

Preparation and Application of Nanocellulose Hydrogels

Priprava in uporaba nanoceluloznih hidrogelov

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Why Nanocellulose?

- Most abundant natural polymer – basis of the paper industry
- Growing need for sustainable, bio-based materials
- Nanocellulose → renewable, biodegradable, high-performance material
- Unique nanoscale structure → new functional properties
- Key role in transition to circular materials economy



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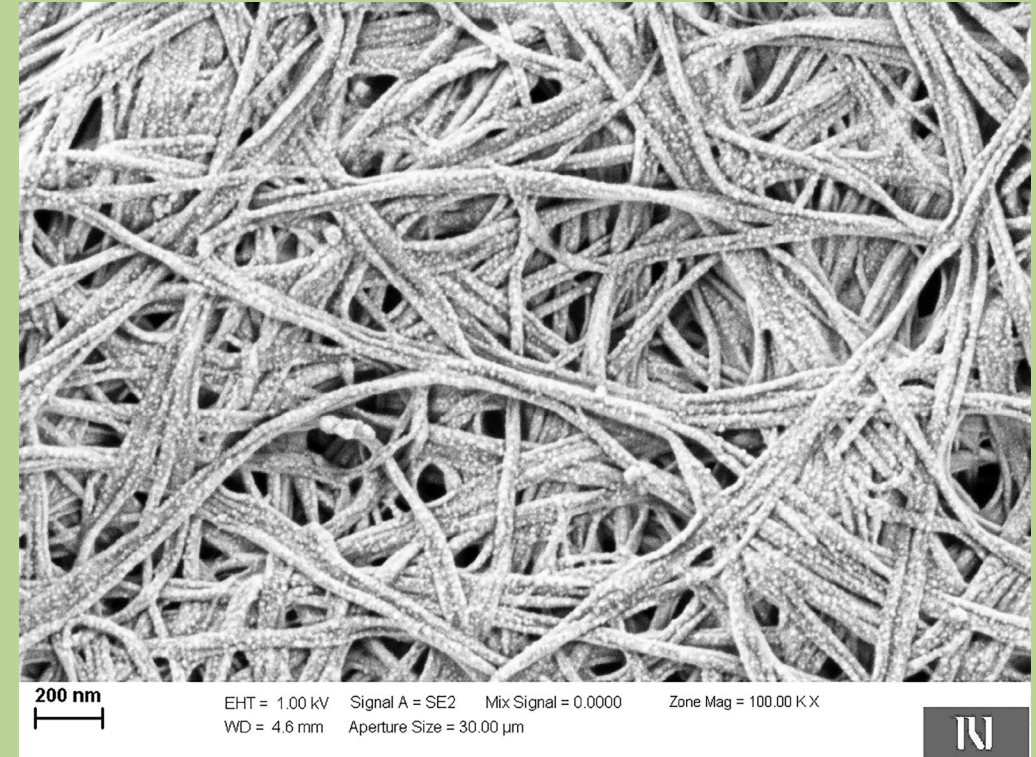
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Types of Nanocellulose

<i>Type</i>	<i>Source</i>	<i>Production</i>	<i>Characteristics</i>
CNC (nanocrystals)	Plant cellulose	Acid hydrolysis	Rigid, crystalline
CNF (nanofibrils)	Plant cellulose	Mechanical fibrillation	Flexible, fibrous
BNC (bacterial)	Bacteria (Komagataeibacter)	Fermentation	Pure, 3D network

Bacterial Nanocellulose (BNC)

- Produced by bacteria, e.g. *Komagataeibacter xylinus*, through fermentation
- Chemically pure – no lignin or hemicellulose
- Preformed 3D nanofibrillar network
- High crystallinity, strong hydrogen bonding
- Excellent water retention and film-forming ability



Advantages of Bacterial Nanocellulose

<i>Property</i>	<i>Advantage</i>	<i>Relevance</i>
Purity	Free of lignin and hemicellulose	No need for chemical processing
Structure	3D nanofibrillar network	Dimensional and structural stability
Water retention	Up to 200× its dry mass	Suitable for hydrogel formation
Biocompatibility	Non-toxic, renewable	Bio-based material
Formability	Films, gels, 3D structures	Adaptable for packaging and printing



