# Crosslinked Cellulose Nanocrystal Microbeads Produced by Spray Drying

Gili Bar | MASc Student

Department of Chemical and Biological Engineering, University of British Columbia

Supervisor: Professor Emily D. Cranston

Did you know that the average person eats at least 50,000 non-degradable microparticles a year?

World Economic Forum (2023)

# Non-Degradable Microbeads are Everywhere

Microbeads in personal care and cosmetics products are washing down the drain

↓

Passing through wastewater treatment processes

↓

Absorbing toxic chemicals

↓

Entering aquatic systems

(1) Can **affect marine ecosystems** for decades

(2) Can **affect the food we eat**

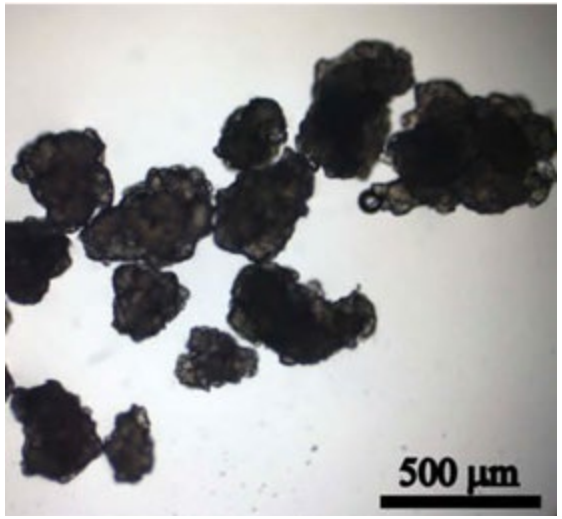

**We need to eliminate the use of non-degradable microbeads**

# Microbeads in Personal Care Products

**Main disadvantages of non-degradable microbeads:**

(1) Negative effect on the environment/health

(2) Non-uniform morphology & performance




*Polyethylene microbeads in personal care products*

**Advantages of crosslinked cellulose nanocrystal (CNC) microbeads produced by spray drying:**

(1) CNCs are bio-based/biodegradable and commercially available

(2) Spray drying is a scalable production method with the possibility to tailor properties for different applications


Volant et al. *Journal of Polymers and the Environment* **2022**, *30*, 2254

Ju et al. *Green Chemistry* **2021**, *23*, 6953

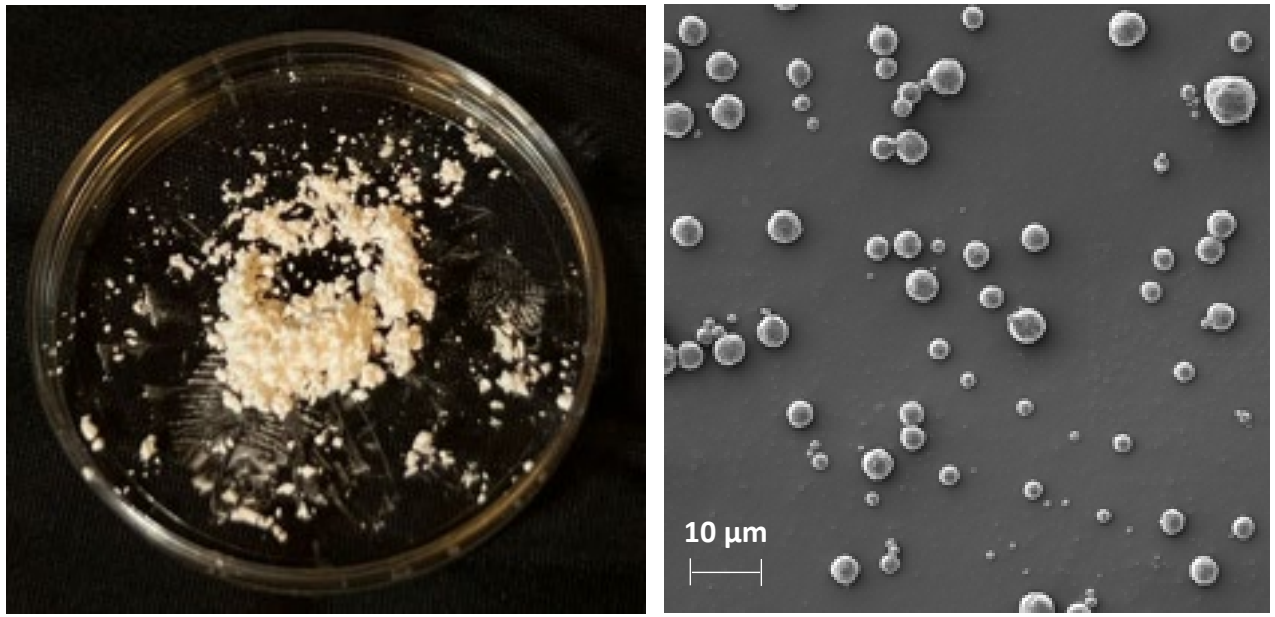
Hunt, Lin & Voulvoulis. *Nature Sustainability* **2021**, *4*, 366

Fendall & Sewell. *Marine Pollution Bulletin* **2009**, *58*, 1225

# Target Properties of Our Microbeads

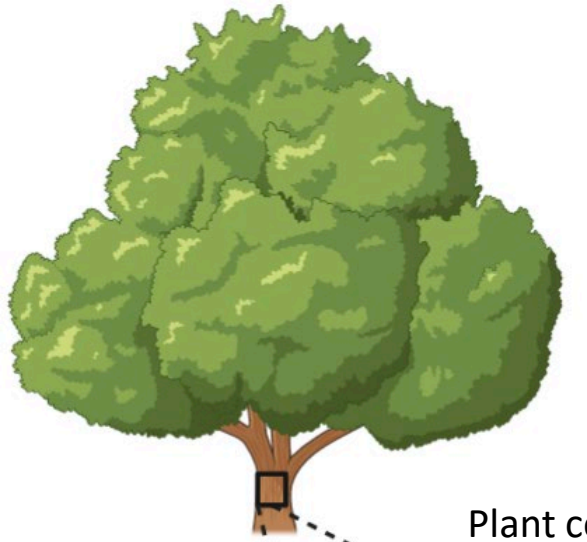
- In addition to providing an **environmentally-friendly alternative** for non-degradable microbeads, the crosslinked CNC microbeads have a **morphological advantage**

| | |
|---|---|
| **Size** | Uniform |
| **Shape** | Spherical |
| **Porous** | ✓ |
| **Stable** | DO NOT break apart in liquids |
| **Biodegradable** | ✓ |

