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Microfibrillated Cellulose (MFC): High Solids Production and Barrier Coating of Fruits

J.Y. Zhu

USDA Forest Service, Forest Products Lab, Madison, WI

Contributors:

Jing Geng, Xiao Zhang Voiland School Chem. Eng. and Bioeng., Washington State University

Jonatha Crane, Yuncong Li Tropical Research and Education Center, IFAS, University of Florida

Xiaoxue Zhang, Nicole Stark, Peter Kitin, Kevin Perzynski USDA Forest Products Lab

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The Problems and Research Rationale

- Postharvest losses of fruits and vegetables (F&V) in the storage and transportation accounts for 20-55% of production, which represents a significant economic loss.
- Barrier coating by forming a physical barrier can preventing gas permeation to extend the shelf life of F&V and decrease postharvest loss
- Cellulose fibrils are inherently safe and have been demonstrated effective for barrier coating.
- Cellulose fibrillation is energy intensive and often conducted at 2% solids, represents great water usage and high transportation cost.

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Relevant to Land Management

- Expand wood fiber utilization by commercialization of cellulose nanomaterials technologies
- Support the US pulp and paper industry with many pulp mill closures in recent years.
- Support wood residue usage
- Support US agriculture

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Research Objectives

- Demonstrate MFC barrier coating of various fruits
  - Appearance. Weight loss, Firmness, Soluble solids
  - Respiration
- Field trial of MFC barrier coating
  - Appearance. Weight loss, Firmness, Soluble solids
- Demonstrate high solids production of microfibrillated cellulose (MFC), or cellulose microfibrils (CMF)
  - Understand solids loading on fibrillation

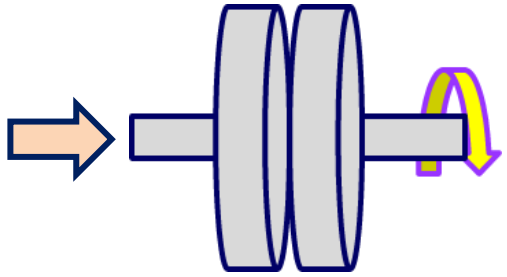
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MFC Production



2.5 kWh/kg

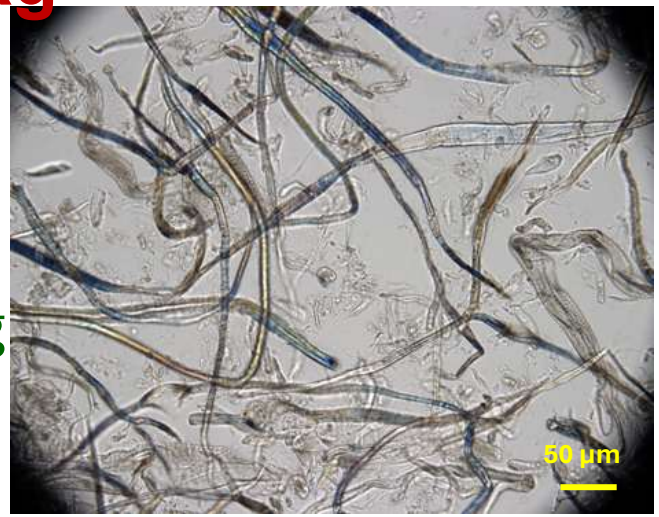
Mechanical
Grounding/Refining

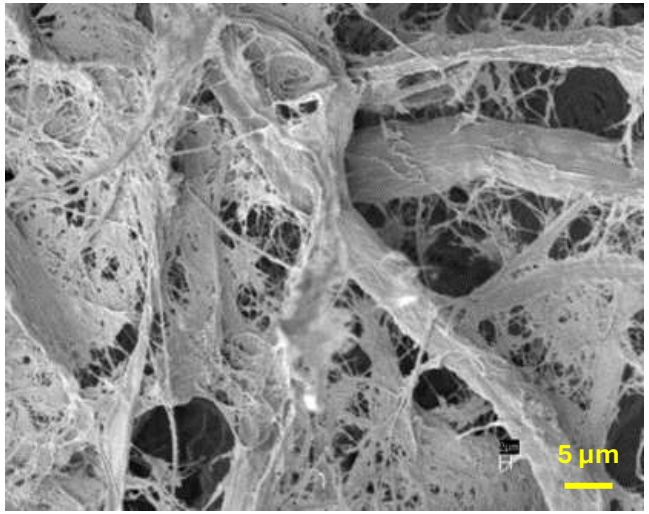


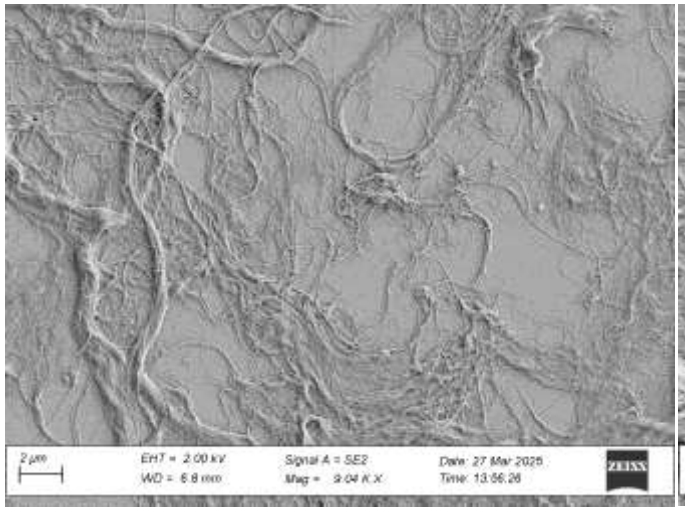
Varied solids

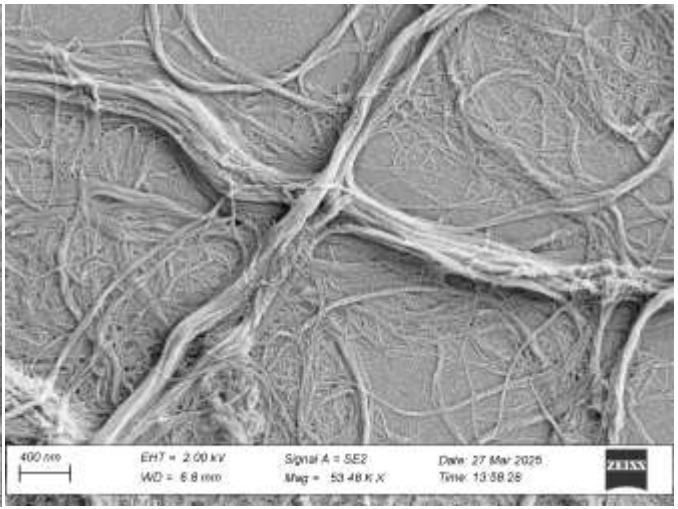


~8 kWh/kg









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Lab Study: Barrier Coating of Fruits – Objective 1



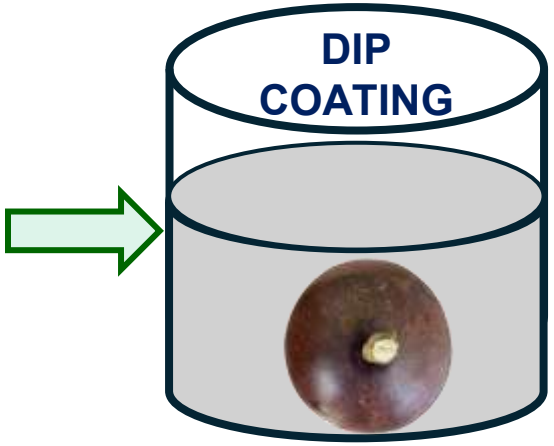
Bleached kraft hardwood pulp



MECHANICAL FIBRILLATION

CMC





DRYING

STORAGE

Coated star apple



Uncoated star apple



STORAGE



Barrier Coating on Star Apple

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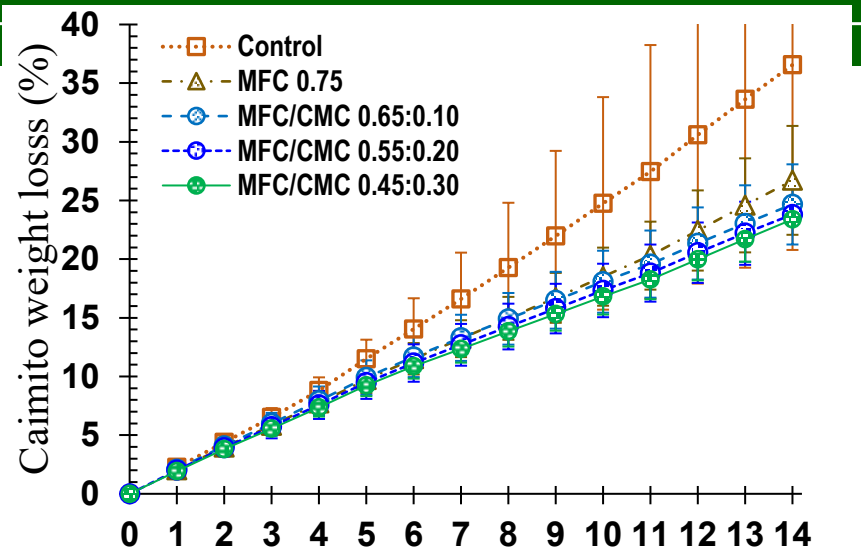