Research Focus

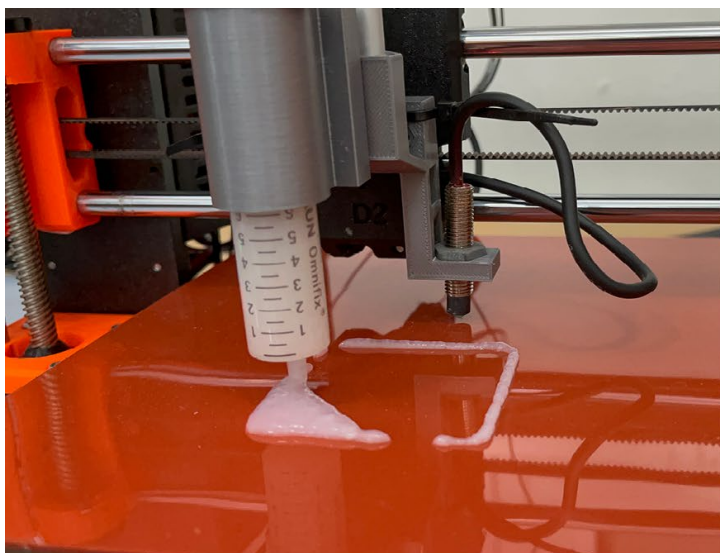
- Develop hydrogel formulations based on BNC and cationic starch
- Study effects of additives:
 - Citric acid (crosslinker)
 - Sodium hypophosphite (catalyst)
 - Glycerol (plasticizer)
- Evaluate structure, stability, and rheological properties

Experimental Process

- Two-phase research approach:
 - Phase 1: BNC + cationic starch (no additives)
 - Base formulations: 50/50, 60/40, and 70/30 BNC/starch ratios (2% solids)
 - Phase 2: Addition of citric acid, sodium hypophosphite, and glycerol
 - Base formulation: 60/40 BNC/starch ratio (2% solids)
- Aim: evaluate printability, structure, and drying behavior

Results: Phase 1 – Base Formulation

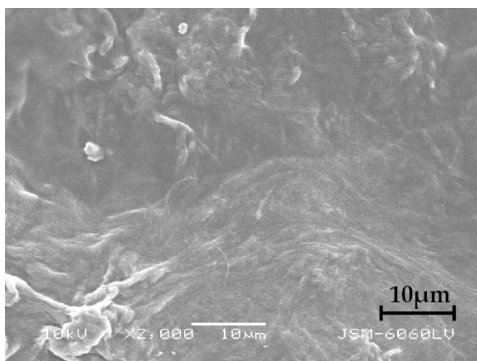
- BNC–starch hydrogels successfully 3D printed into foils
- All three ratios printable: 50/50, 60/40, 70/30
- All showed good printability and surface uniformity
- Demonstrated good layer adhesion and structural integrity



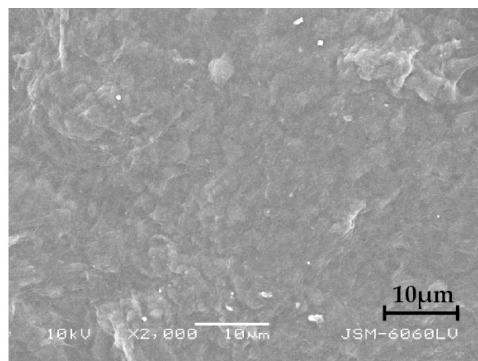
(a)



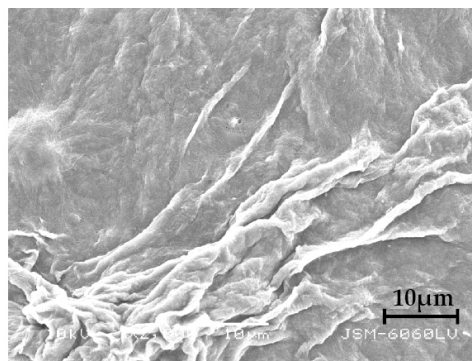
(b)



(a)



(b)



(c)



(a)



(b)



(c)



(d)