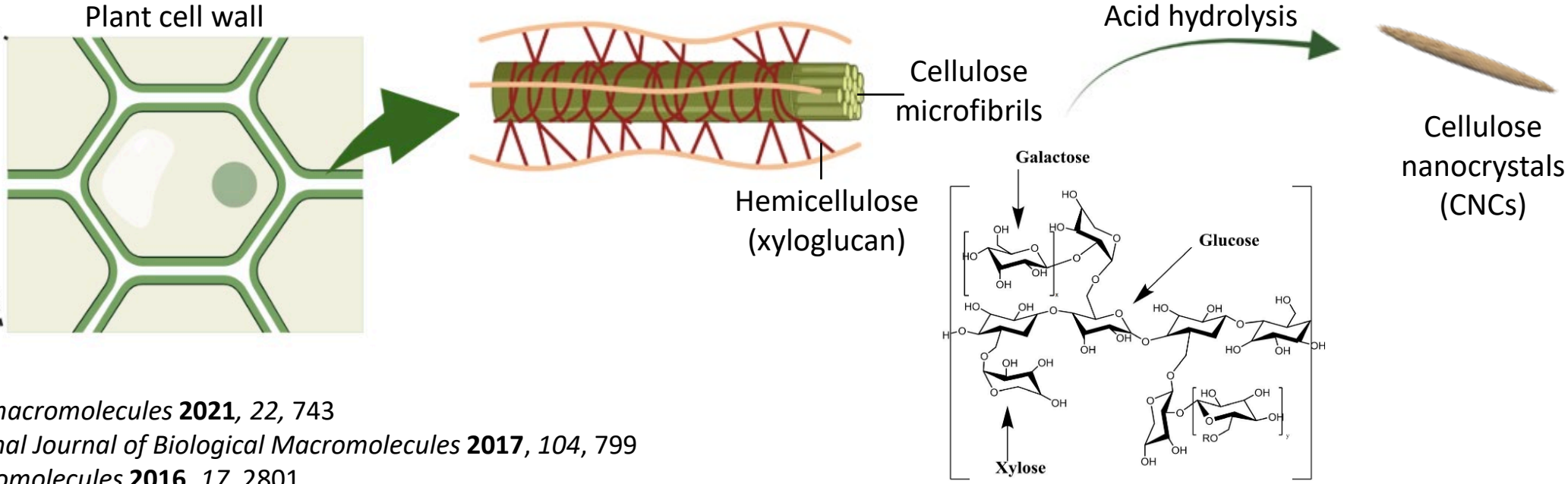



*Overview of what our spray dried crosslinked CNC microbeads look like*

# Biodegradable Microbead Composition



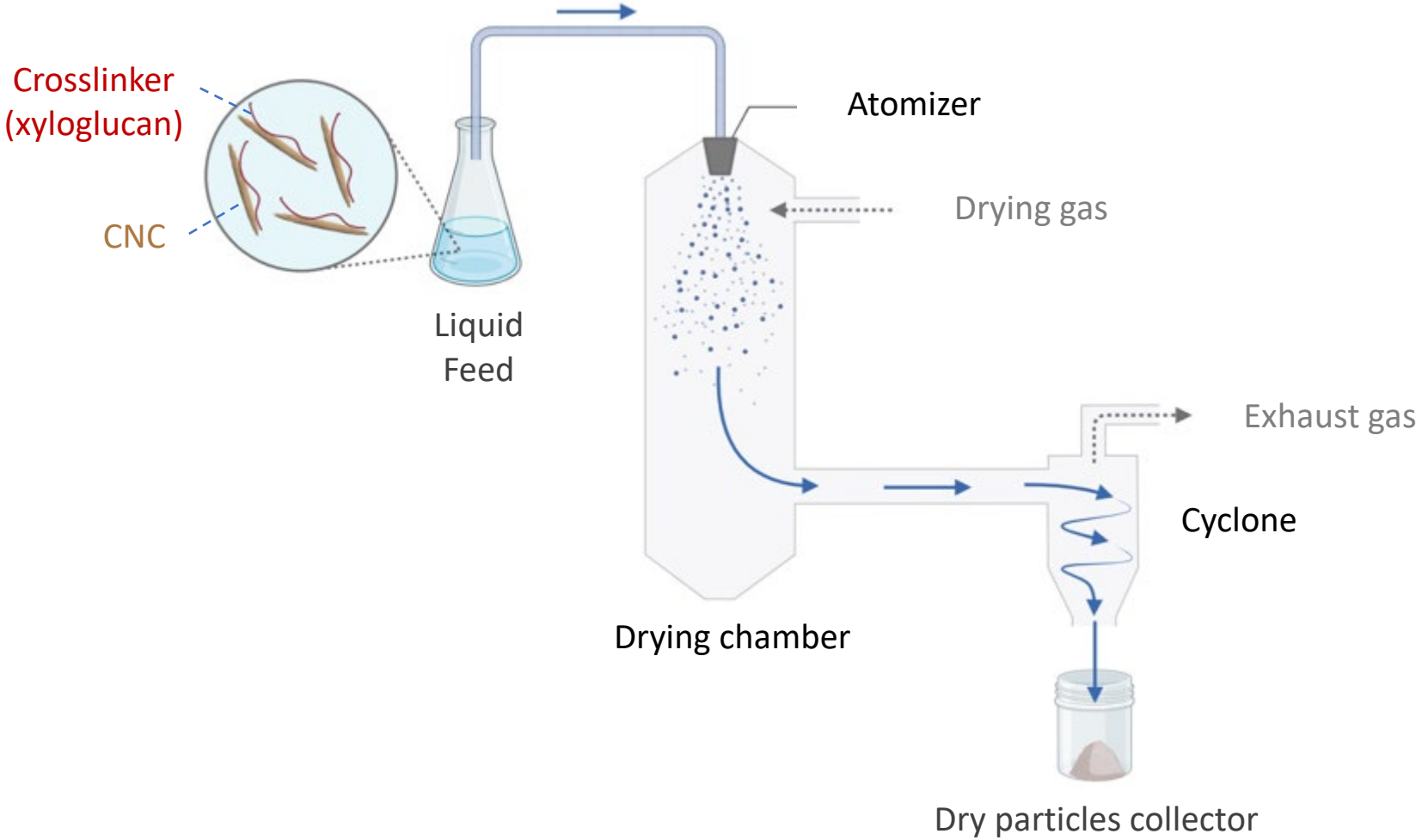
- **CNCs** and **xyloglucan** are the **main components** in our biodegradable microbeads inspired by their strong interactions in nature
- **Lab-made CNCs** are produced by sulfuric acid hydrolysis
- Xyloglucan (XG) is a hydrophilic polysaccharide





Talantikite, M. et al. *Biomacromolecules* **2021**, *22,* 743
Kulkarni et al. *International Journal of Biological Macromolecules* **2017**, *104*, 799
Benselfelt et al. *Biomacromolecules* **2016**, *17*, 2801
Brandt, Grasvik, Hallett & Welton. *Green Chemistry* **2013**, *15*, 550

