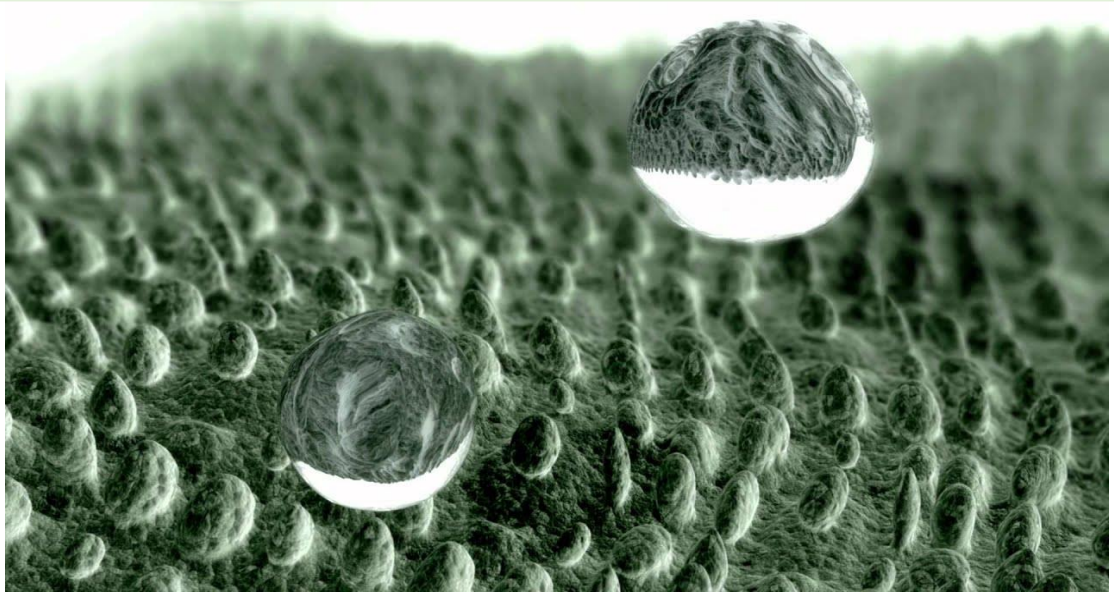
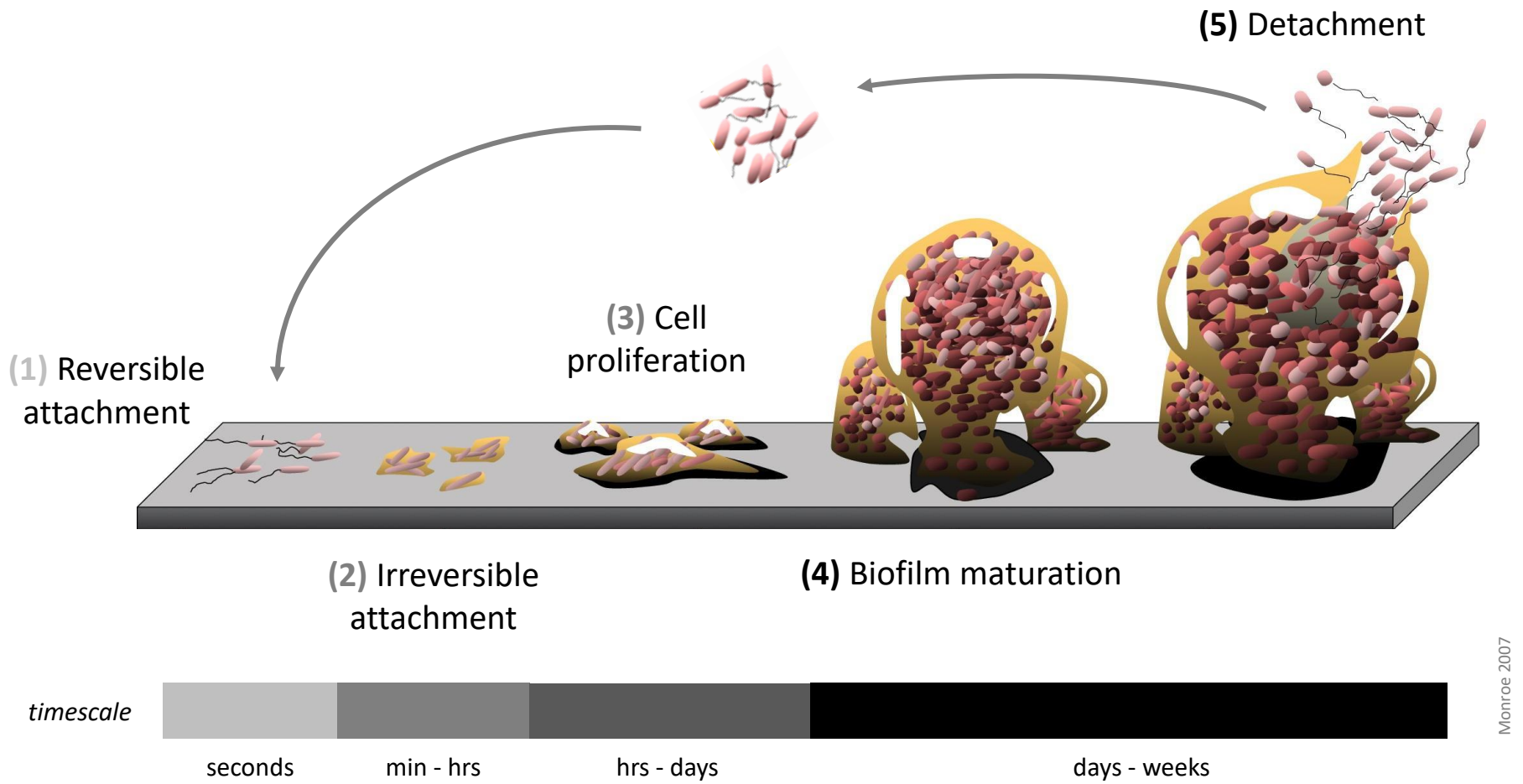
Drawing Inspiration From Nature To Develop Antifouling Surfaces



LUCIANA GOMES
Junior Researcher
(luciana.gomes@fe.up.pt)

Biofilms are complex and dynamic structures



Biofilms are communities of microorganisms which are protected by a self-produced matrix of extracellular polymeric substances

Biofilms are everywhere…

“Bad” biofilms



drinking-water distribution systems



food processing



industrial equipment



medical implants



ship hulls

Negative effects:

- Pipe plugging, corrosion and water contamination
- Decrease of industrial productivity due to equipment damage and energy losses
- Impact on the safety and quality of food products
- Persistent and recurrent infections involving indwelling medical devices
- Increased corrosion, drag and fuel consumption related to hull fouling

Biofilms are everywhere…

“Bad” biofilms



drinking-water distribution systems



food processing



industrial equipment



medical implants



ship hulls

“Good” biofilms

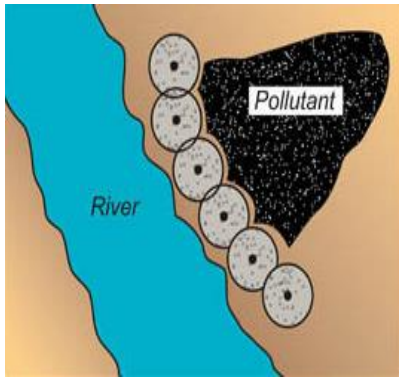


production of industrial chemicals

(e.g. ethanol, lactic acid and acetic acid)



wastewater treatment



bioremediation

Factors influencing adhesion and biofilm formation

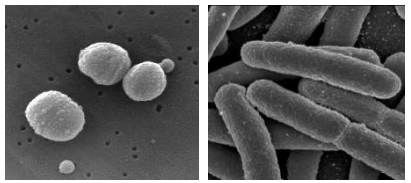


Surface properties

- chemistry
- topography
- roughness
- hydrophobicity
- organic fouling

Microbial strains

- cell density
- cell surface characteristics
- single or multiple species

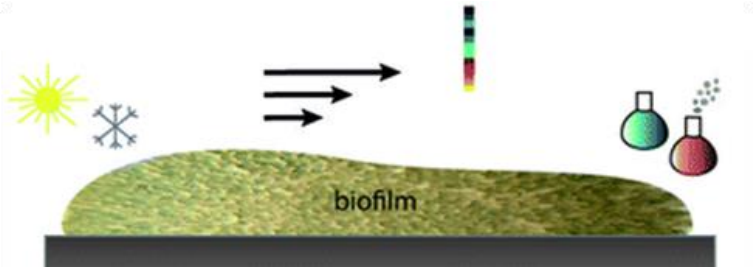


Environment

- nutrient availability
- temperature
- pH

Hydrodynamics

- flow regime
- flow rate
- shear forces



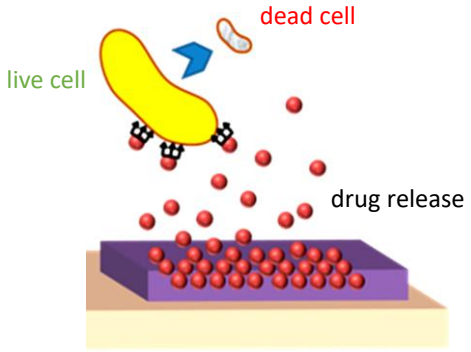
Understanding the mechanisms of biofilm formation is essential to **find efficient ways to promote or inhibit biofilm growth**