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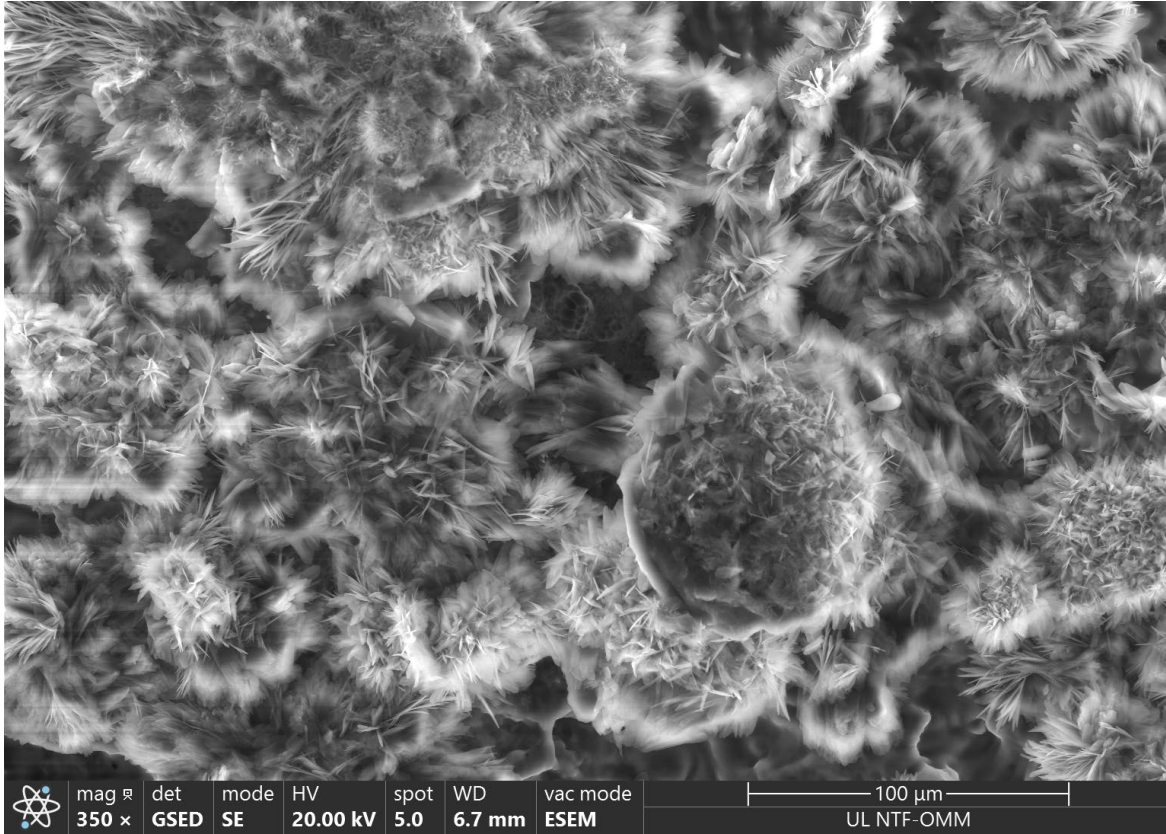
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Phase 2 – Additive Testing

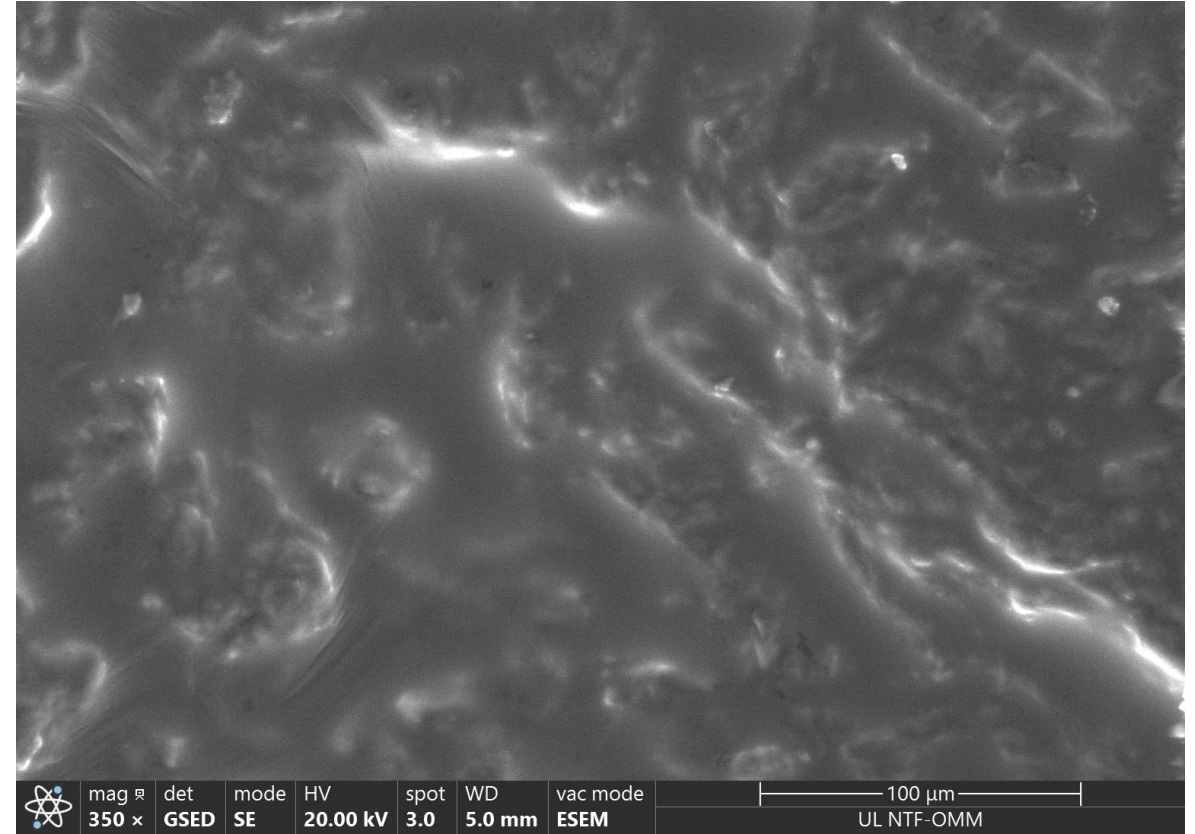
- Reference base: 60/40 BNC/starch hydrogel
- Additives tested:
 - Citric acid (crosslinker)
 - Sodium hypophosphite (catalyst)
 - Glycerol (plasticizer)
- 12 formulations prepared and analyzed by SEM/EDS

