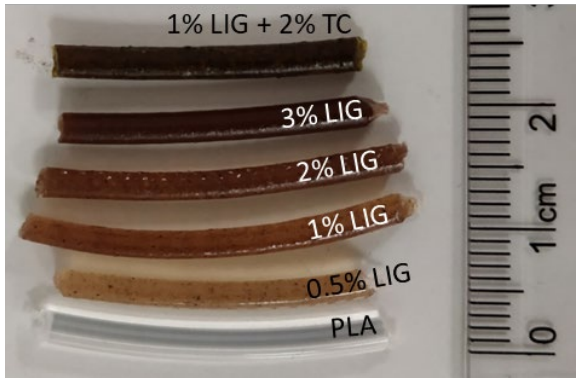


Weisman *et al*. International Journal Nanomedicine 2015, 10, 357–370.

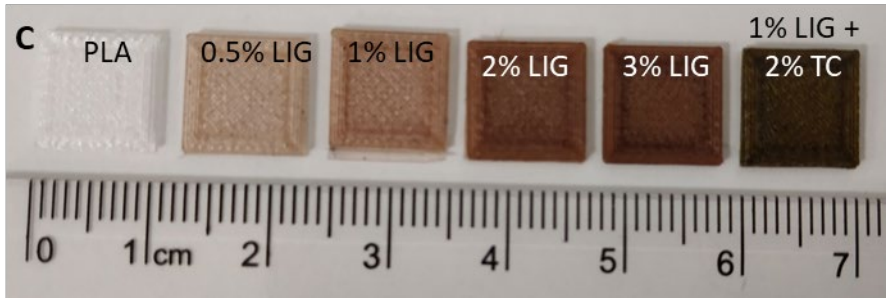
Results

Materials production and characterization

Filaments

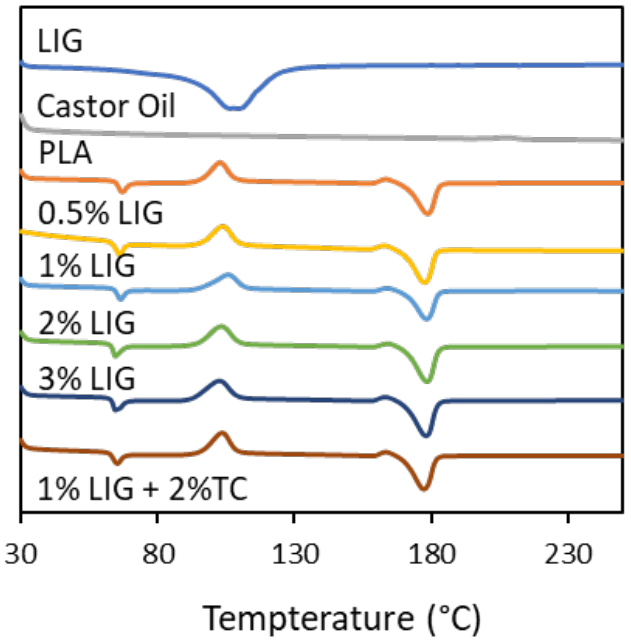


3D printed materials

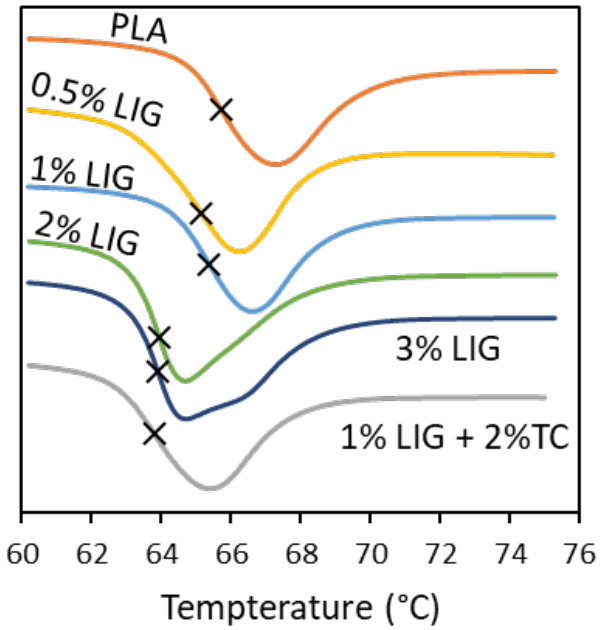


- Good homogeneity → No aggregates
- Increasing lignin concentration → Darker materials