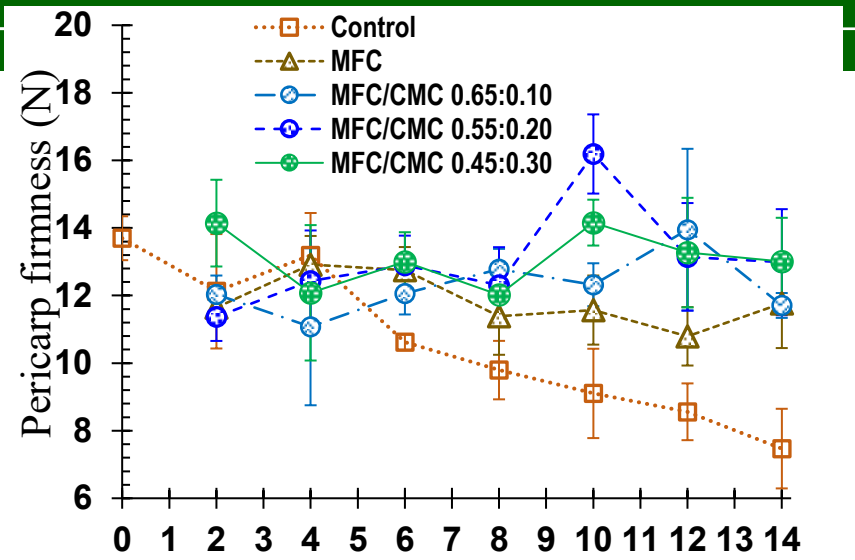
Barrier Coating on Star Apple

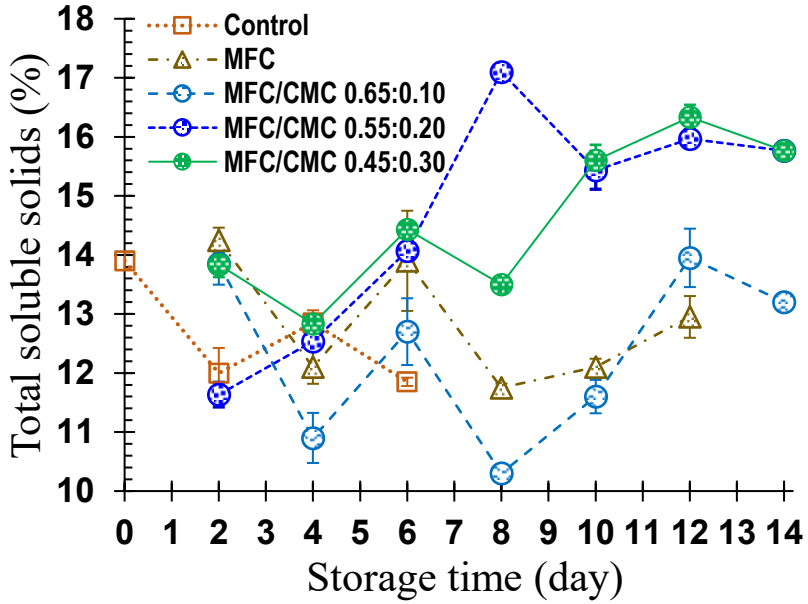


Weight loss, Firmness, TSS

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Geng et al (2026)