# Spray Drying Offers Tunability

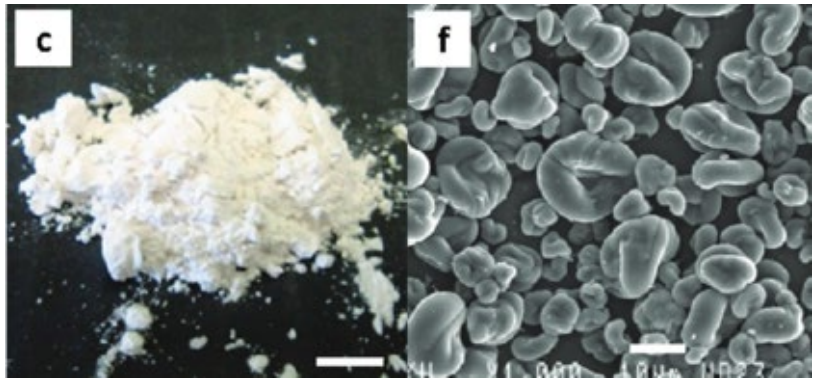



- ✓ Rapid
- ✓ Continuous
- ✓ Cost-effective
- ✓ Scalable process

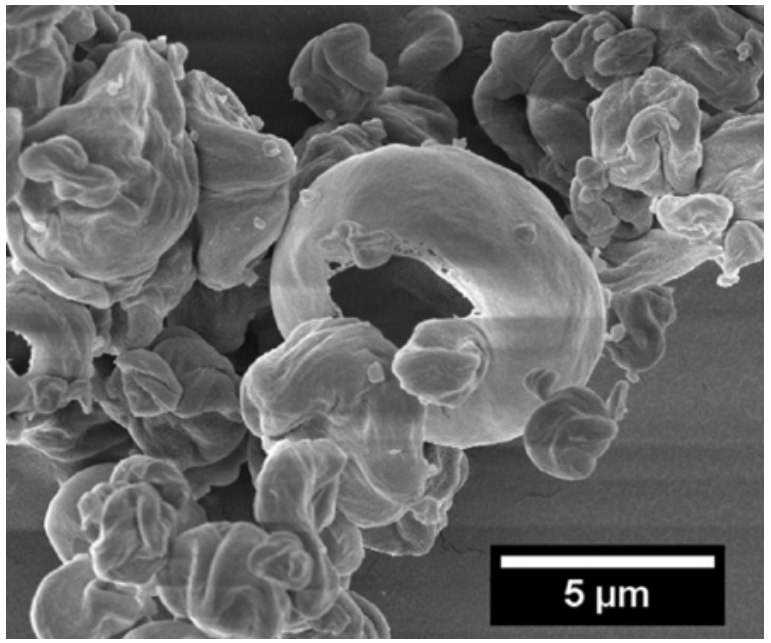
- ✓ The dry form is favorable
  - ↑ Product shelf-life
  - ↓ Shipping cost

Sosnik & Seremeta. *Advances in Colloid and Interface Science* **2015**, *223*, 40

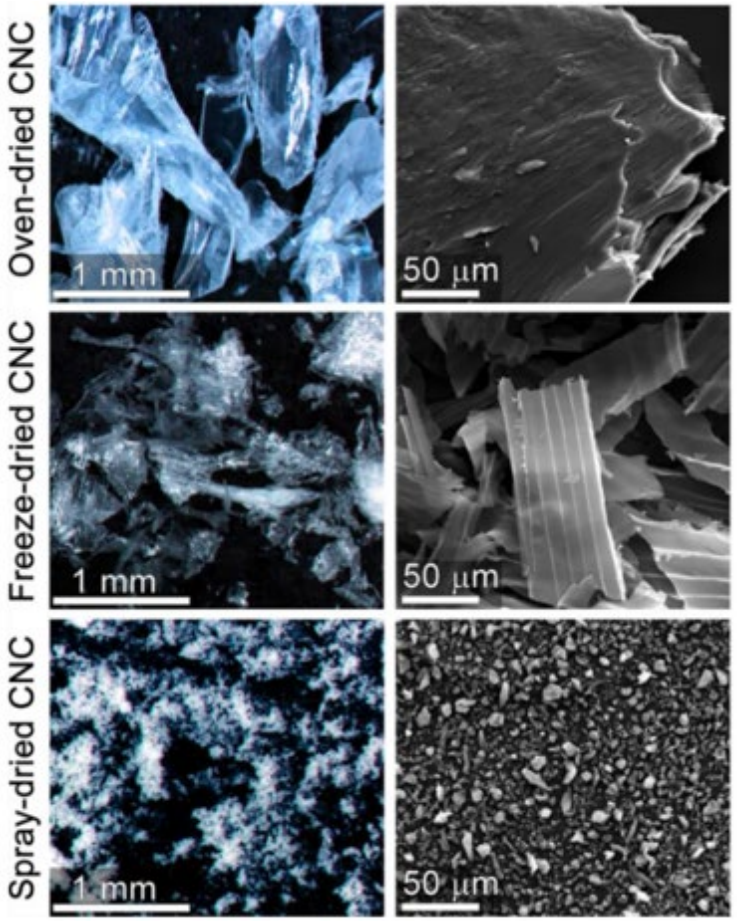
# Spray Drying + CNCs - Past Research




- Spray dried CNC powders are 5-30 µm, and require sonication to be fully redispersed in water.
- Spray dried sodium-form CNCs are easier to redisperse than acid-form CNCs.[1]




- Redispersable CNCs can be produced through spray drying parameters and additives.[2]




- CNCs can be dried into powders using different methods.[3]

**No examples of spray drying CNCs + xyloglucan (polysaccharides) exist in the literature to date**

1. Beck, Bouchard & Berry. *Biomacromolecules* **2012**, *13*, 1486
2. Esparza, Ngo, Fraschini & Boluk. *Industrial & Engineering Chemistry Research* **2019**, *58*, 19926
3. Sinquefield, Ciesielski, Li, Gardner & Ozcan. *ACS Sustainable Chemistry & Engineering* **2020**, *8*, 9601

# Hypothesis

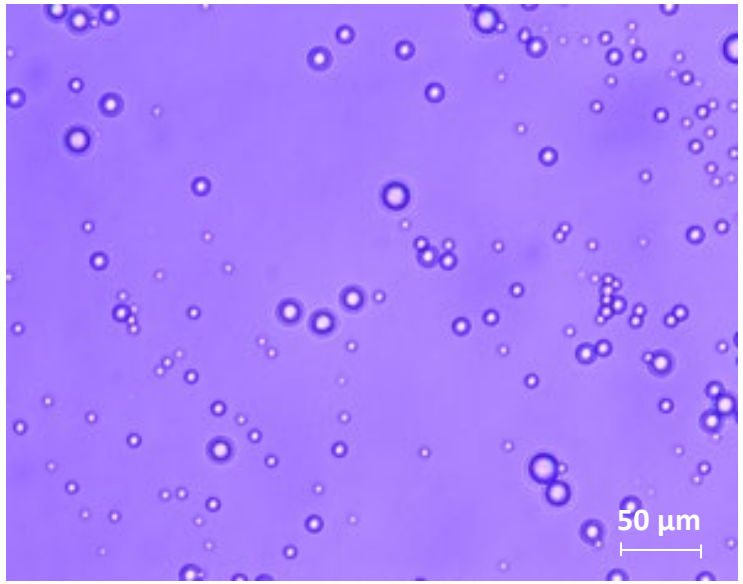
We can **control** crosslinked CNC microbead **morphology**
(size, shape, roughness, porosity, degree of crosslinking) and the **yield of the process** by

1. Changing the **concentration of CNCs and xyloglucan (and their ratio)**

2. Changing the **operational process parameters** of the spray dryer
   (temperature, aspirator rate and dry gas flow rate)

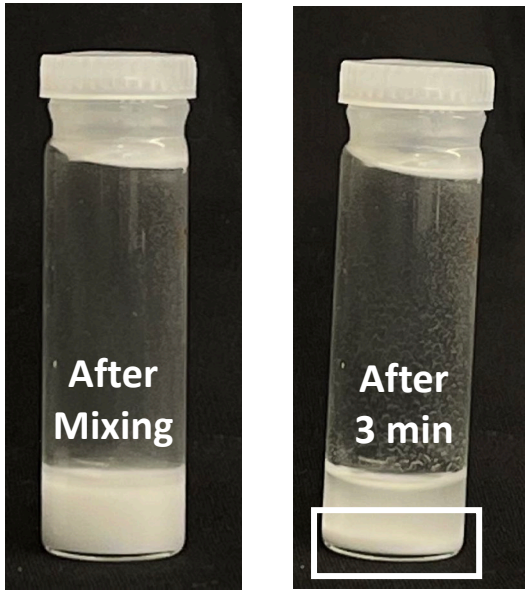
# Crosslinked CNC Microbeads in Water and Ethanol

- Crosslinked CNC microbeads could be spray dried into uniform powders under a variety of conditions