SEM and EDS Analysis

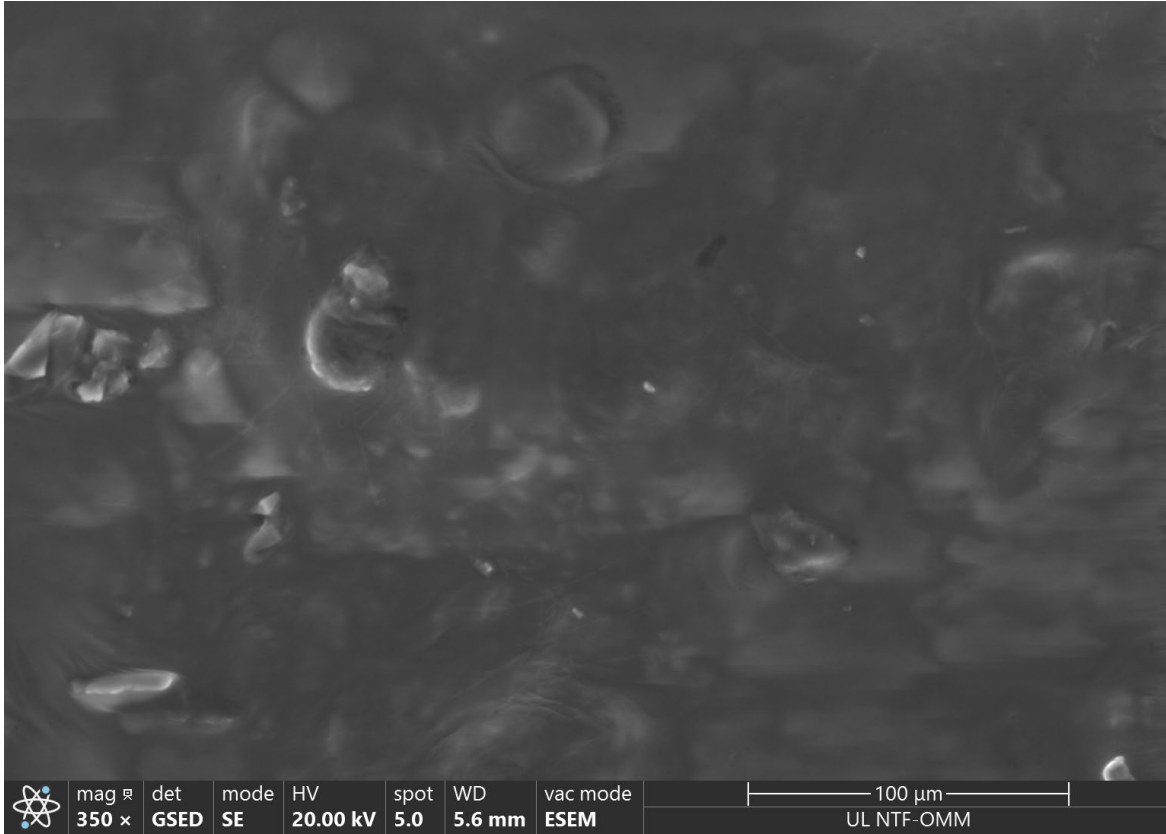
- Structural and morphological differences between samples
- Crystalline deposits at higher citric acid content
- Smoother surfaces with glycerol addition
- Na and Ca residues from culture medium