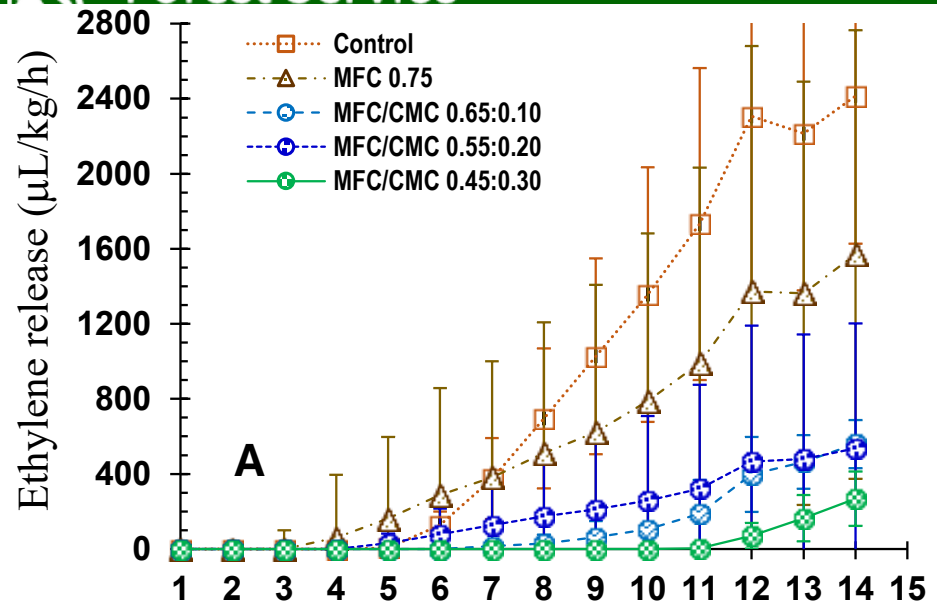
Sustain Food Technol

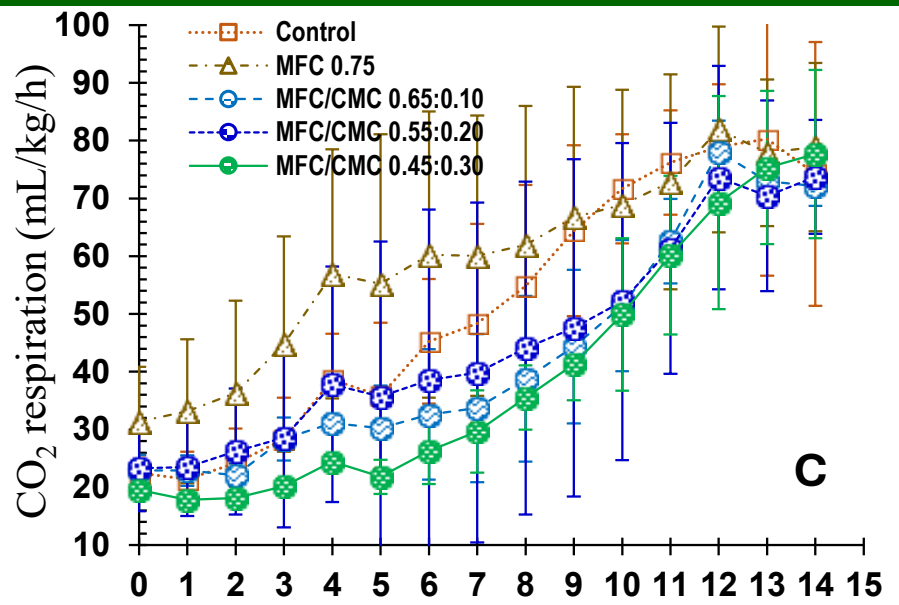
DOI: 10.1039/D6FB00169F

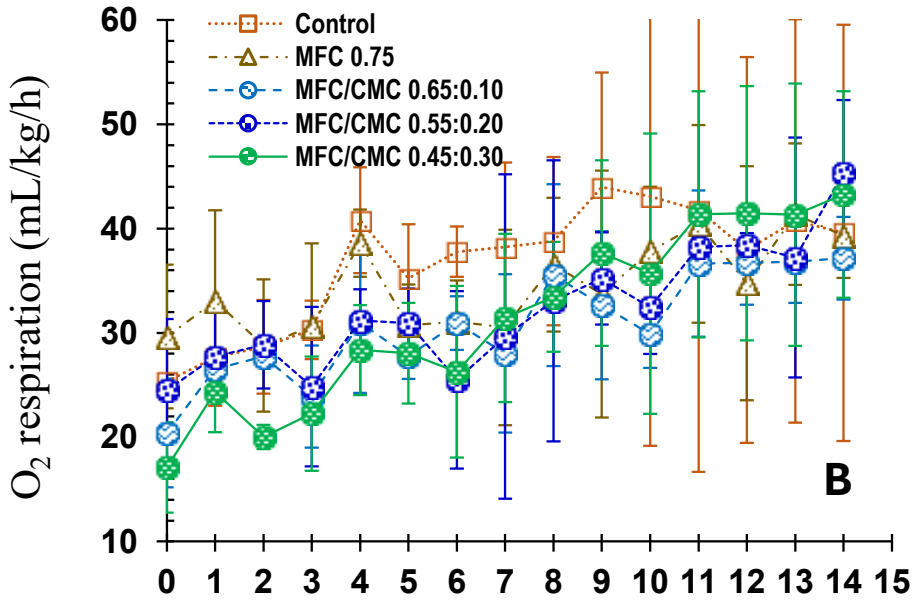
Gas Respiration

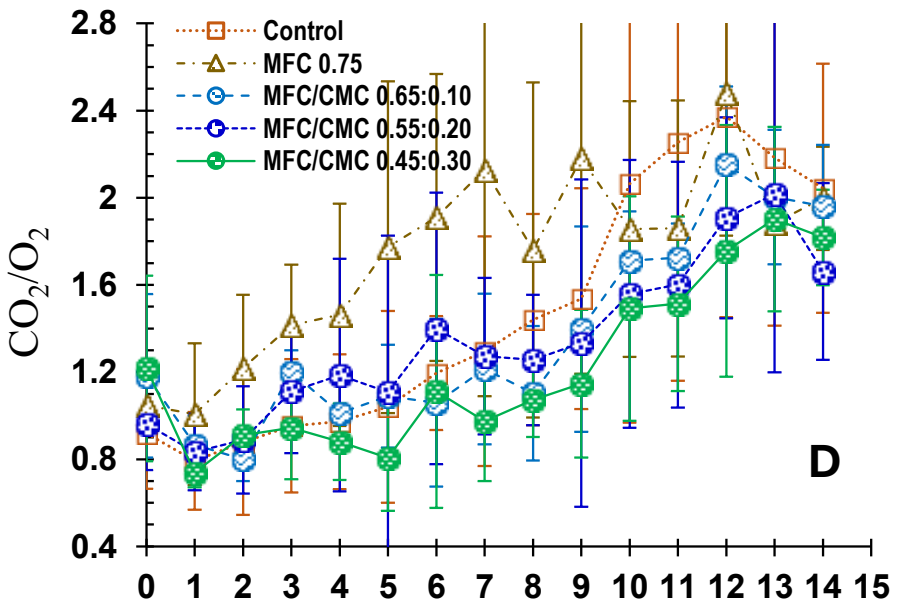
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Geng et al (2026) *Sustain Food Technol* DOI: 10.1039/D6FB00169F









Costs of Materials and Energy Estimates

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Geng et al. (2026) *Sustain. Food Technol.* 4, DOI: 10.1039/D6FB00169F

- **Coating materials cost: 0.696 g/kg $0.0035/kg star apple**
  - Coating film grammage: 10 g/m^2; MFC and CMC $5/kg
  - Star apple: density = 1.116 g/cm^3; D = 7.73 cm; W = 269.8 g

Star apple in S FL at $20/kg

- **Electricity inputs:**
  - Electricity for: CMC = 1.50 Wh/kg CMC = 0.42 Wh/kg star apple @40% CMC
  - Cp = 3.5 kJ/kg/K; MFC = 13 MJ/kg MFC = 1.51 Wh/kg star apple @60% MFC
  - For cooling to 5 °C for preservation: 6.08 Wh/kg star apple
  - For cooling to 20 °C with barrier coating: 2.43 Wh/kg star apple
  - COP = 4; Truck (15x2.5x3 m) R = 30; Storage space inefficiency = 30%
  - For cooling maintaining at 5 °C for 14 days: 0.824 Wh/kg star apple
  - For cooling maintaining at 20 °C for 14 days: 0.330 Wh/kg star apple

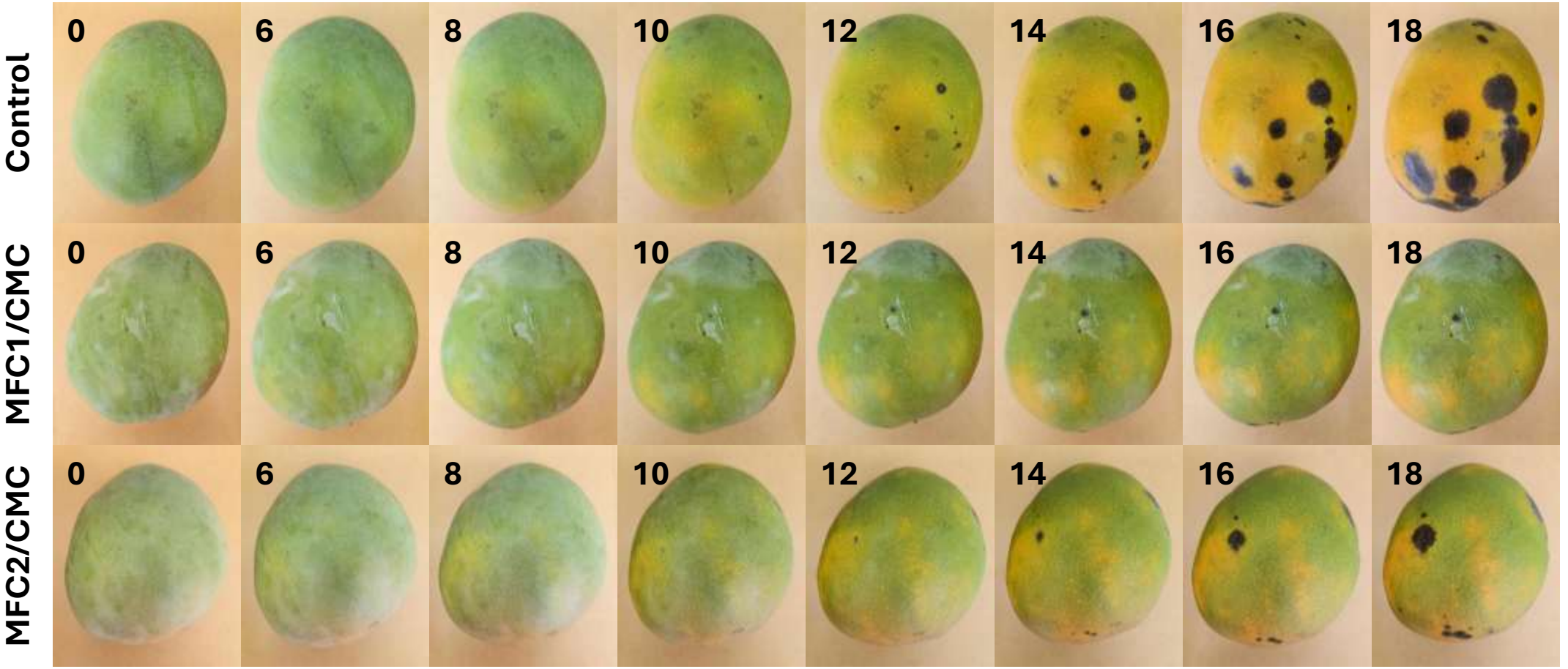
Electricity saving: 2.22 Wh/kg star apple

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Barrier coating of ‘Kent’ Mango

‘Kent’ Mango

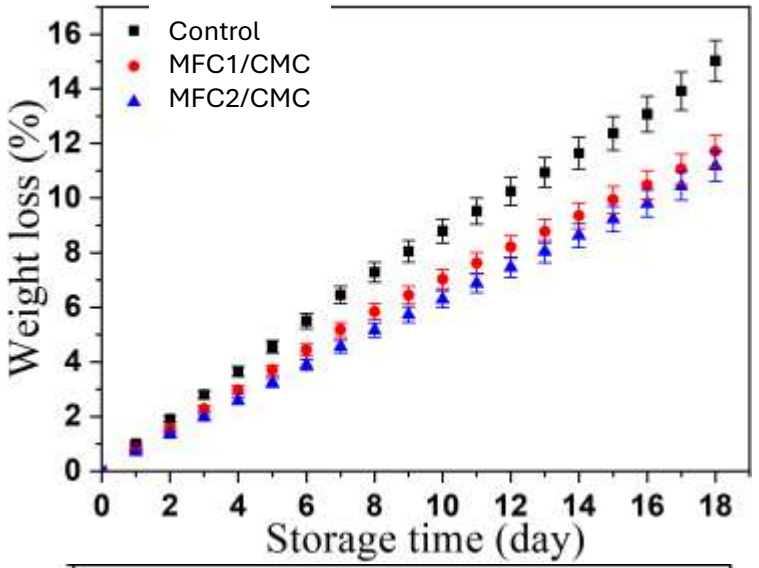
0.70:0.05 wt% MFC/CMC
0.70:0.05 wt% UMFC/CMC