DSC thermograms



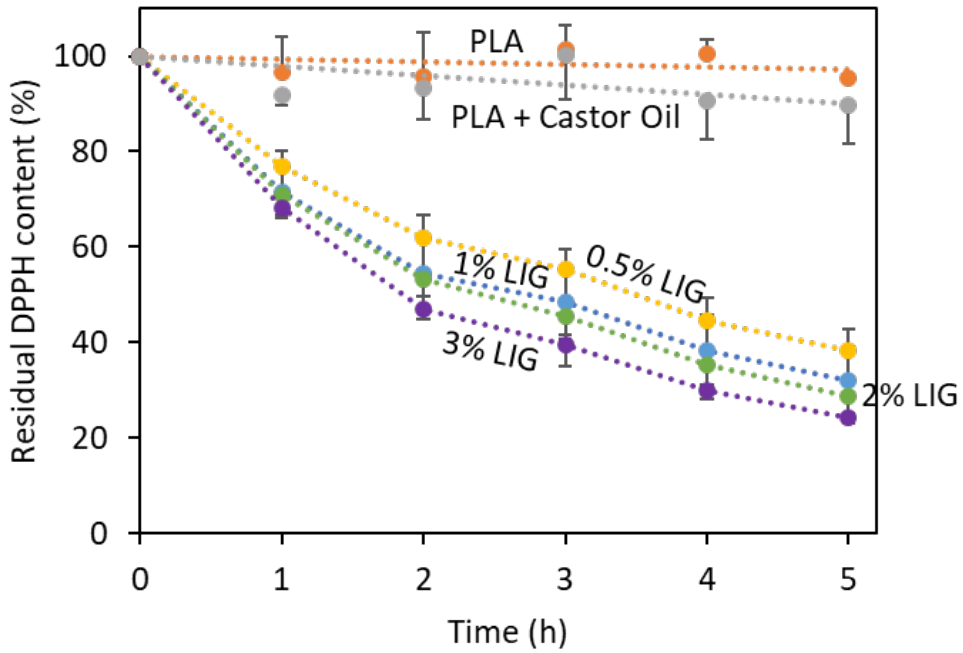
Glass transition temperature



- Lignin produces a reduction in the T_g of the material, indicating the existence of an interaction between the PLA and lignin.
- Melting point was not affected by the presence of lignin, which is ideal for FDM applications.

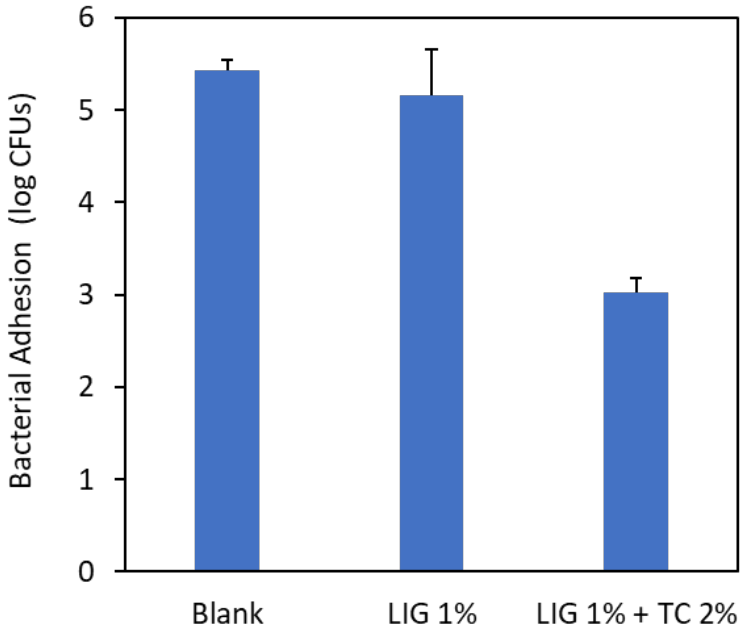
Results

Antioxidant properties



- PLA and PLA + oil did not show a reduction in DPPH concentration
- The presence of lignin provided antioxidant activity to the 3D printed materials
- As expected, more lignin = higher antioxidant activity