*Polarized optical microscopy of crosslinked CNC microbeads in water*

- Dry crosslinked CNC microbeads can be dispersed in a variety of liquids without breaking apart
- Microbeads are visually stable and similar in water and ethanol
- Some phase separation was observed after 3 min

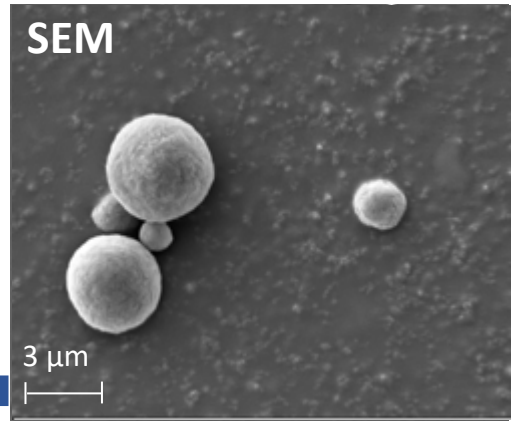


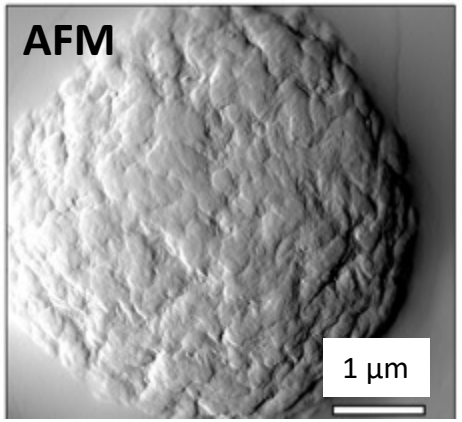

Phase separation

**Crosslinked CNC microbeads stay in-tact when exposed to liquids which is crucial for formulation and application**

# Concentration Affects the Microbead Yield and Morphology

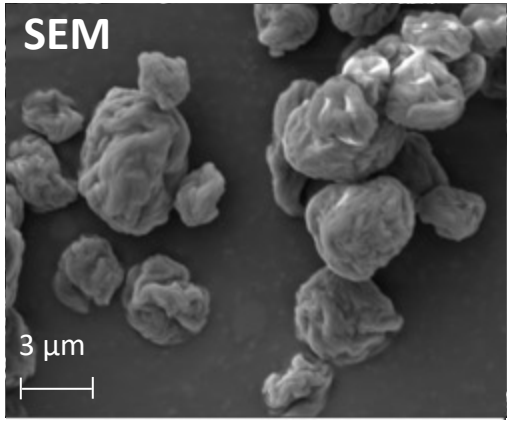
**Low conc.** 0.7 wt% CNC with 0.055 wt% xyloglucan