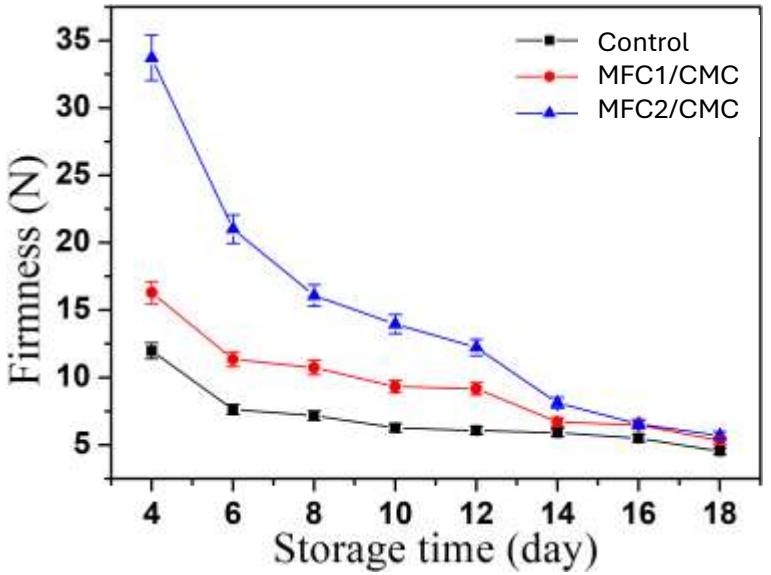


‘Kent’ Mango

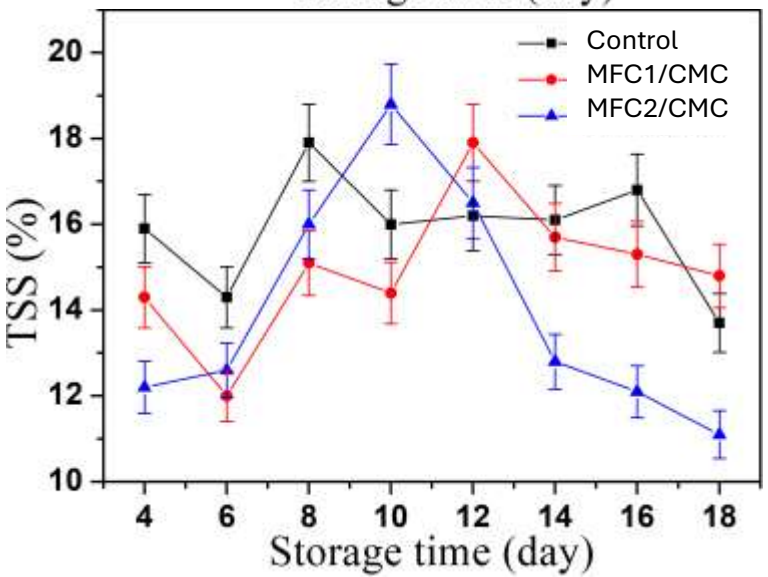
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Geng et al. (2026) *Sustain. Food Technol.* 4, DOI: 10.1039/D6FB00169F

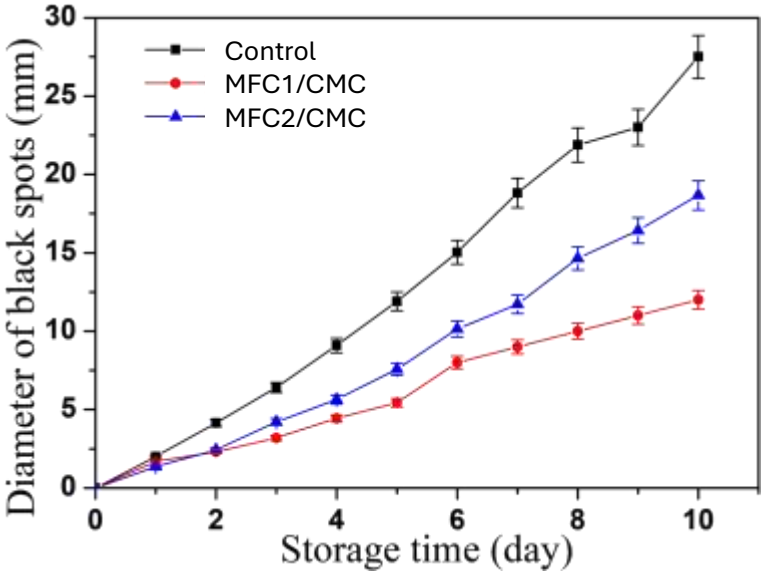




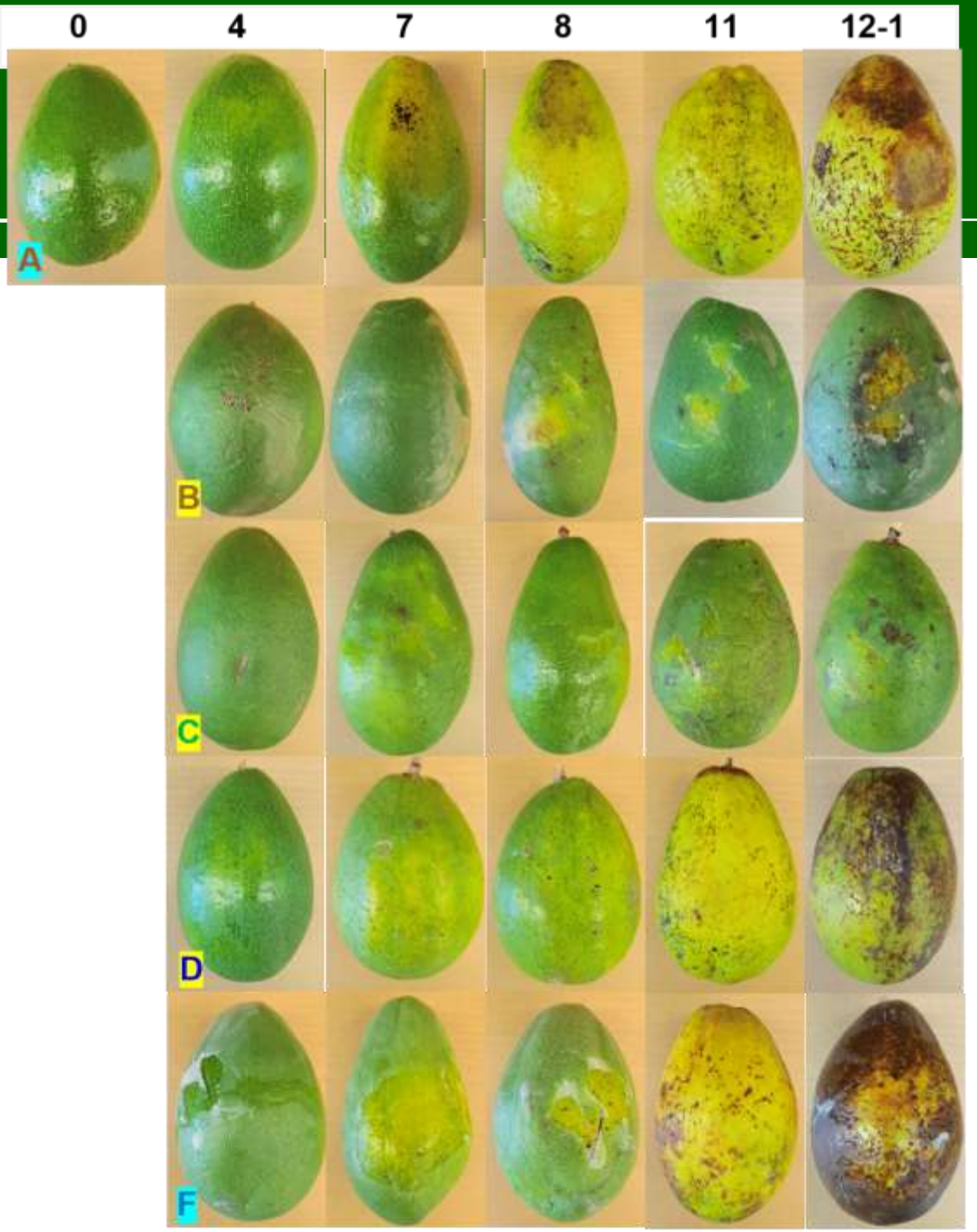
UMFC/CMC coating can reduce weight loss and delay the pulp softening more than MFC/CMC coating.