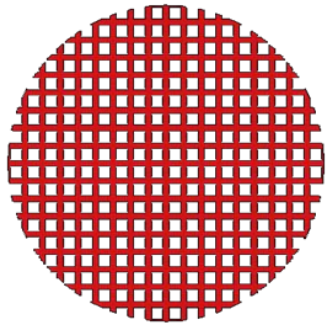
Antimicrobial properties



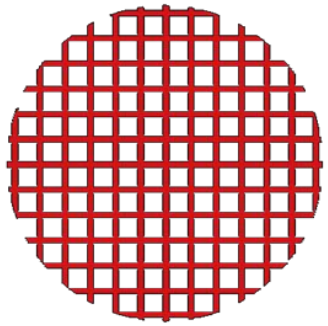
- 1% of Lignin did not provide any antibacterial activity
- TC showed significant reduction in bacterial adherence

Types of **3D printed meshes**: Potential wound healing applications

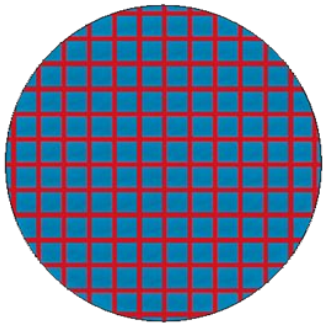
Antioxidant materials can be extremely beneficial for healthcare applications such as wound dressing



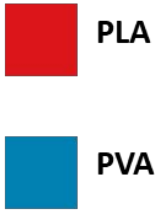
Mesh size: 1 mm
Diameter: 25 mm

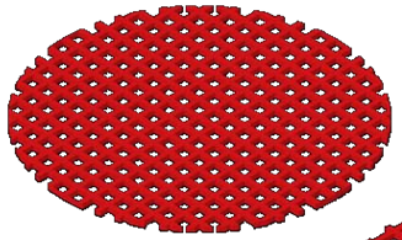


Mesh size: 1.5 mm
Diameter: 25 mm

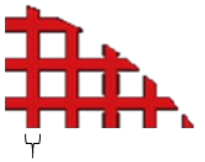


Mesh size: 1.5 mm
Diameter: 25 mm

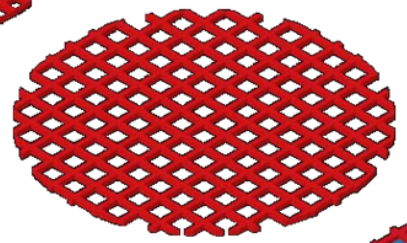




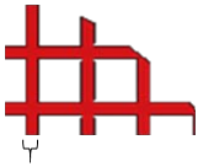
Thickness: 0.4 mm



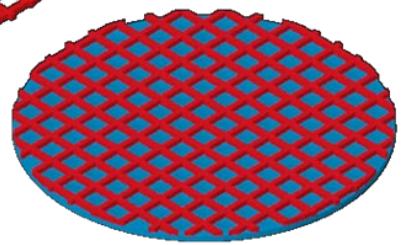
0.4 mm



Thickness: 0.4 mm



0.4 mm

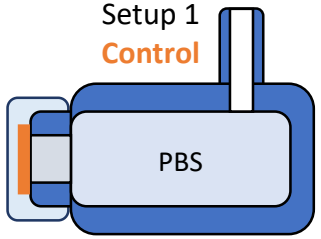


Thickness: 0.8 mm
0.4 mm (PLA layer) + 0.4 mm (PVA layer)
Mesh size PLA layer: 1.5 mm

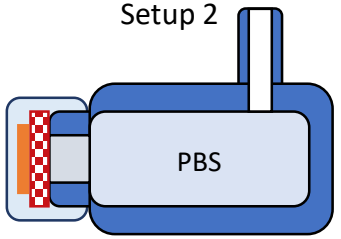
Permeation experiments through the **3D printed meshes**