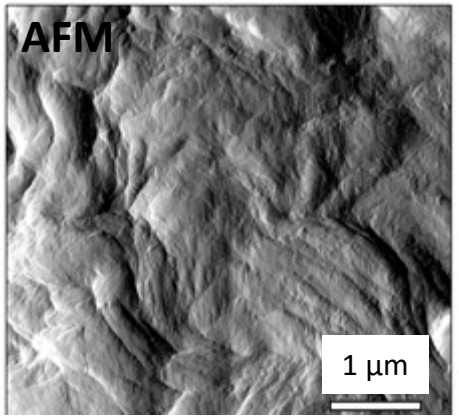


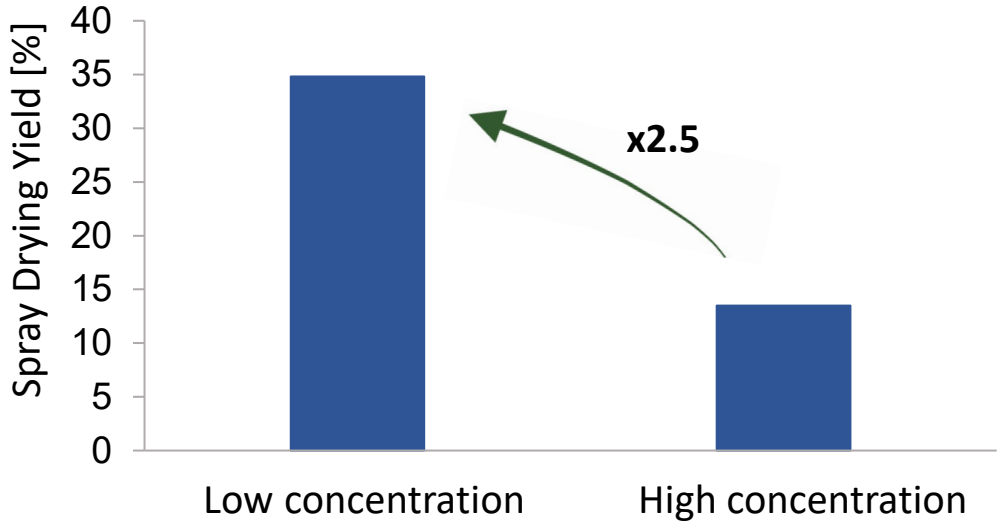



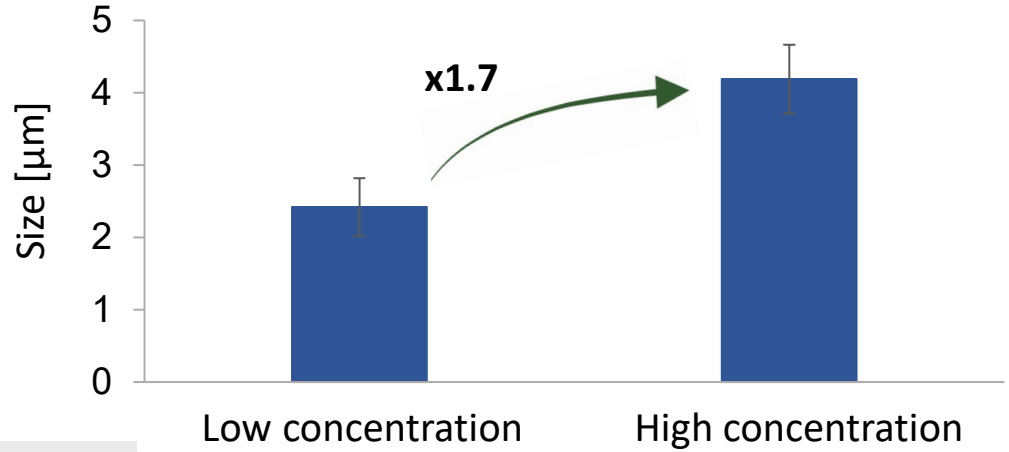

**Same CNC:XG ratio**
X3
in conc.

**High conc.** 2.1 wt% CNC with 0.165 wt% xyloglucan



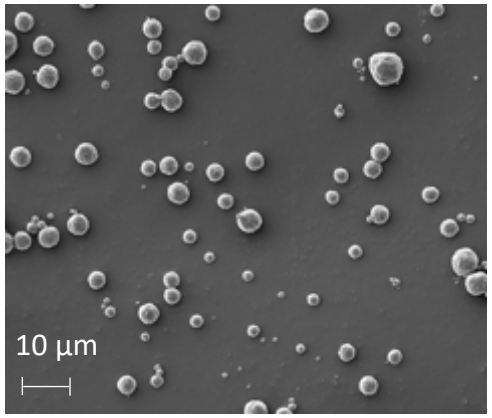



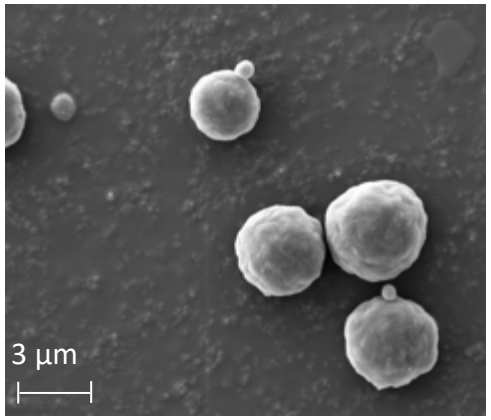




**Spherical particles with high process yield are produced when using low concentrations**

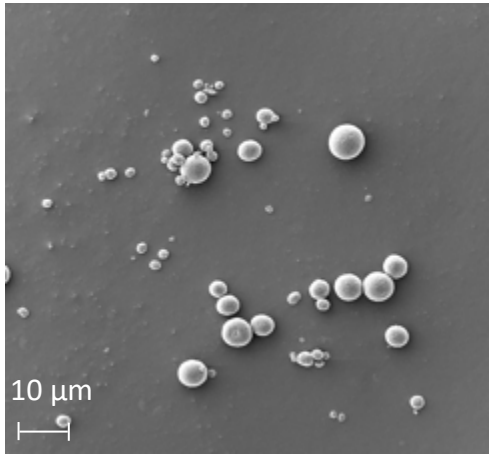
# Xyloglucan Affects Microbead Roughness