MFC/CMC coating can better inhibit the conversion to sugars, and slow down the spread of black spots.

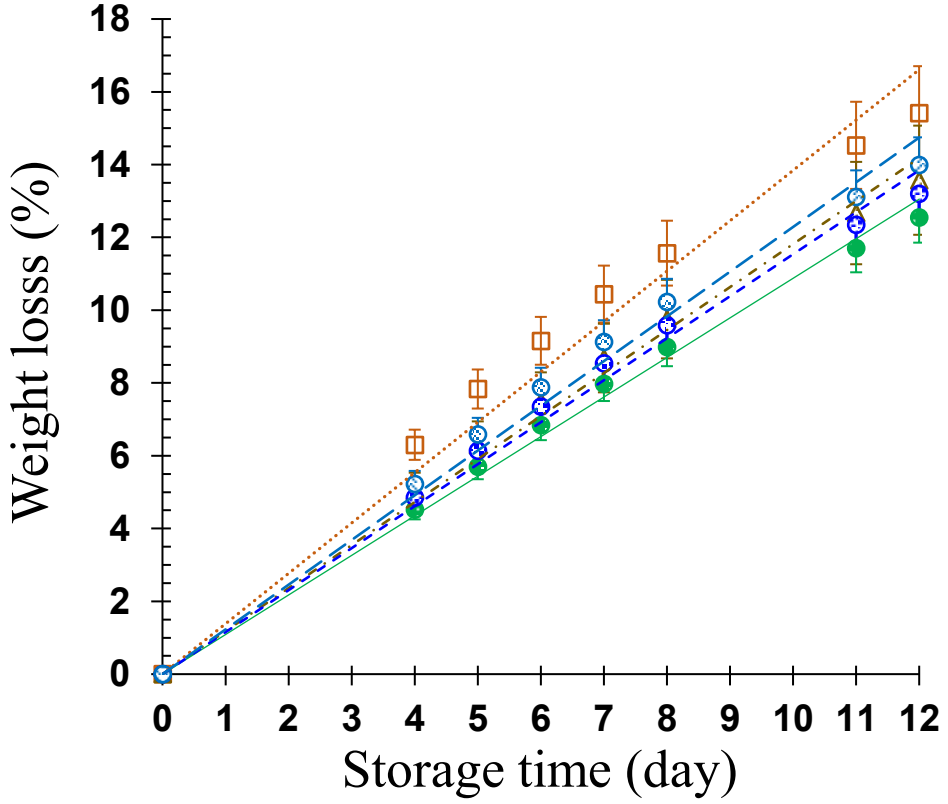


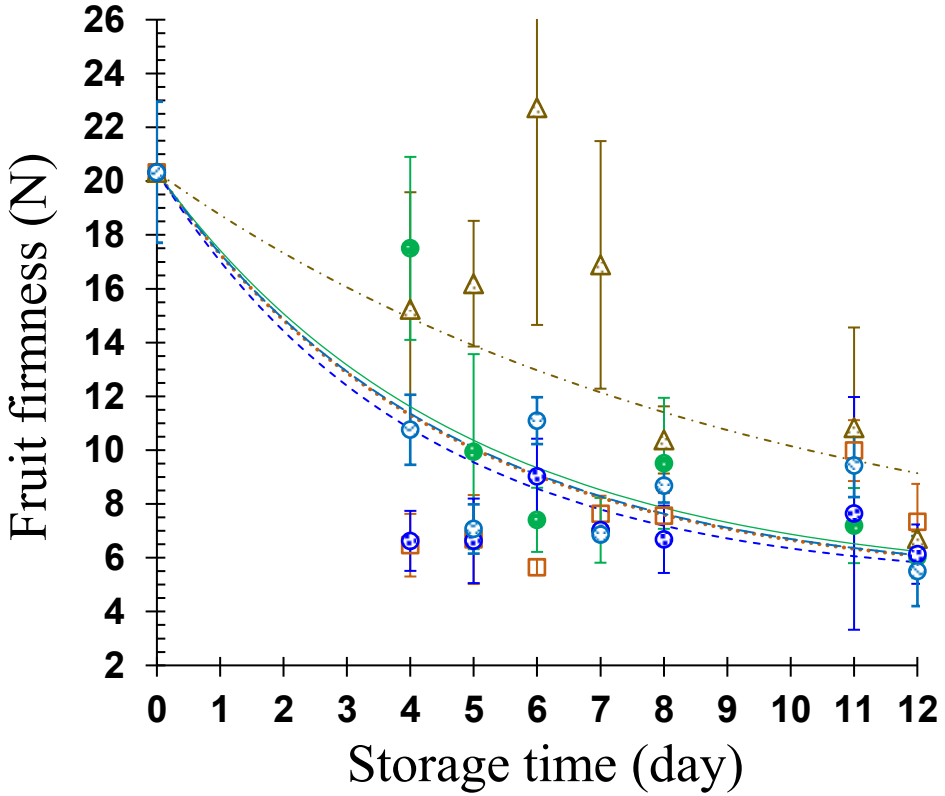

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Avocado – Lab Study





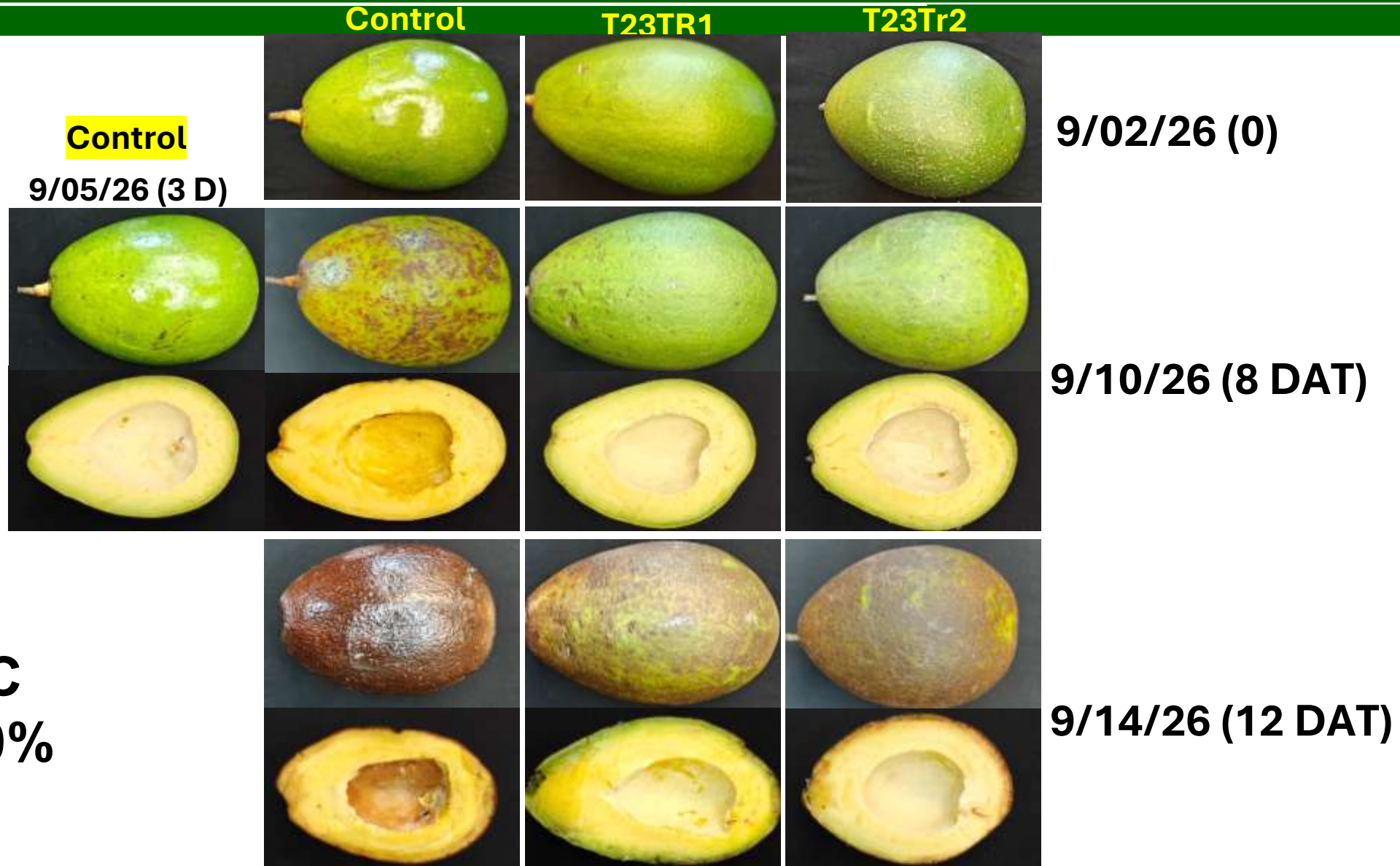
Avocado – Field Trial: Objective 2





Avocado – Field Trial Study
Objective 2: Storage at 23°C

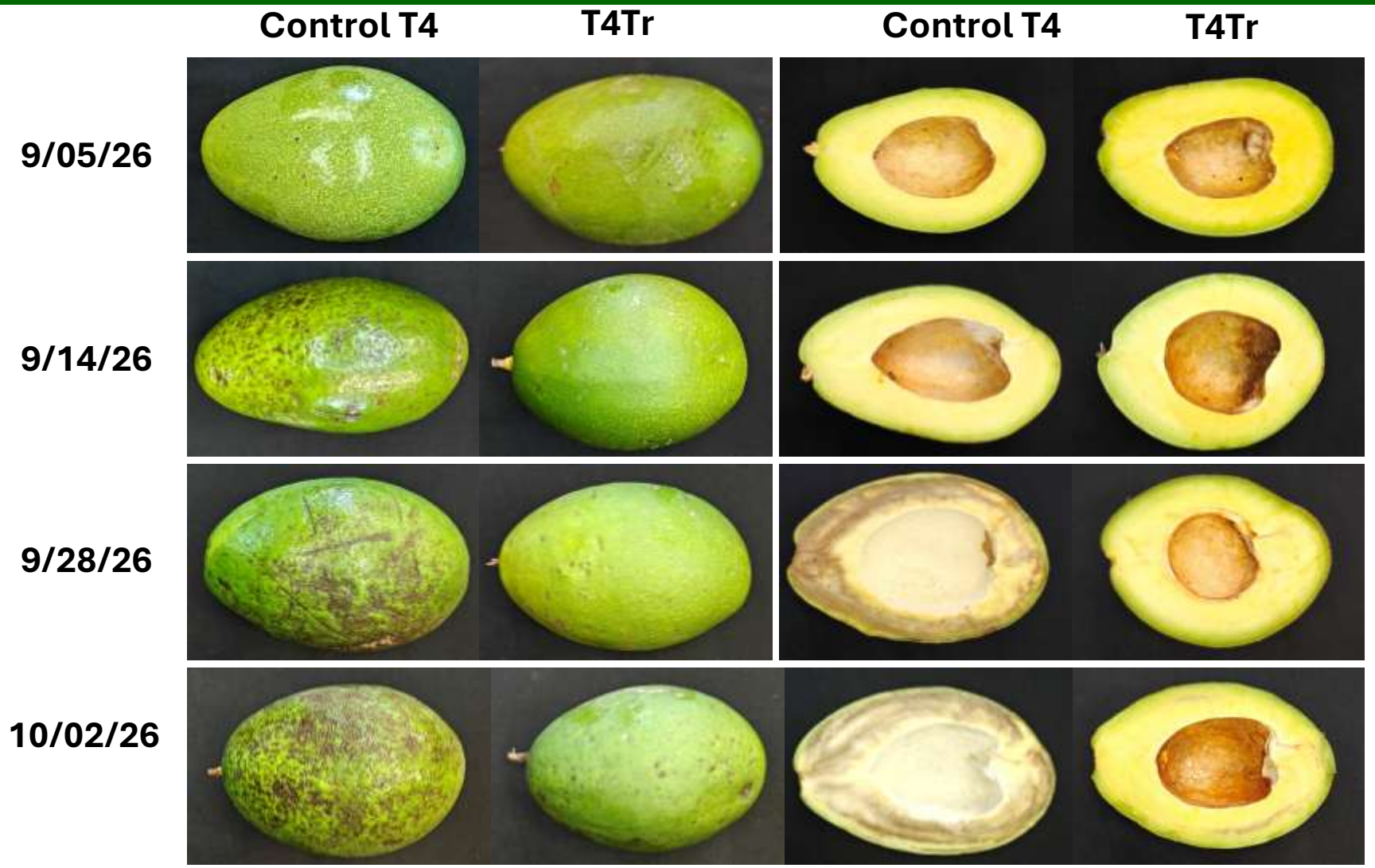
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T = 23°C
RH = 60%

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Avocado – Field Trial Study
Objective 2: Storage @ 4°C