Strategies to prevent biofilm formation

Antimicrobial agents release

controlled release of high-local concentration of antimicrobial agents

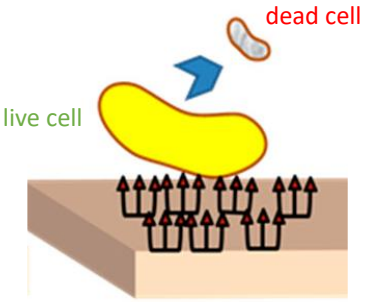
(e.g., metals, antibiotics or bacteriophages)



Contact-killing

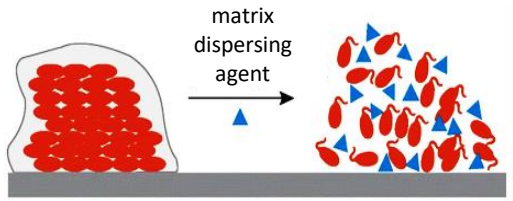
compounds immobilized on the surface

(e.g., carbon nanotubes or graphene oxide)



Disruption of biofilm architecture

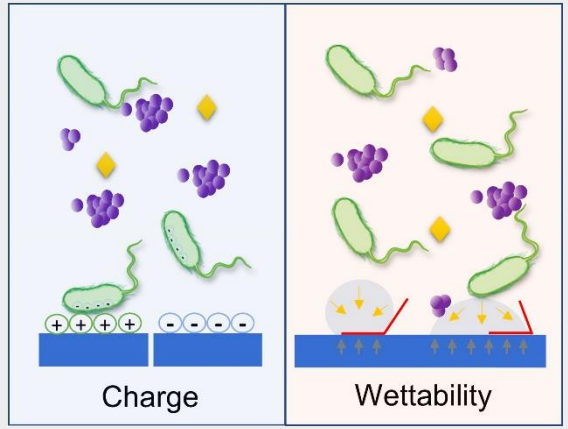
matrix degradation or QS interruption

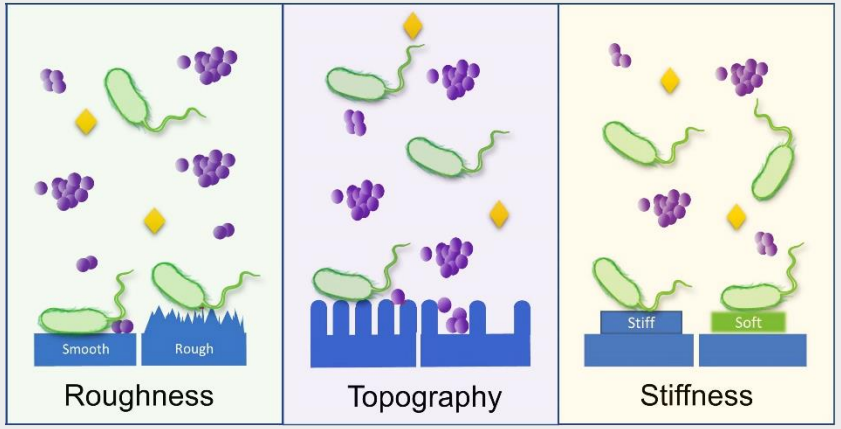


Andrade-Del Olmo et al. 2020; Azman et al. 2019

Inhibition of microbial adhesion

SURFACE MODIFICATION





Zeng et al. 2021

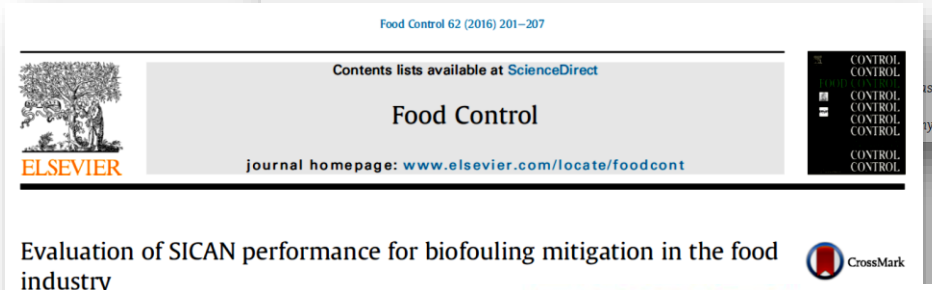
Previous study on modified surfaces for the food industry

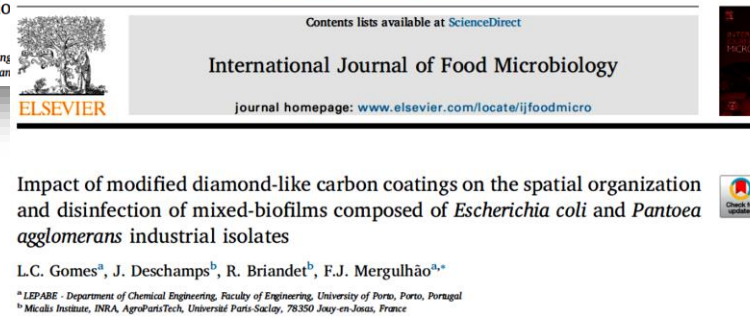


e.g., fresh-cut vegetable industry

Biofilm formation on **food contact surfaces** is a major cause in **pathogen persistence** in food processing environments, leading to **economic losses** and **health concerns**