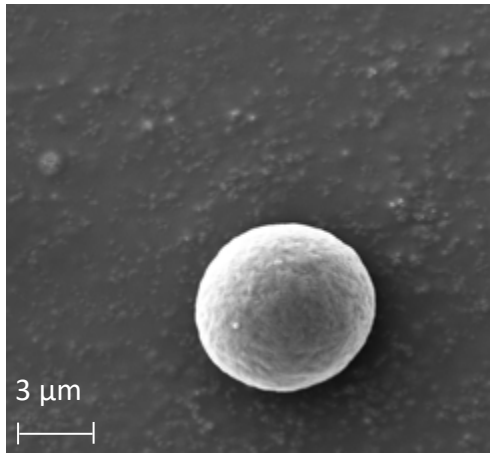
**CNC-only** 0.7 wt% CNC

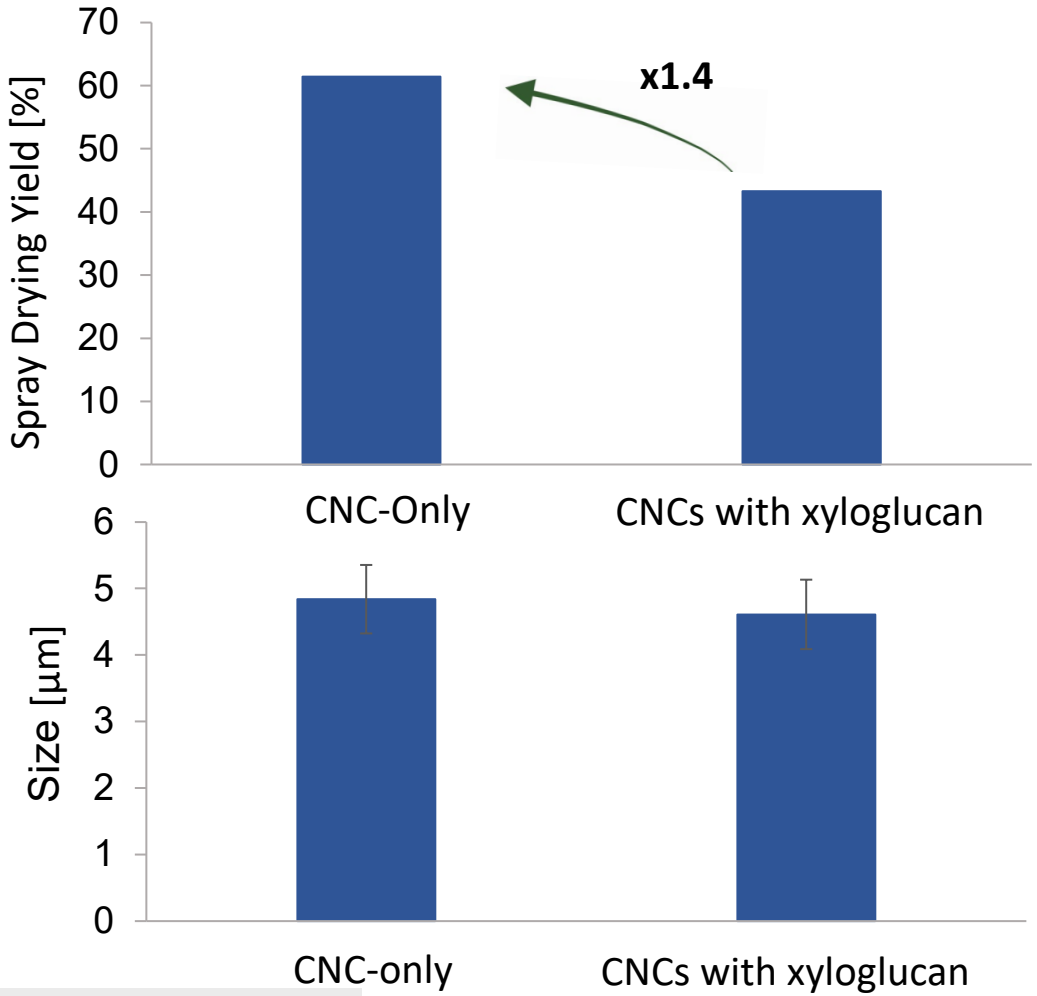



**CNC with xyloglucan** 0.7 wt% CNC with 0.1 wt% xyloglucan



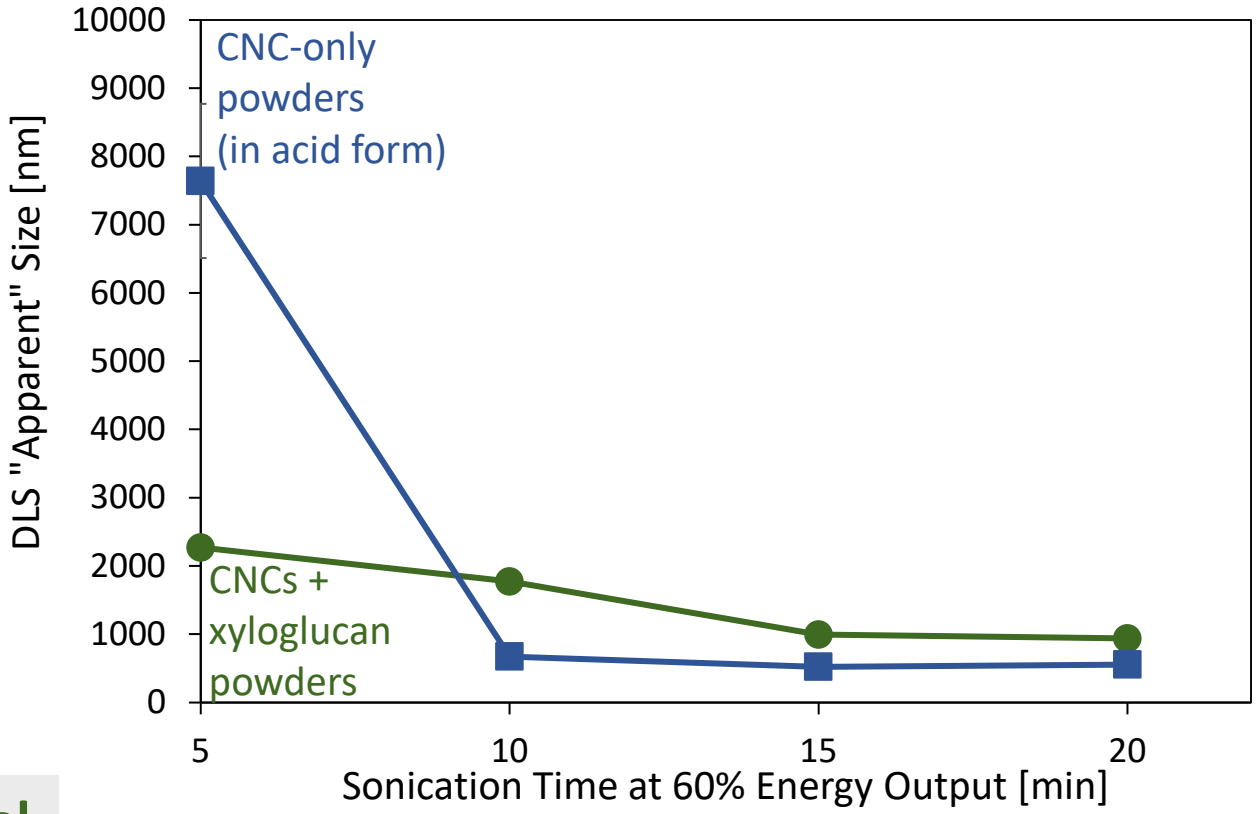




**Xyloglucan preserves spherical shape and size while reducing roughness (hopefully changes porosity & structural integrity)**

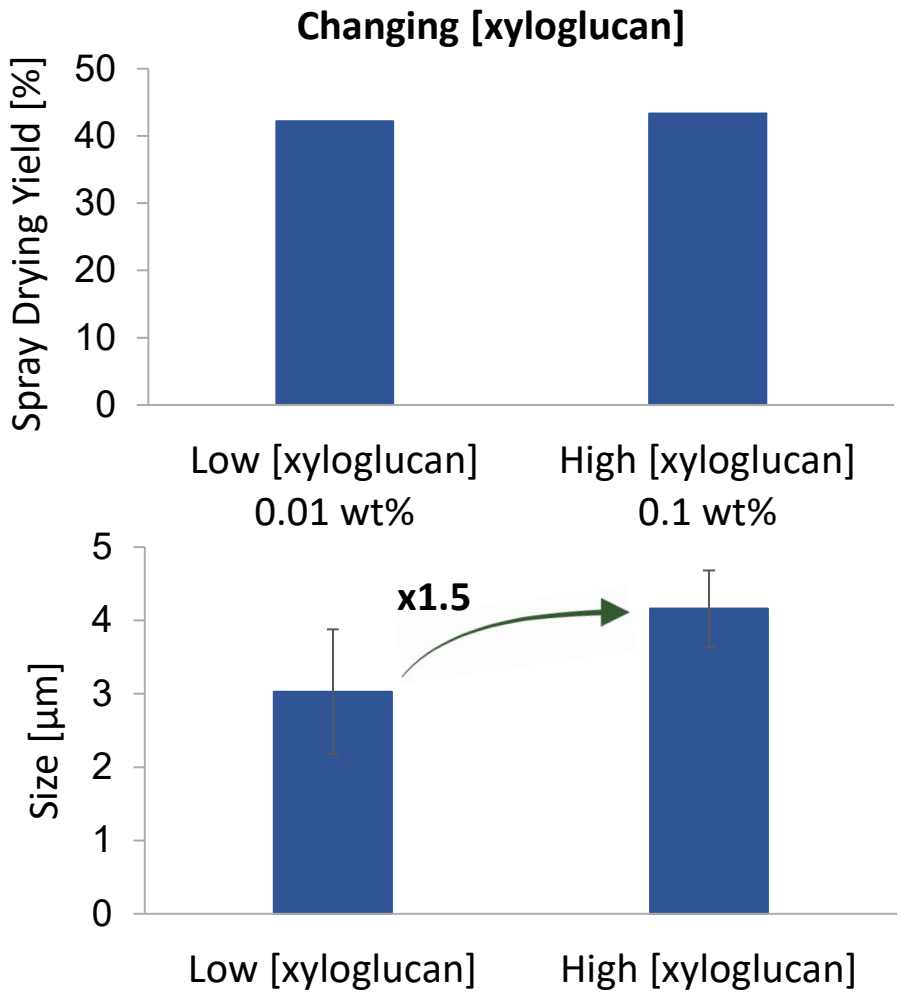
# Xyloglucan Effectively Crosslinks the Microbeads

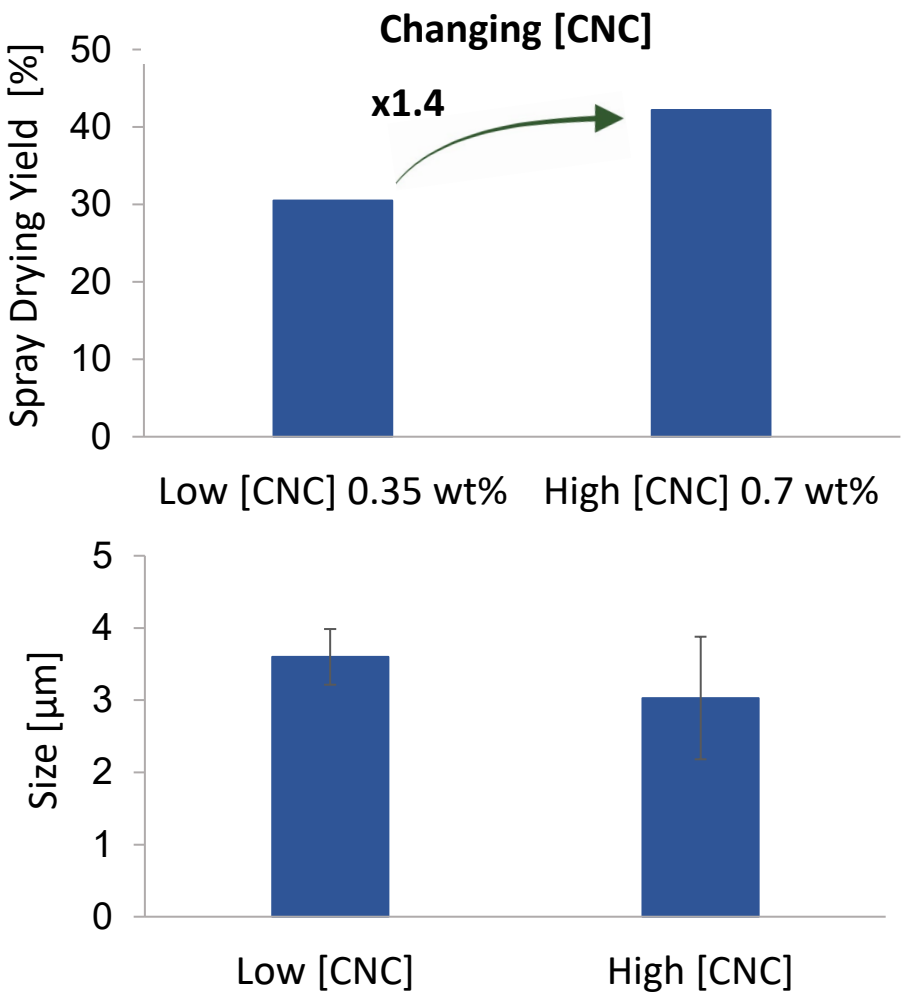
- Sonicating xyloglucan-CNC microbeads in water extensively only breaks them down to ca. 1 µm suggesting that xyloglucan is crosslinking the CNCs together
- Un-crosslinked CNCs in acid form break down more readily with sonication
- This is consistent with previous work on spray drying CNC-only powders in acid form
  (Beck, Bouchard & Berry. *Biomacromolecules* **2012**, *13*, 1486)