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Summary – Objective 1&2

- MFC/CMC barrier coating was very effective for non-climacteric fruit –Star apple preservation by at least 14 days. Weigh loss decreased by 36% (14 percentage points)

- Ethylene surge is associated with fruit decay for Non-climacteric Star Apple

- MFC/CMC barrier coating was also very effective in extend shelf life for mangos with significant weight loss reduction 25% (4 percentage points). 14 days extension for Kent Mango

- MFC barrier coating can also be applied to avocados and apples

High Solids Fibrillation - Objective 3

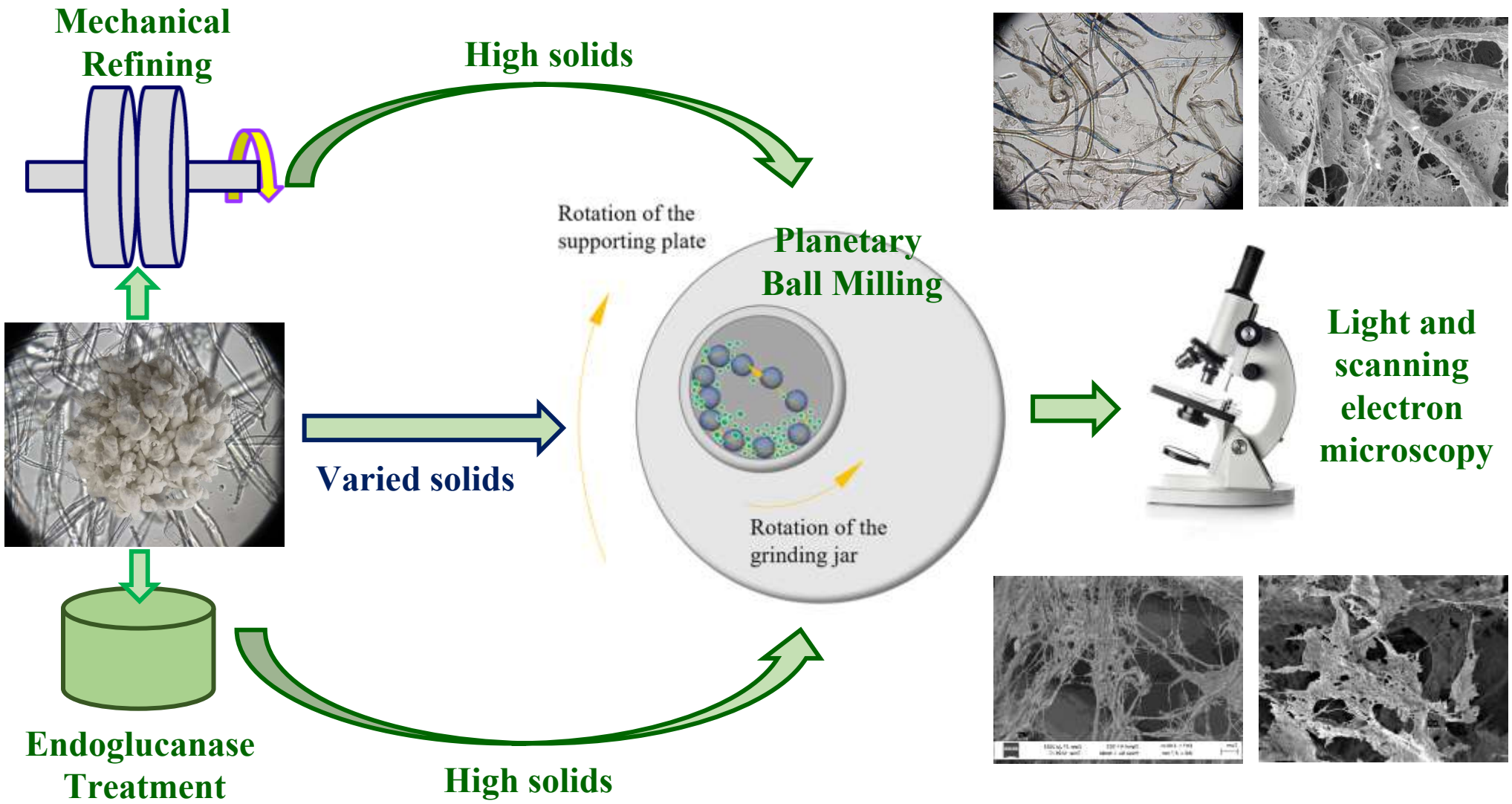
Zhang et al. (2024) *Biomacmolecules* 25:2509