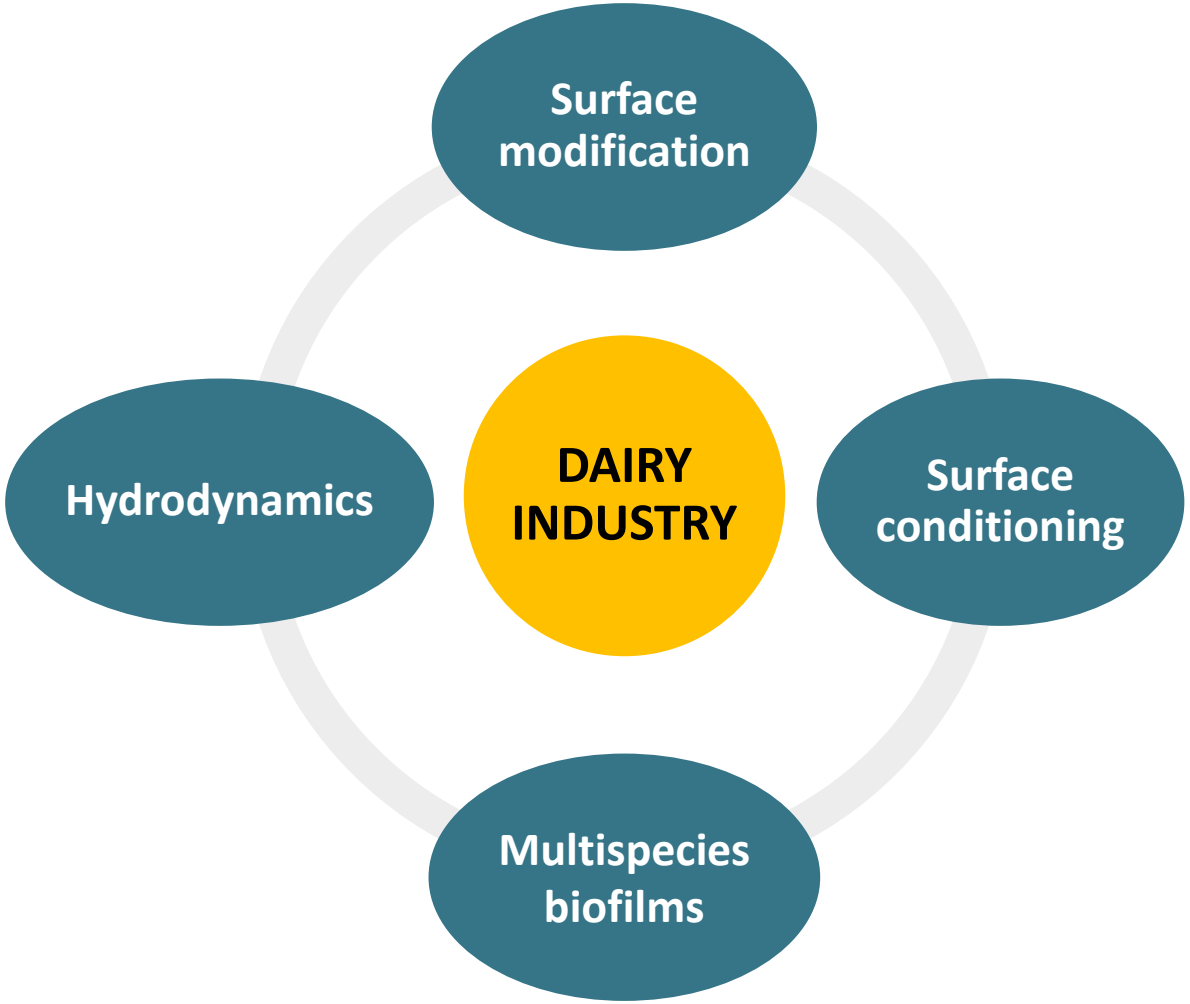
SUSCLEAN
SUSTAINABLE CLEANING AND DESINFECTION IN FRESH CUT FOOD INDUSTRIES



1) Characterization and monitoring of microbial contamination patterns
2) **Improving the hygienic design of equipment (geometry and surface)**
3) Designing new decontamination approaches for fresh-cut food and sanitation strategies
4) Proposing guidance and recommendations to renew the available processing techniques

modified diamond-like carbon (DLC) surfaces

Surface modification to reduce microbial and organic fouling in the dairy industry

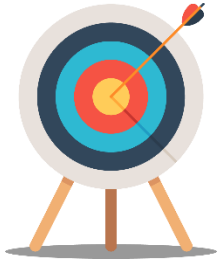




INNOVATION: integrated strategy

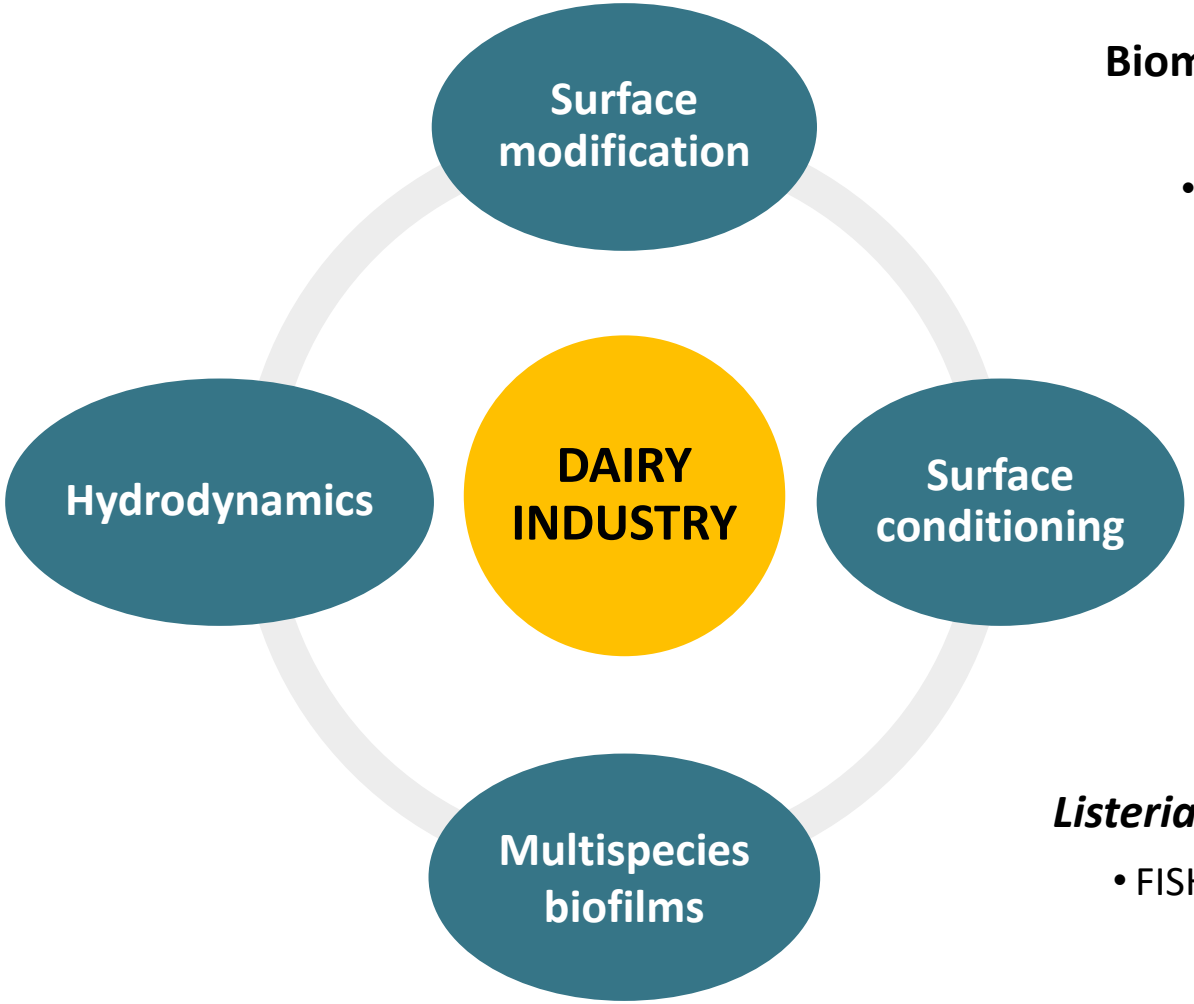


how surface modification affects conditioning and multispecies biofilm formation



find critical areas in processing plants that may benefit from the use of antifouling materials

Surface modification to reduce microbial and organic fouling in the dairy industry



Biomimetic polymeric surfaces

- surface topography
- surface physicochemistry

Conditioning agents

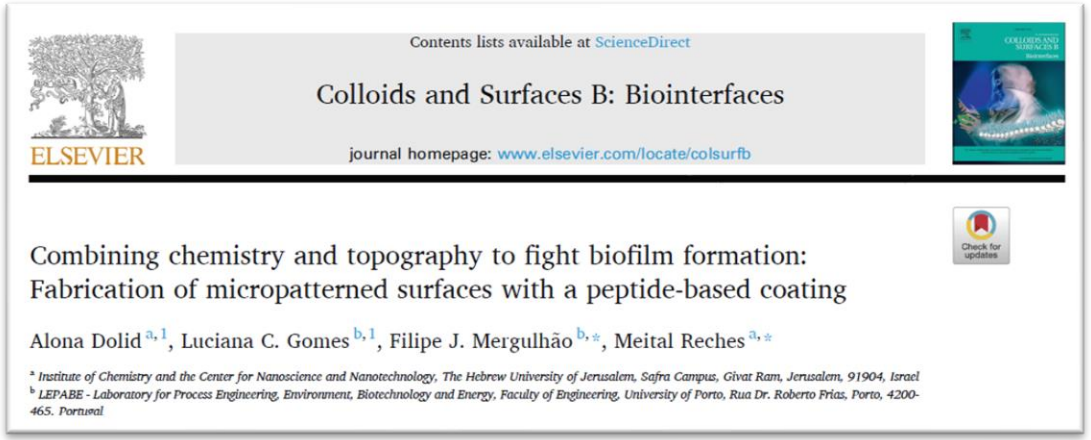
- proteins
- carbohydrates
- inorganic salts

(etc.)