Parafilm
CUR film
LIG/PLA Mesh
PVA Film

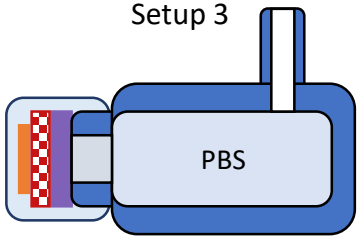
Horizontal Franz Cell
Setup 1
Control

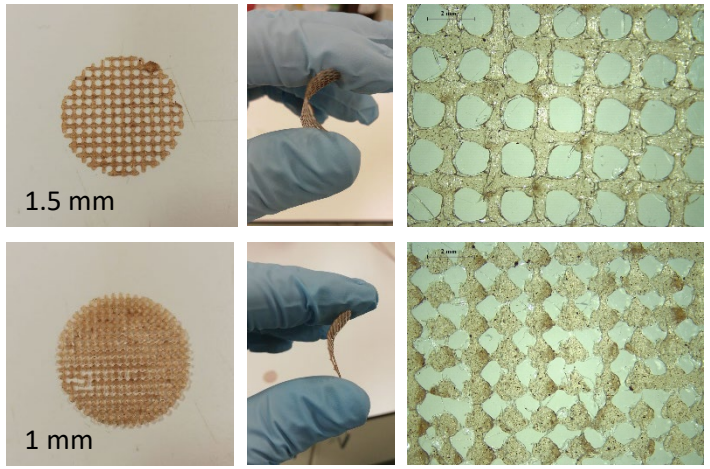


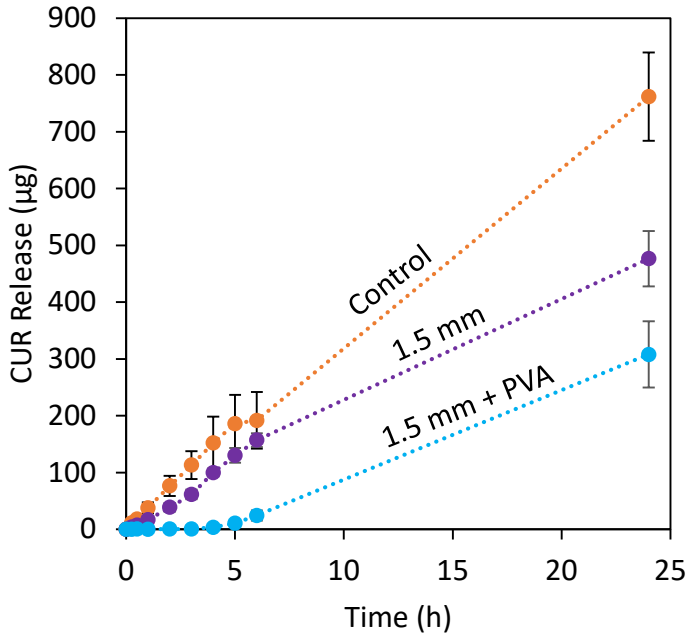
Horizontal Franz Cell
Setup 2

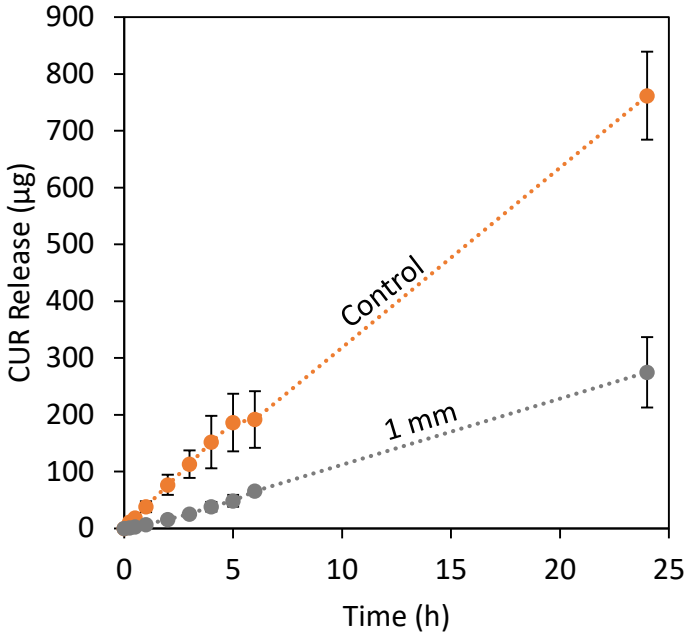


Horizontal Franz Cell
Setup 3









- The 1.5 mm and 1 mm meshes provided a slower release than the control
- The release rate could be delayed by combining the mesh with a PVA film

Conclusions

The main conclusions are:

- The direct combination of PLA and lignin seemed to be a good approach to obtain green 3D printable biomaterials with antioxidant properties.
- This method can be used to incorporate multiple compounds such as antibiotics, showing an effective reduction of *S. aureus* adhesion to the prepared 3D printed materials.
- PLA/Lignin shaped as meshes, which can be used in wound dressings to provide controlled delivery of active molecules.

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Thank you very much!