- Low solids loading fibrillation: water footprint, dewatering, transportation
- Effect of solids loading on high solids CMF production
- Using laboratory ball milling to obtain fundamental mechanisms

High Solids Fibrillation - Objective 3

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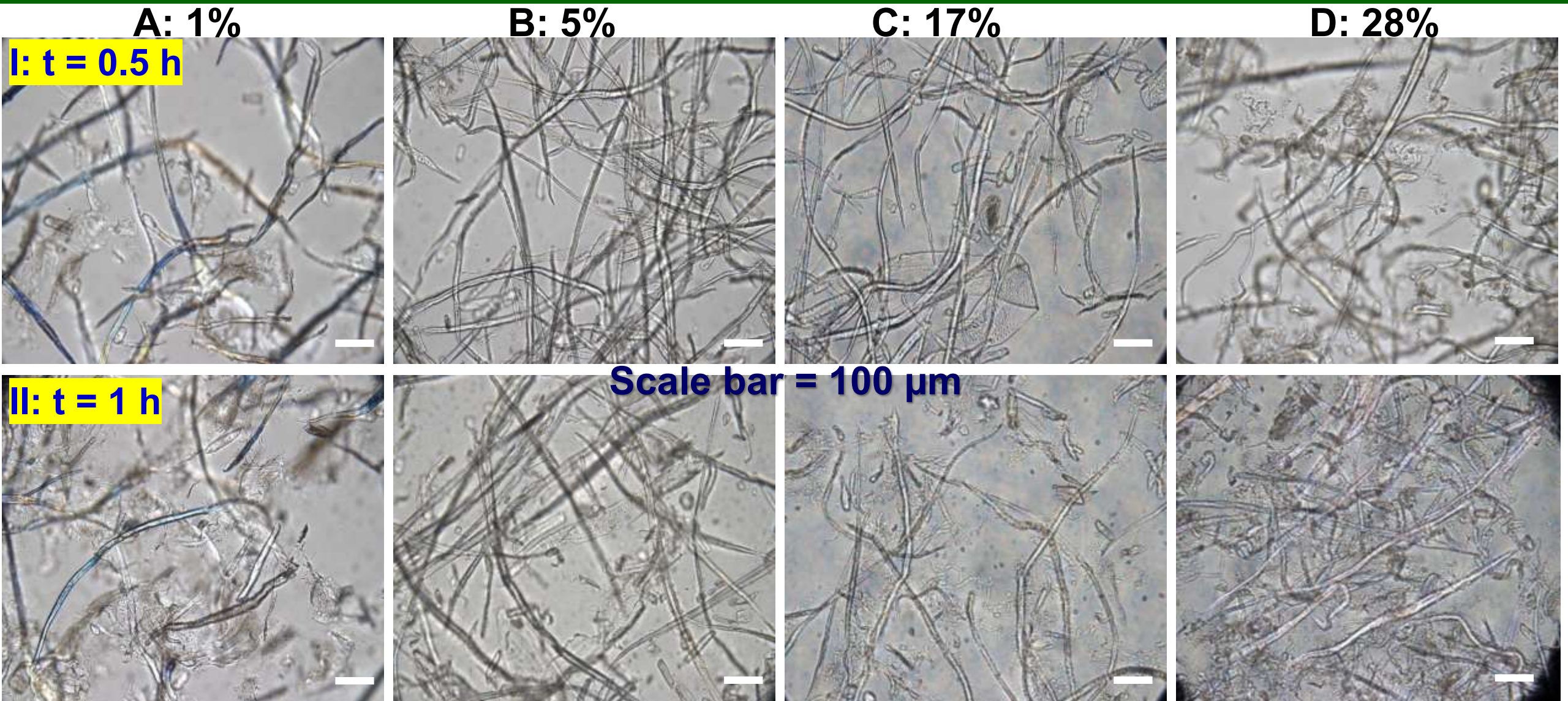
Zhang et al. (2024) *Biomacmolecules* 25:2509