Listeria monocytogenes* / *Escherichia coli

- FISH (fluorescence *in situ* hibridization)
- biofilm spatial organization

First work on biomimetic surfaces



Contents lists available at ScienceDirect

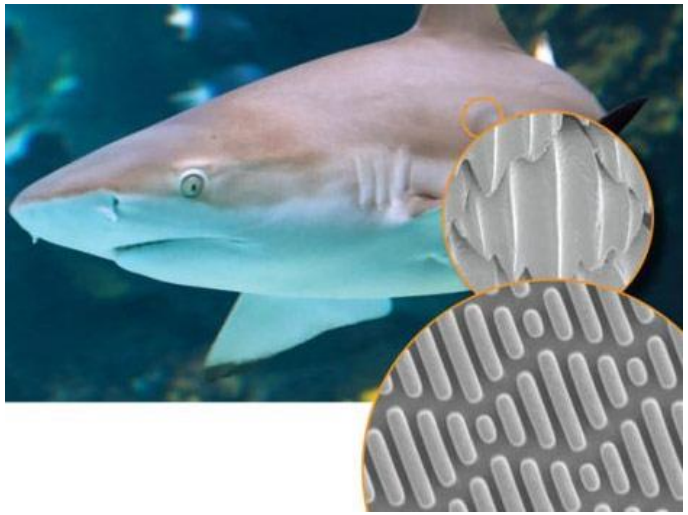
Colloids and Surfaces B: Biointerfaces

journal homepage: www.elsevier.com/locate/colsurfb

Combining chemistry and topography to fight biofilm formation: Fabrication of micropatterned surfaces with a peptide-based coating

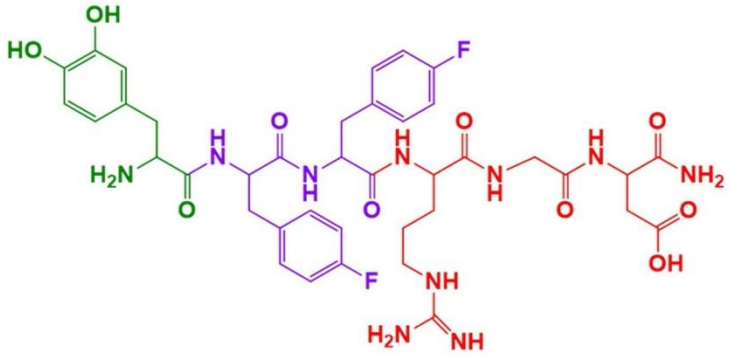
Alona Dolid [a,1], Luciana C. Gomes [b,1], Filipe J. Mergulhão [b,*], Meital Reches [a,*]

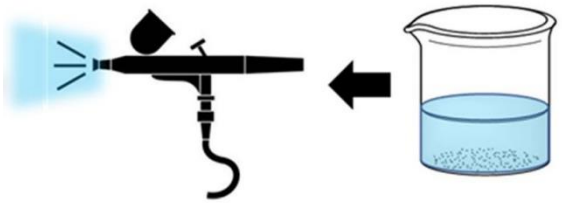
[a] Institute of Chemistry and the Center for Nanoscience and Nanotechnology, The Hebrew University of Jerusalem, Safra Campus, Givat Ram, Jerusalem, 91904, Israel
[b] LEPABE - Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, Porto, 4200-465, Portugal



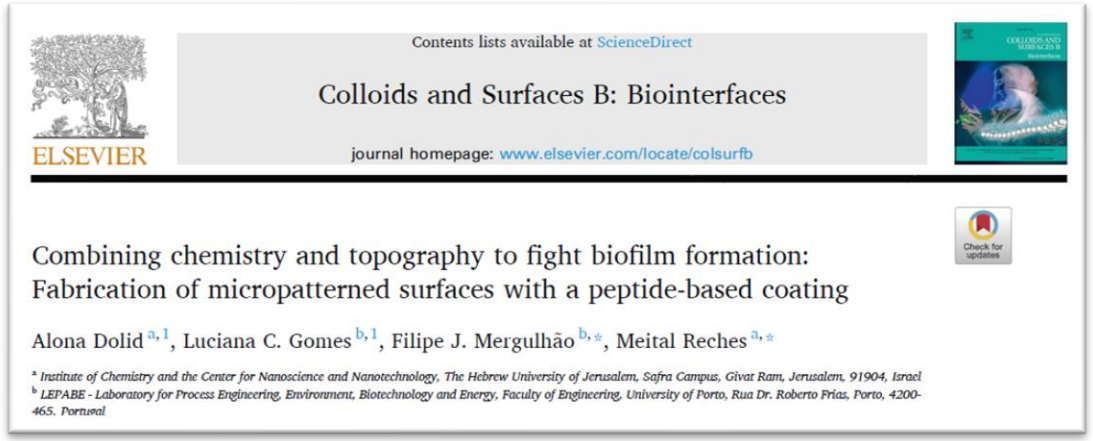
shark skin surface

peptide





First work on biomimetic surfaces



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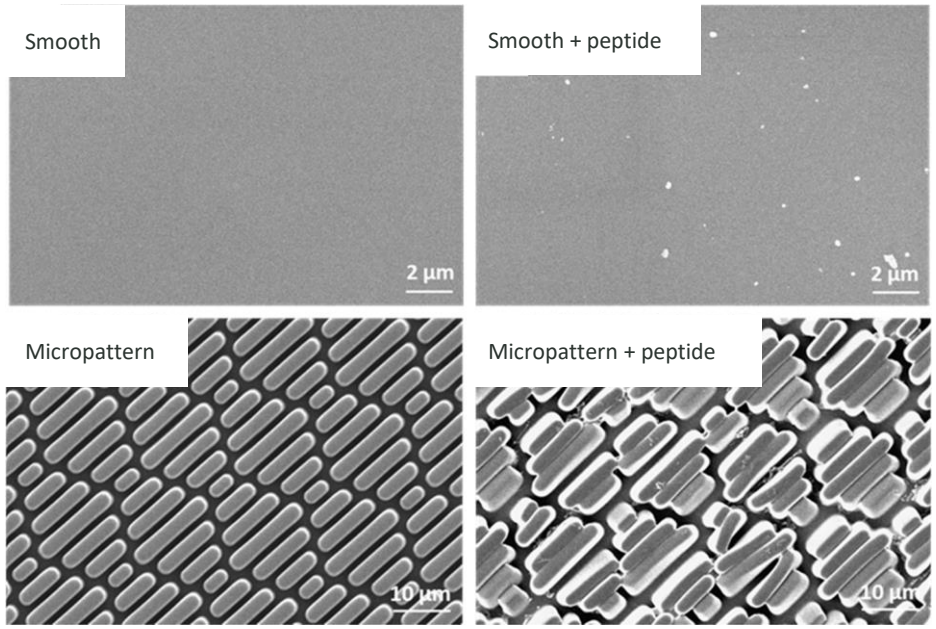
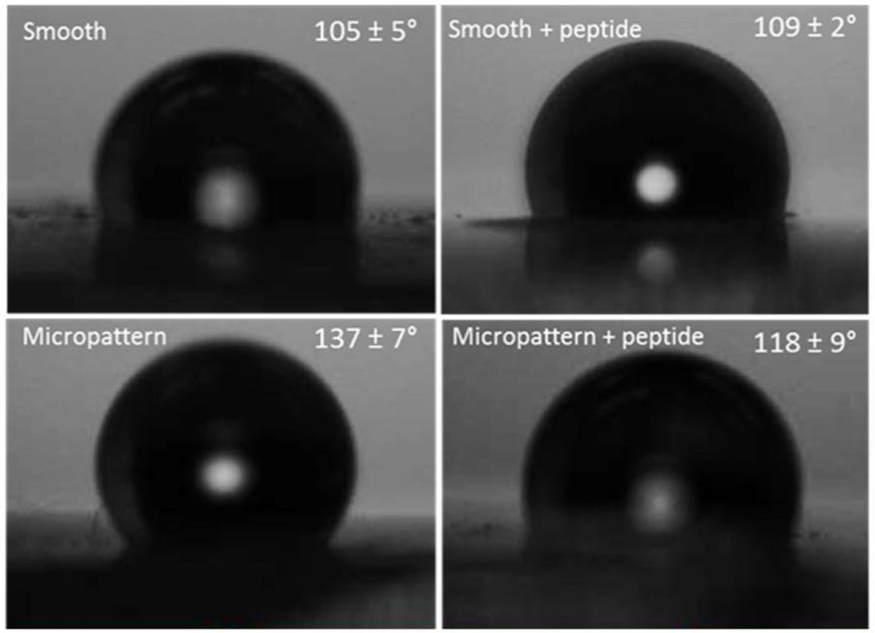
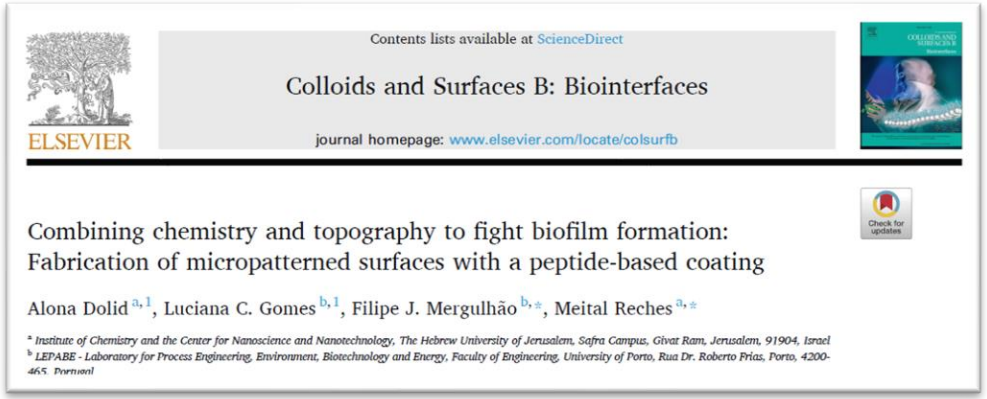
SEM images:



Water contact angles:



First work on biomimetic surfaces



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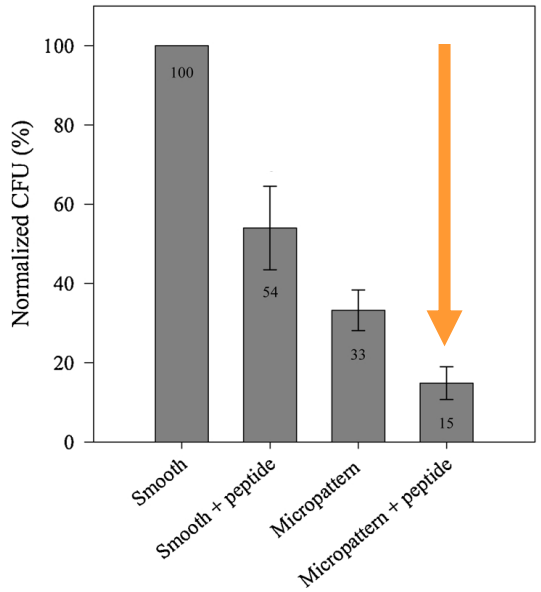
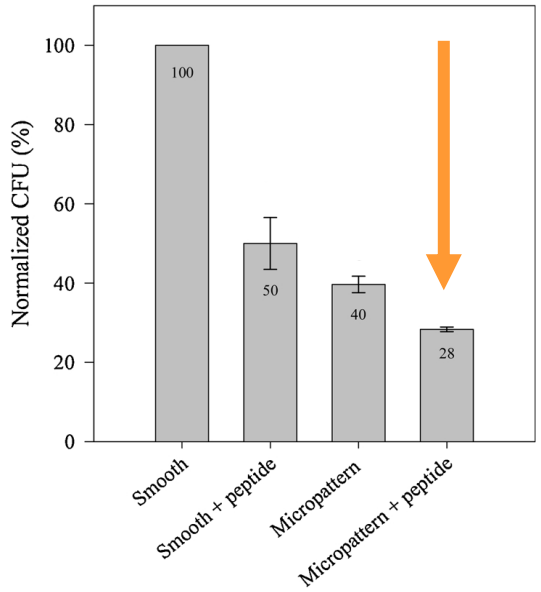
- **Static and dynamic assays**
- **22 h** of biofilm formation and **30 min** of adhesion
- Gram-negative (***E. coli***) and Gram-positive (***S. epidermidis***) bacteria

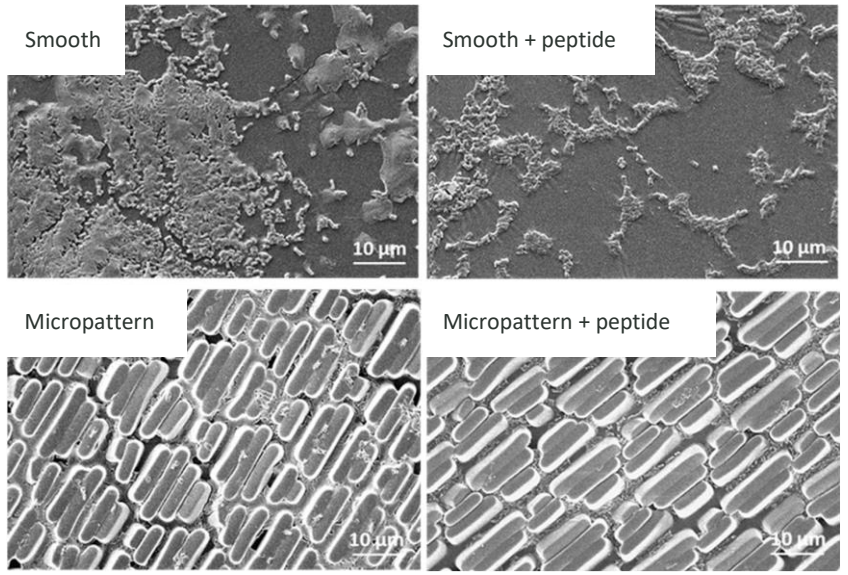
E. coli



S. epidermidis



SEM images of *E. coli* biofilms:



The micropattern + peptide coating had higher antifouling properties

SurfSAFE project

European Project approved within the Horizon 2020 call topic Widespread-05-2020, Twinning (2021-2023)

Focused on the field of surface modification and biofilm analysis, necessary to enable development of **tailor-made antifouling and antimicrobial, non-toxic surfaces inspired by nature**

Surfsafeproject

SurfSAFE project

@SurfSAFE1

surfsafeproject.eu

Consortium

SurfSAFE

Coordination:

Faculty of Engineering - University of Porto (UPORTO, PT)



Filipe Mergulhão



Kathryn Whitehead

Manchester Metropolitan University (ManMet, UK)

surface engineering

biofouling

microbial interactions

hydrodynamics

biofilm analysis

University Medical Center Groningen (UMCG, NL)