**The addition of xyloglucan increases the structural integrity of the microbeads in water**



# [Xyloglucan] Increases Size and [CNC] Improves Yield




**Increasing [Xyloglucan] → increases the size of the microbeads**

**Increasing [CNC] → increases the spray drying yield**

# Conclusions Part 1: Effect of Composition on Microbeads

- ✓ The **ideal CNC concentration** for producing spherical microbeads with high process yield: 0.7 wt% CNC

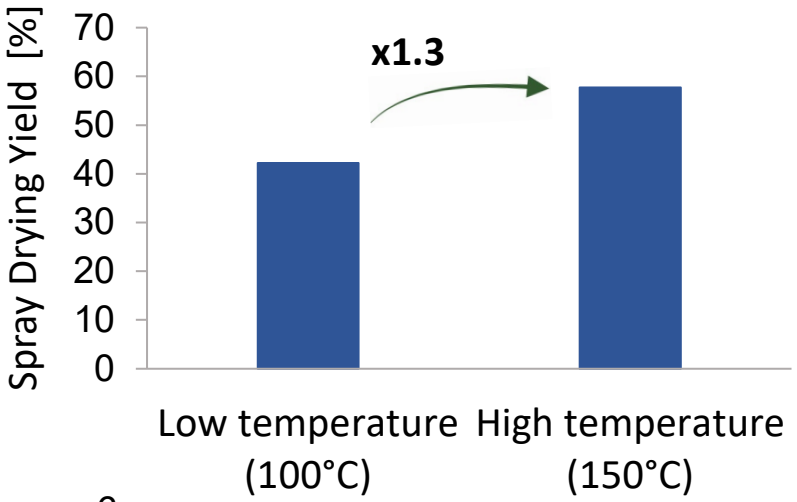
- ✓ The **contribution of adding xyloglucan:**
  (1) Ideal spherical particles
  (2) Control the roughness of the microbeads
  (3) Increases structural integrity (powders do not break apart)

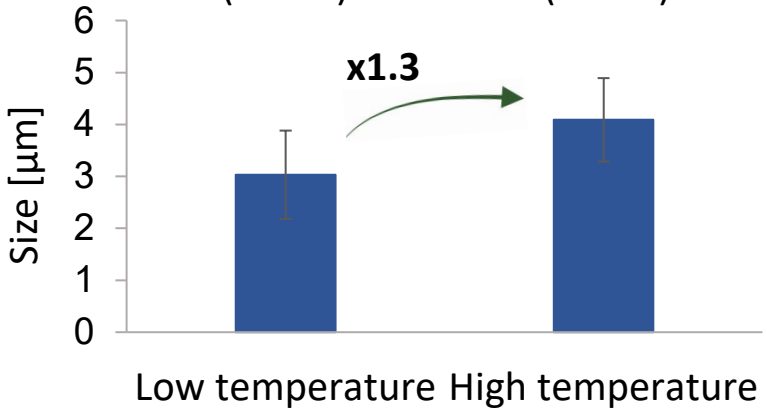
- ✓ **Changing [CNC]** primarily influences the process yield, whereas changing **[xyloglucan]** influences the particle size

**But what will happen if we play with the spray drying operational process parameters?**

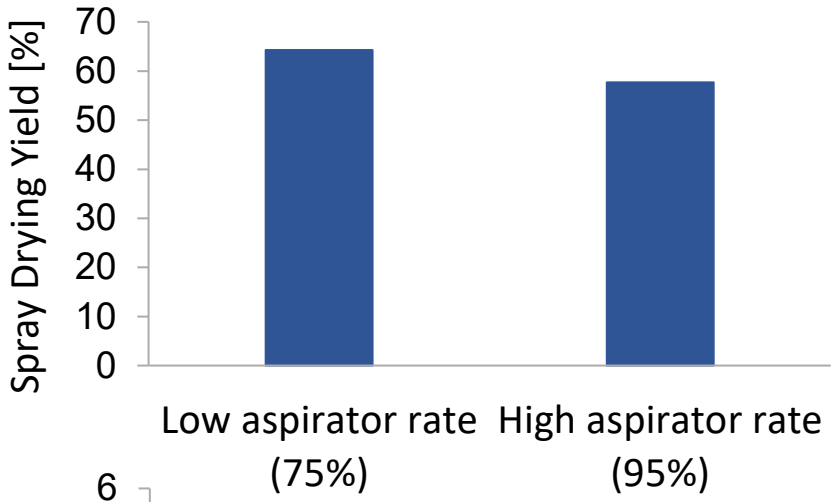
# Effect of Temperature, Aspirator Rate and Gas Flow