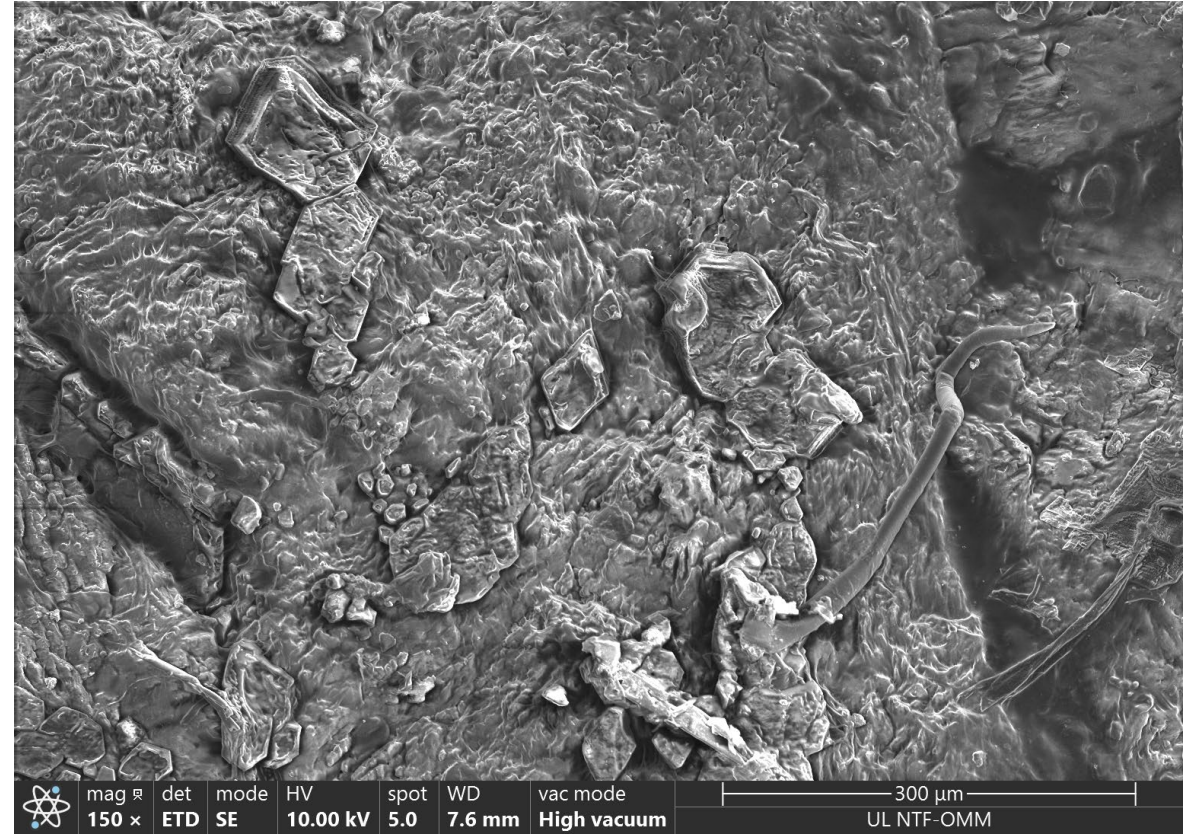
Sample 2 – H L L (20% CA, 0.5% SHP, **0% Gly**)



Sample 6 – H L H (20% CA, 0.5% SHP, **2% Gly**)



Sample 8 – H H H (20% CA, **2% SHP, 2% Gly**)



Sample 11 – CA 20% Only

Preliminary Findings

Observation	Preliminary Interpretation
Crystalline areas at high citric acid content	Excessive crosslinking and partial crystallization
Smoother surfaces with glycerol	Improved homogeneity, lower drying stability
Catalyst promotes uniform structure	Enhanced network formation
Na and Ca detected	Residues from BNC cultivation medium

Current Stage and Next Steps

- Phase 1: confirmed printability of BNC/starch hydrogels
- Phase 2: testing additive combinations
- Next phase: rheological, mechanical, and thermal analysis
- Goal: stable 3D-printable hydrogels for packaging

Outlook

- BNC-based hydrogels unite biotechnology and material science
- Printable, tunable, and sustainable
- Potential for advanced bio-based packaging
- Supports the transition to a circular bioeconomy

Thank you.

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