Jelmer Sjollema



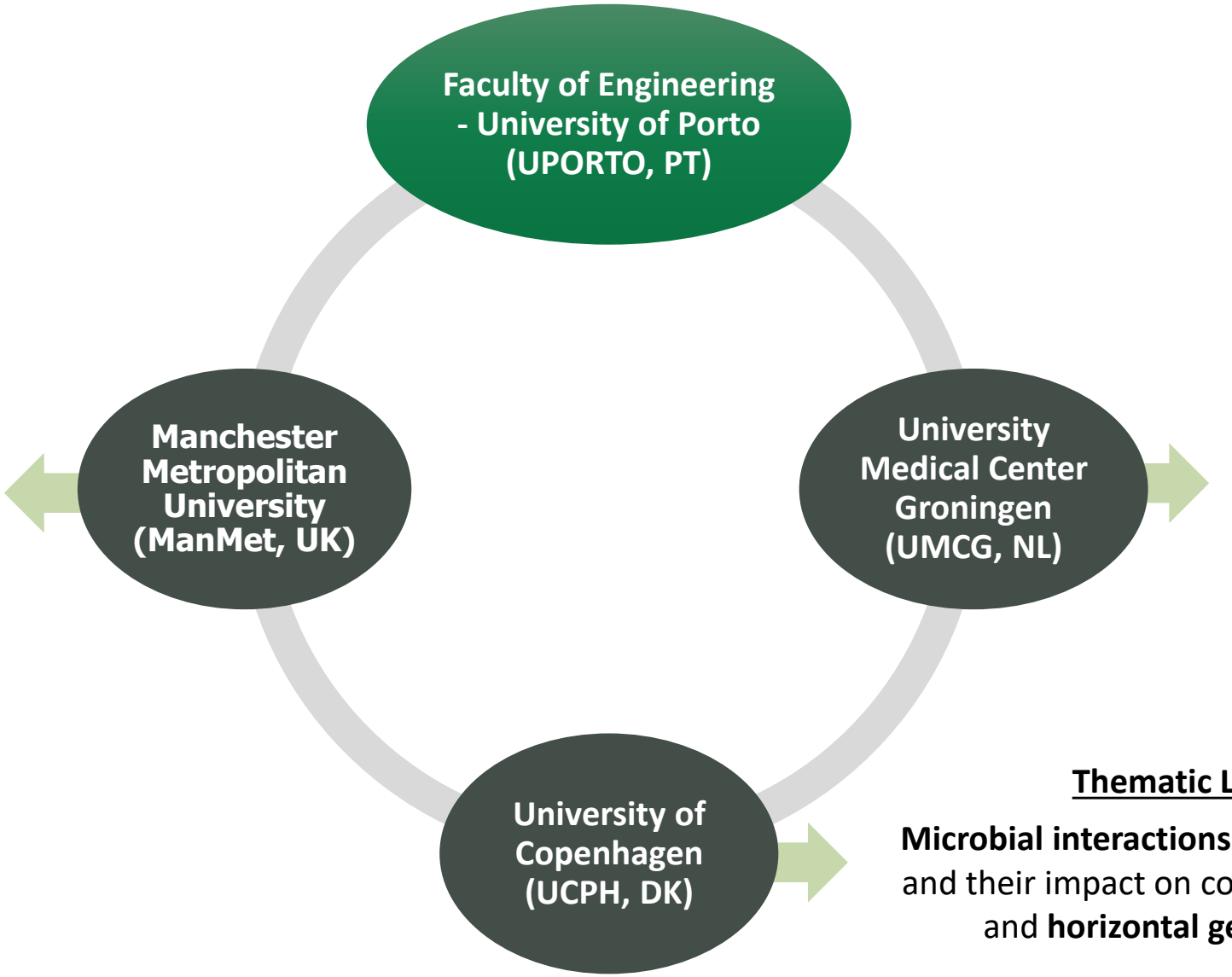
Mette Burmølle

University of Copenhagen (UCPH, DK)

Consortium

SurfSAFE

Coordination:



Thematic Line 1:

Design, manufacture and characterization of antiadhesive and antimicrobial surfaces

Thematic Line 3:

Evaluation of the efficacy of antiadhesive and antimicrobial surfaces in the **presence of organic material**

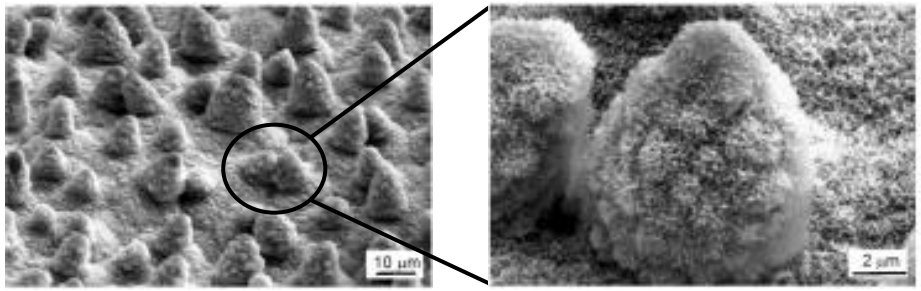
Thematic Line 2:

Microbial interactions in mixed biofilms and their impact on community survival and **horizontal gene transfer**

Leaves as models for biomimetic surfaces

SurfSAFE

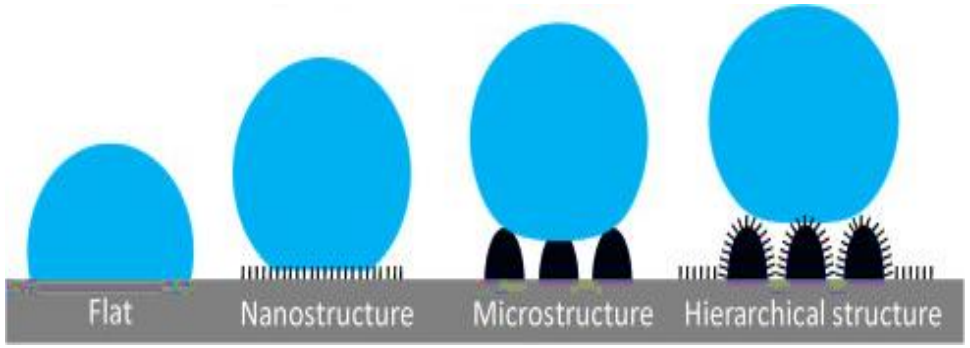
Lotus leaf:





Bhushan and Jung 2011

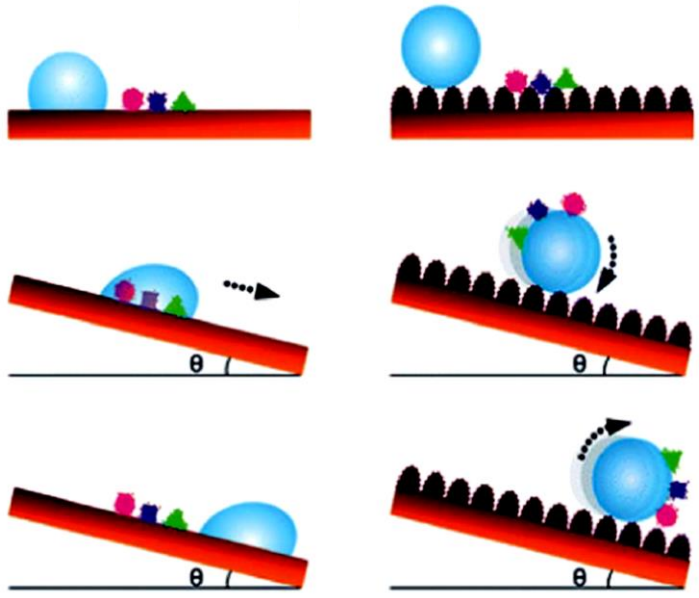
microstrutures with water-repelling nanostructured wax crystals



Bhushan and Jung 2011

WETTABILITY

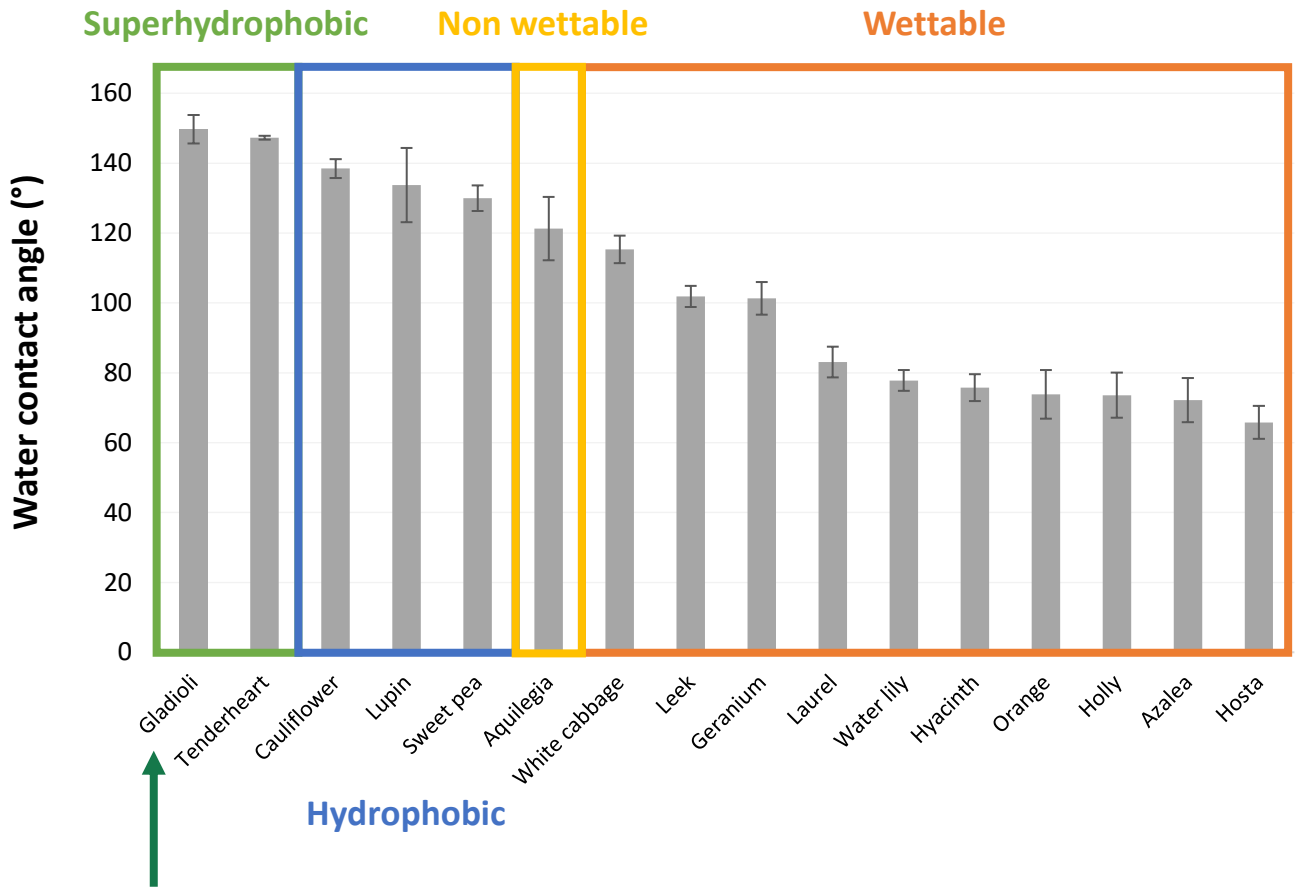
flat surface | superhydrophobic surface



Darmanin and Guittard 2014

SELF-CLEANING

Rationale



Are the superhydrophobic leaves of Gladioli interesting to produce biomimetic surfaces?