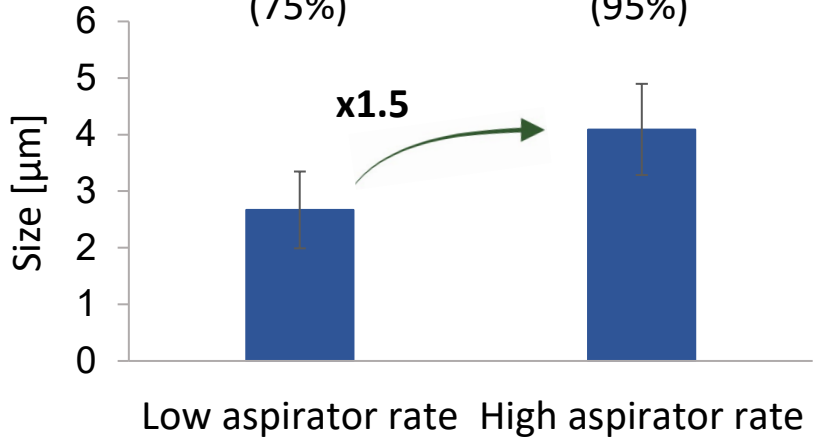
**Changing the temperature**



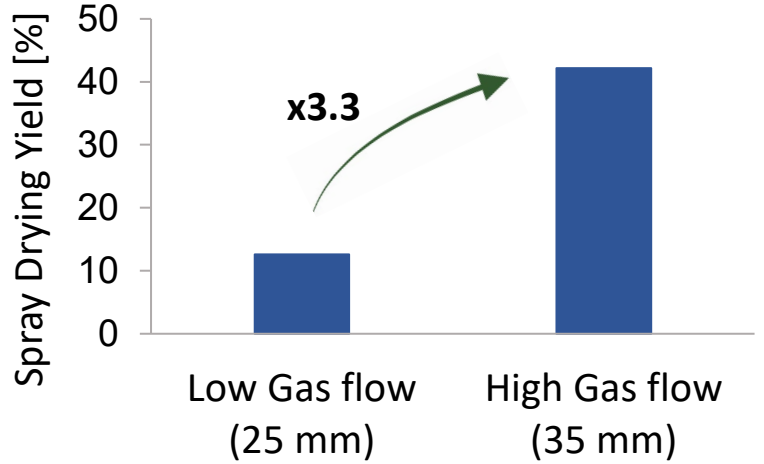



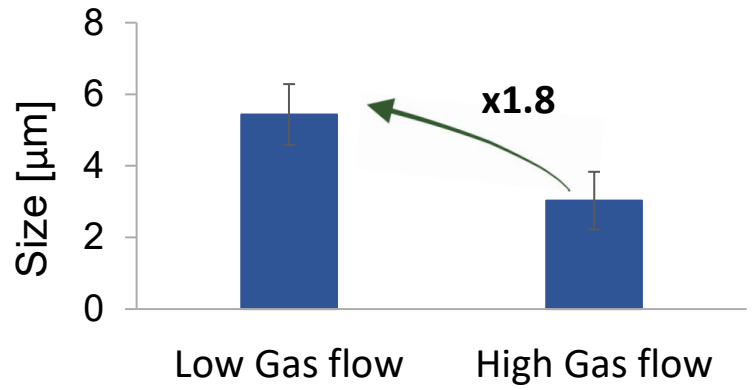

**Changing the aspirator rate (volume flow)**




**Changing the gas flow rate**




**The spray drying gas flow rate has the largest effect on the process yield and the size of the xyloglucan-CNC microbeads**

# Conclusions Part 2: Effect of Operational Process Parameters

- ✓ *Increasing* the *temperature* → *increases* the process yield and the size of the microbeads

- ✓ *Increasing* the *aspirator rate* → slightly *decreases* the process yield and *increases* the size of the microbeads

- ✓ *Increasing* the drying *gas flow rate* → *increases* the process yield and *decreases* the size of the microbeads

**Different parameters can produce microbeads with different properties**

# Ongoing Work: Design of Experiments (DOE)

- By conducting *repetitive experiments:*
  (1) *Predict* how different parameters affect the desired outputs
  (2) *Determine* the direction for future experiments and create a protocol for tailored microbeads

- *Inputs:* (1) aspirator rate, (2) inlet temperature, (3) spray gas flow, (4) CNC:XG ratio

- *Outputs:* (1) size, (2) yield, (3) roughness

*Number of Experiments:* $2^4 + 3 = 19$

4 inputs

Two levels from each input (high and low)

Triplicates from the central point

**Design of experiments approach (DOE) will be used to quantitatively predict how different inputs control microbead performance**

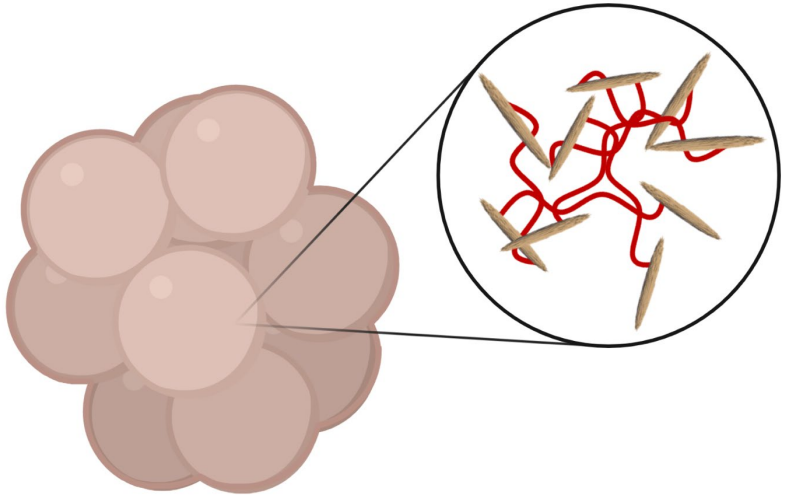
# Future Work

- Conducting **DOE** and statistical modelling
- Evaluating xyloglucan-CNC microbead **stability in water** over time
- Understanding **surface area** and **porosity** of microbeads for controlled sorption/release applications
- Exploring **modified xyloglucan** and other crosslinkers
- Evaluating the degree of **biodegradability** of the microbeads

# Take Home Message

- Spray drying operational process parameters allowed for the production of tailored dry powder microbeads and spray drying is a scalable technique
- CNC and xyloglucan concentration influence microbeads morphology (size, roughness)

**Biodegradable crosslinked CNC microbeads with morphological control were prepared by spray drying. These microbead may be an environmentally friendly alternative for non-degradable microbeads in personal care and cosmetics products**



# Acknowledgments


Special thanks

Orlando Rojas

Eupidio Scopel

Marcus Johns

Ariane Fernandes


Thank You for Listening

תודה

Regarding questions about [CNC] and [XG]:

A. Why does increasing [CNC] increase the process yield? Less water content → more dry.
**CNCs are the main components** of the biodegradable microbeads. **When increasing [CNC] in the precursor: (1)** increase **viscosity**, **(2)** decrease **water content**. The first may lead to **bigger droplets**, and the second leads to the **production of dry microbeads** that tend to stick **less on the edges of the chamber**, which results in a high process yield.
I would expect that it increase the size of the microbeads too since the suspension is more viscous.

B. Why does increasing [XG] increase the size of the microbeads?
XG has a high affinity to CNC. When increasing [XG] it leads to the formation of more crosslinked CNC particles and suspension with **higher viscosity**. As a result, bigger droplets pass through the aspirator, creating bigger particles.

C. Why does the addition of XG reduce roughness (more smooth particles)?
**XG fills in spaces between randomly oriented CNCs** leading to **smoother and denser structure** (the structure is somewhat stratified due to drying steps during deposition)

D. Why does the addition of XG increase the structural integrity of the microbeads? Higher resistance of the microbeads – mimic the behavior in nature.
In nature, the main rule of **XG is to increase the mechanical strength of the plant cell wall.** Due to its high affinity to CNC, XG **increases the strength of the microbeads and structural integrity** of the microbeads, **resulting in more stable microbeads that do not tend to break apart.**

Regarding questions about the SD parameters:

E. Why does increasing the inlet temperature increase the process yield?
The process of **solvent evaporation** (heat transfer) is faster, so particles are drier and **stick less on the edges** of the chamber.
I would expect that the particle size decrease since the particles are drier → and less agglomeration is happening.
Answer to that: I believe that the role of the dry gas in this combination is more dominant then the tamp.

F. Why does increasing the aspirator rate lead to increasing the size of the microbeads?
When increasing the aspirator rate **the volume flow is higher**, so **more particles are fed into the chamber** which results in **increasing the size of the microbeads**

G. Why does increasing the spray gas flow rate lead to decreasing the size of the microbeads and increasing the yield?
Increasing the gas rate increases the droplet temperature and **promotes liquid evaporation**. **Dryer microbeads** are produced, that **stick less on the chamber** which results in higher yield.

Decreasing the gas rate results in the production of microbeads with **higher moisture content that tend to agglomerate**, so the size of the **microbeads is bigger**.

2. You might get asked about whether the differences in your yield/size values are statistically significant and you should try to avoid making too many conclusions from “trends” that aren’t significantly different

**I did a t-test for all the variables and the ones that were statistically significant I took into consideration as a proof of concept. Of course, repetitions are needed to be done.**

4. As discussed, lets talk about porosity rather than surface area and somewhere say that we hope that crosslinking will give us microparticles that have pores and internal surface area similar to nanomaterials (and this is important that they don’t go into the skin… what size is that, by the way?)

**Particle penetration into the skin:** there is **no indication that particles bigger than 100 nm in size can pass the skin barrier.**

5. **“my intuition tells me that**…”) and “**we are still in the exploratory phase so that is an excellent question/suggestion**” should be a good answer for almost anything 😊