LANGMUIR

pubs.acs.org/Langmuir Article

Principal Component Analysis to Determine the Surface Properties That Influence the Self-Cleaning Action of Hydrophobic Plant Leaves

Fabien Saubade, Lisa I. Pilkington, Christopher M. Liauw, Luciana C. Gomes, Jake McClements, Marloes Peeters, Mohamed El Mohtadi, Filipe Mergulhão, and Kathryn A. Whitehead*

Cite This: https://doi.org/10.1021/acs.langmuir.1c00853 Read Online

Can hydrophobic surfaces be used to avoid bacterial retention, attachment and adhesion?

Gladioli as a model for biomimetic surfaces

SurfSAFE

1. Fabrication process – Moulding & Casting

Gladiolus hybridus
(Gladioli)



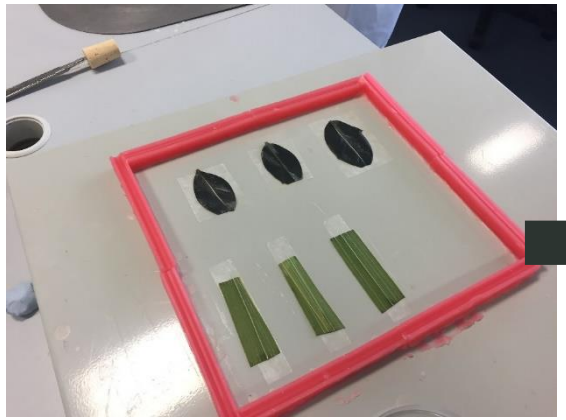
DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

Invited paper

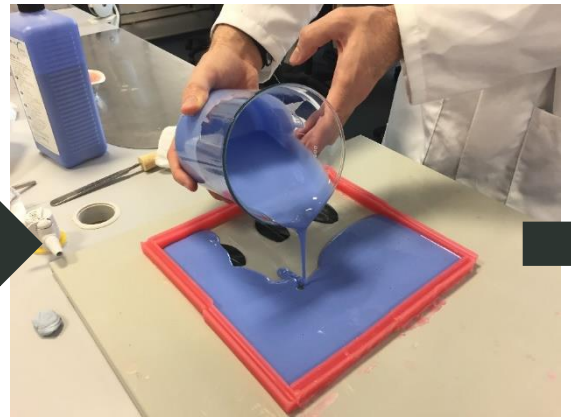
Jake McClements, Luciana C. Gomes, Joshua Spall, Fabien Saubade, Devine Akhidime, Marloes Peeters, Filipe J. Mergulhão and Kathryn A. Whitehead*

Celebrating the centenary in polymer science: drawing inspiration from nature to develop anti-fouling coatings the development of biomimetic polymer surfaces and their effect on bacterial fouling

leaf fixation



silicone pouring



negative silicone



wax pouring

biomimetic surface

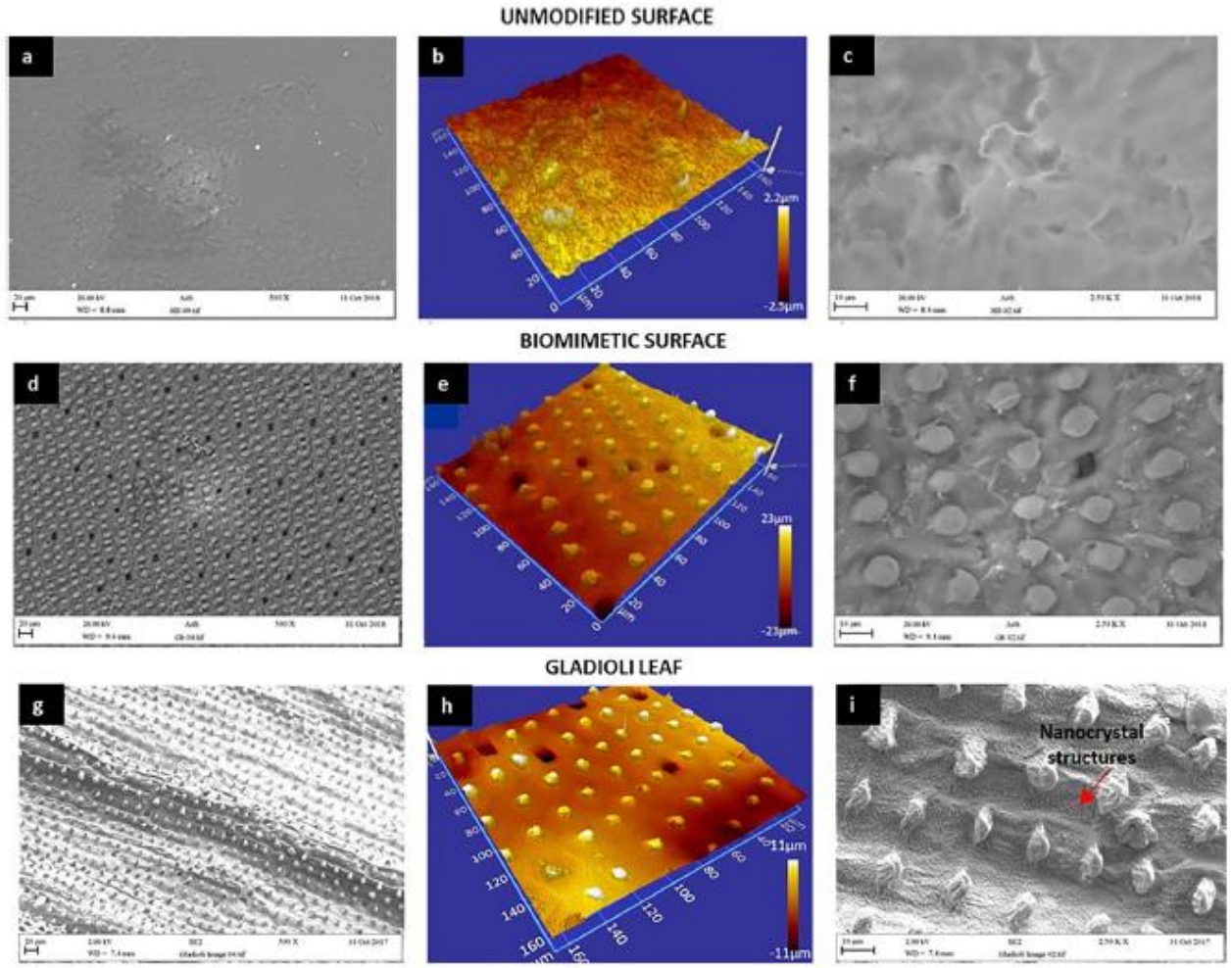


Gladioli as a model for biomimetic surfaces

SurfSAFE

2. Topography and physicochemical properties

SEM: **Optical profilometry:**



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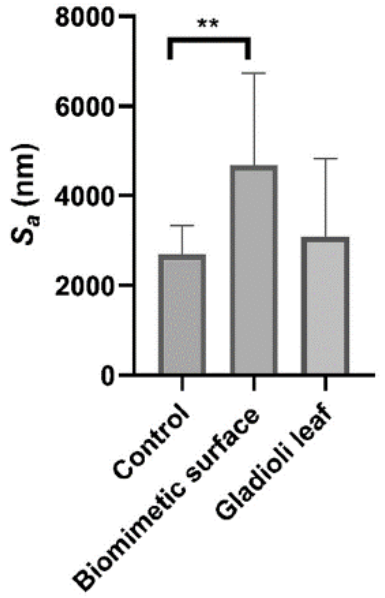
Biomimetic and leaf surfaces had **similar roughness parameters**…



Gladioli as a model for biomimetic surfaces

SurfSAFE

3. Monoculture assays

> **adhesion assay** (spray)

> **attachment assay** (spray + H_2O wash)





> **retention assay** (1 h bacterial incubation)

DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

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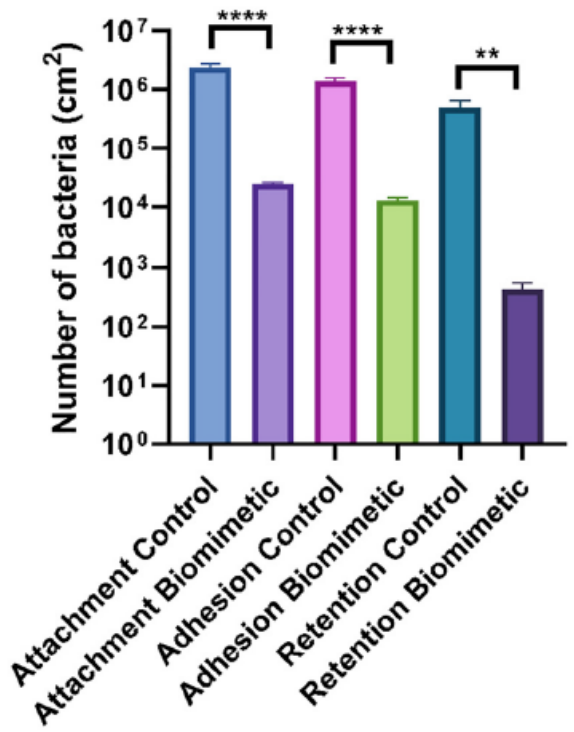
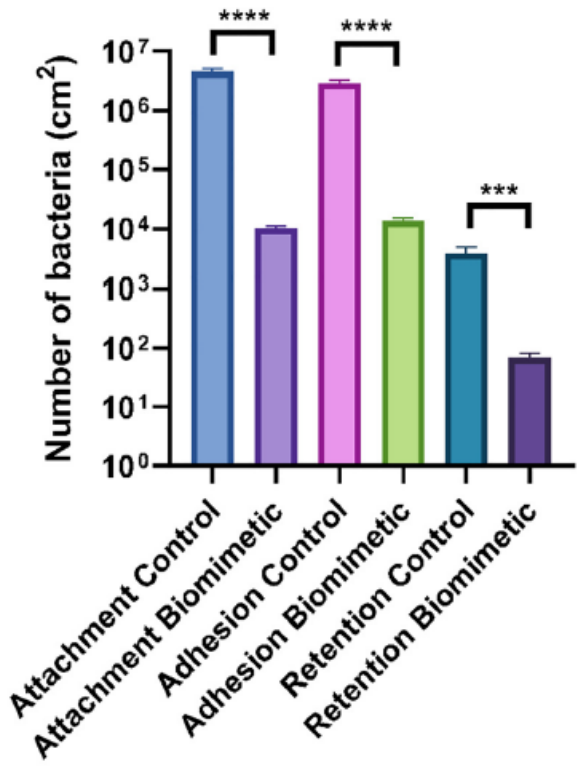
E. coli



L. monocytogenes



Biomimetic surfaces had fewer bacteria than control (unmodified surface)

Gladioli as a model for biomimetic surfaces

SurfSAFE

4. Co-culture assays

> **adhesion assay** (spray)

> **attachment assay** (spray + H_2O wash)





> **retention assay** (1 h bacterial incubation)

DE GRUYTER Pure Appl. Chem. 2021; ■■■(■■■): 1–12

Invited paper

Jake McClements, Luciana C. Gomes, Joshua Spall, Fabien Saubade, Devine Akhidime, Marloes Peeters, Filipe J. Mergulhão and Kathryn A. Whitehead*

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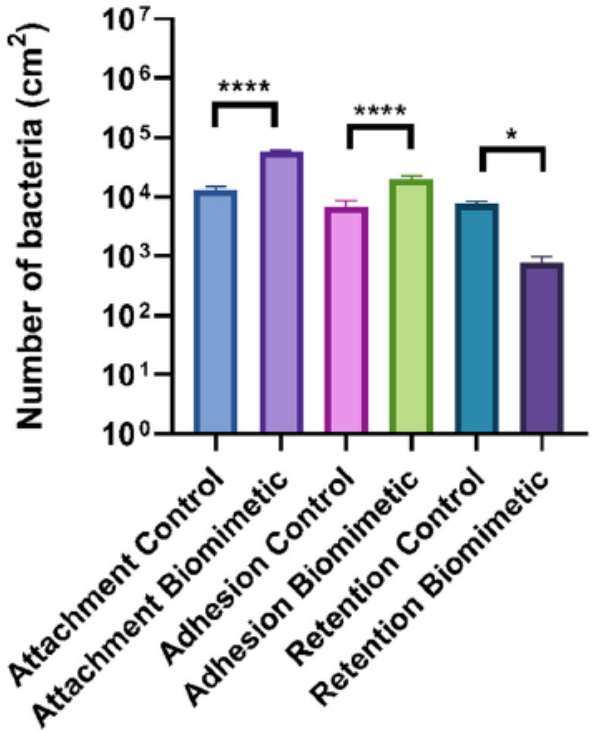
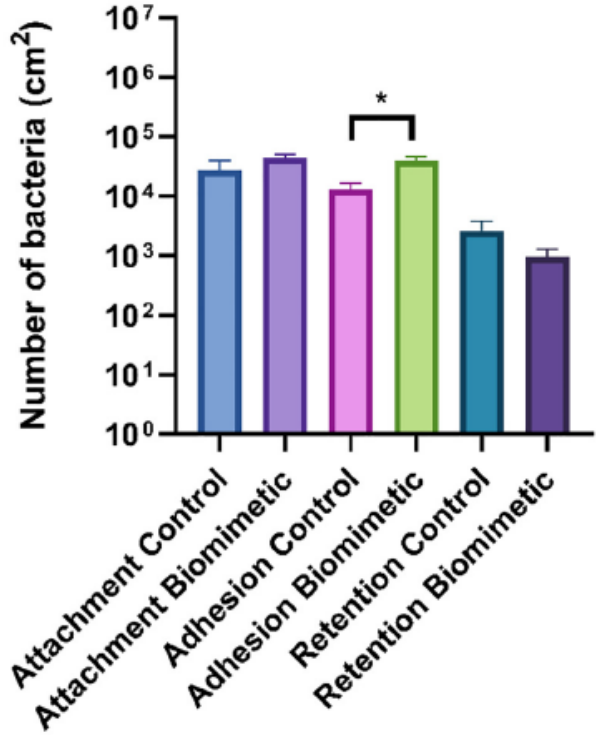
E. coli



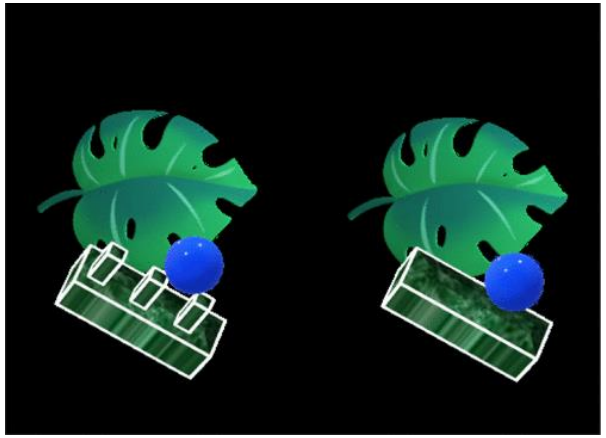
L. monocytogenes



Bacterial numbers were reduced on biomimetic surfaces only following retention assays…

Take home message

- Self-cleaning **biomimetic surfaces** can be of **great benefit to human health**, in addition to **reducing the economic burden on industries**.
- It is known that **many plant leaves display self-cleaning properties**, being promising surfaces to mimic.
- Understanding the **interplay of surface properties** **(topography, chemistry and physicochemistry)** is extremely important to **produce optimized biomimetic surfaces**.
- Such biomimetic surfaces may be effective in reducing biofouling if used in the appropriate medical, marine and industrial scenarios.



Scientific support:

Prof. Filipe Mergulhão & Prof. Kathryn Whitehead

Microbiology at Interfaces Group @ MMU

Financial support:

- SurfSAFE project funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 952471;
- Base Funding - UIDB/00511/2020 of the Laboratory for Process Engineering, Environment, Biotechnology and Energy – LEPABE - funded by national funds through the FCT/MCTES (PIDDAC);
- L.C.Gomes thanks the FCT for financial support of her work contract through the Scientific Employment Stimulus-Individual Call-[CEECIND/01700/2017].

FCT Fundação para a Ciência e a Tecnologia
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THANK YOU!

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