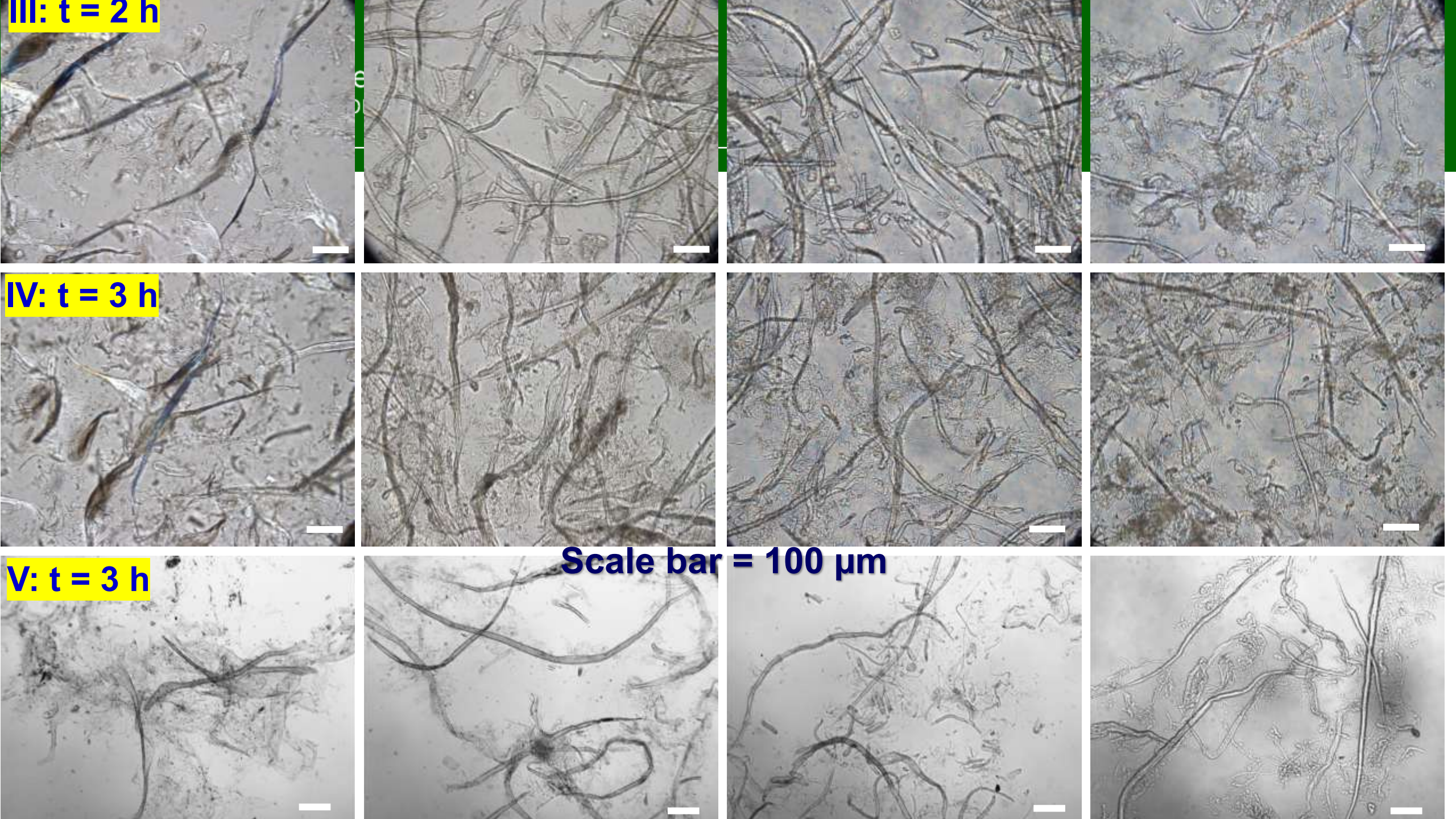


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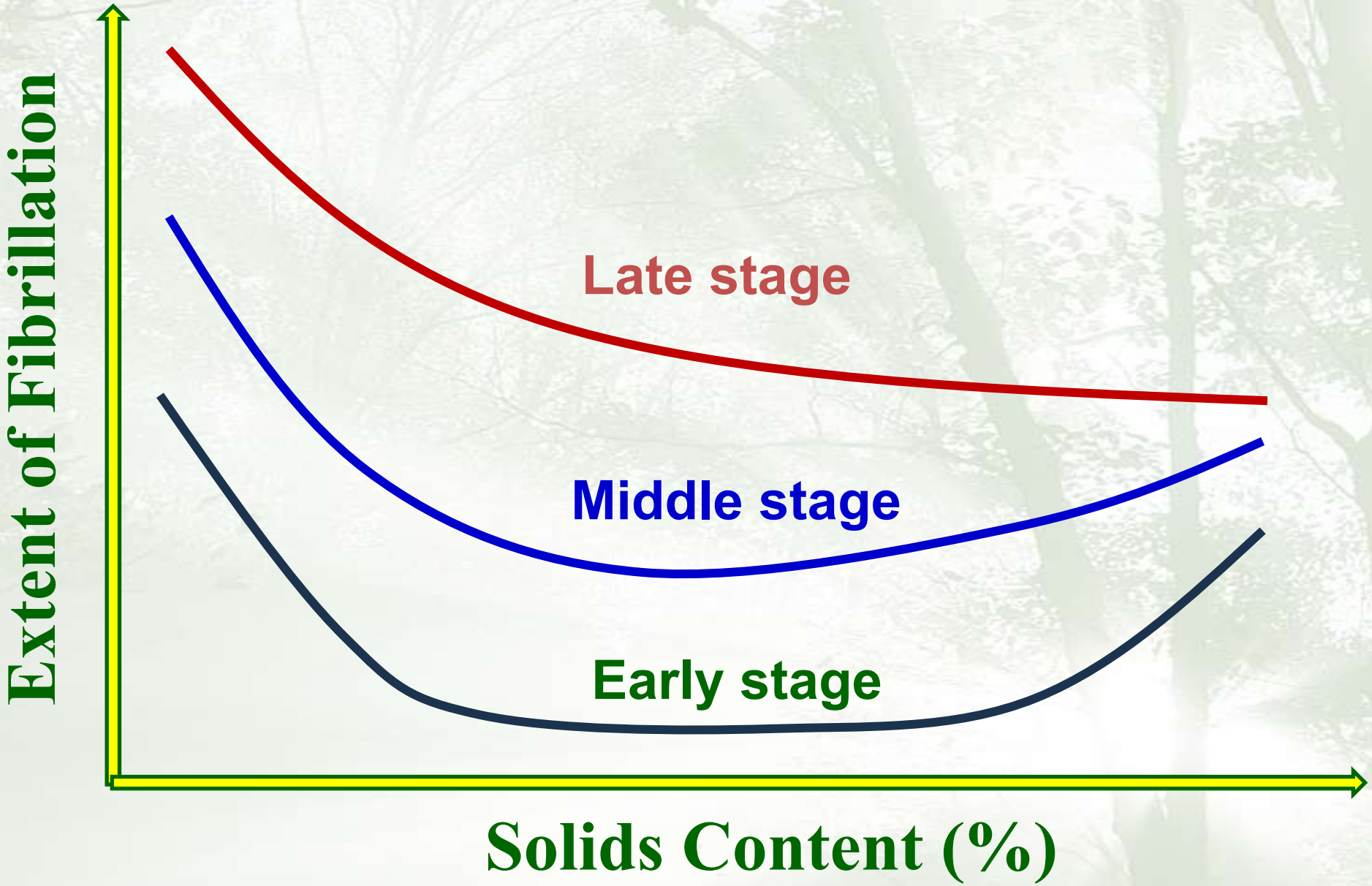
High Solids Fibrillation - Objective 3

Zhang et al. (2024) *Biomacmolecules* 25:2509




III: t = 2 h
IV: t = 3 h
V: t = 3 h
Scale bar = 100 µm

Effects of Solids Content on Fibrillation



Zhang et al (2024) *Biomacromolecules* 25:2509

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High Solids Fibrillation - Objective 3

Sediment t

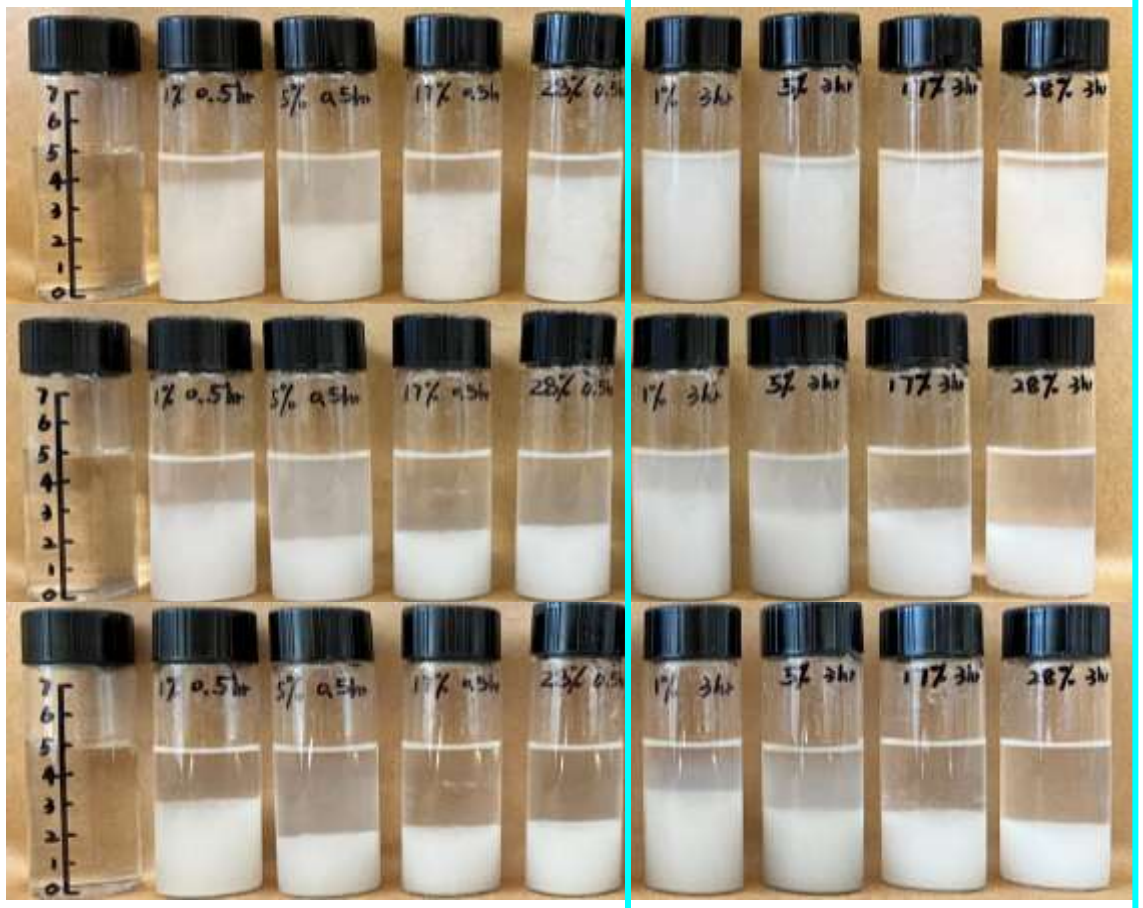
Milling t: 0.5 h
(Early stage)

3 h
(Late stage)

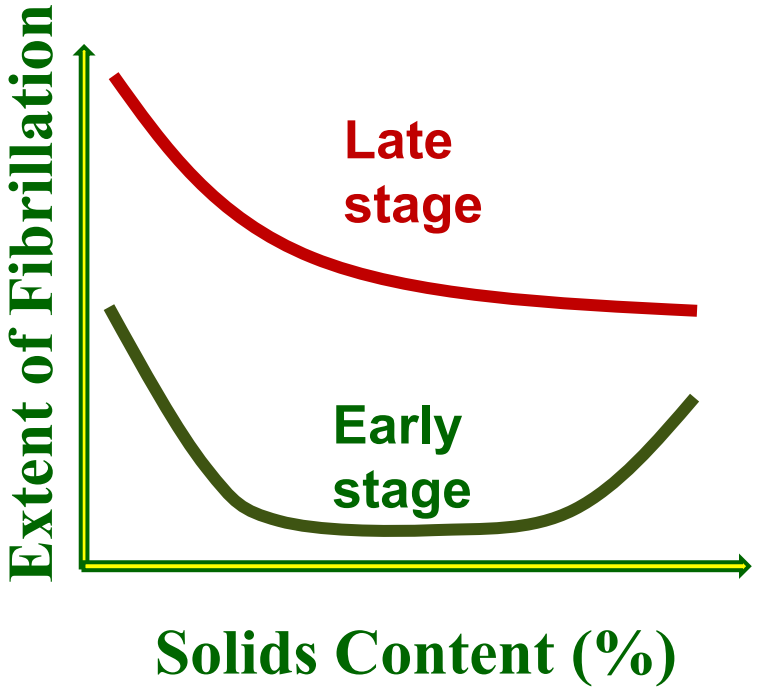
10 min

1 h

8 h



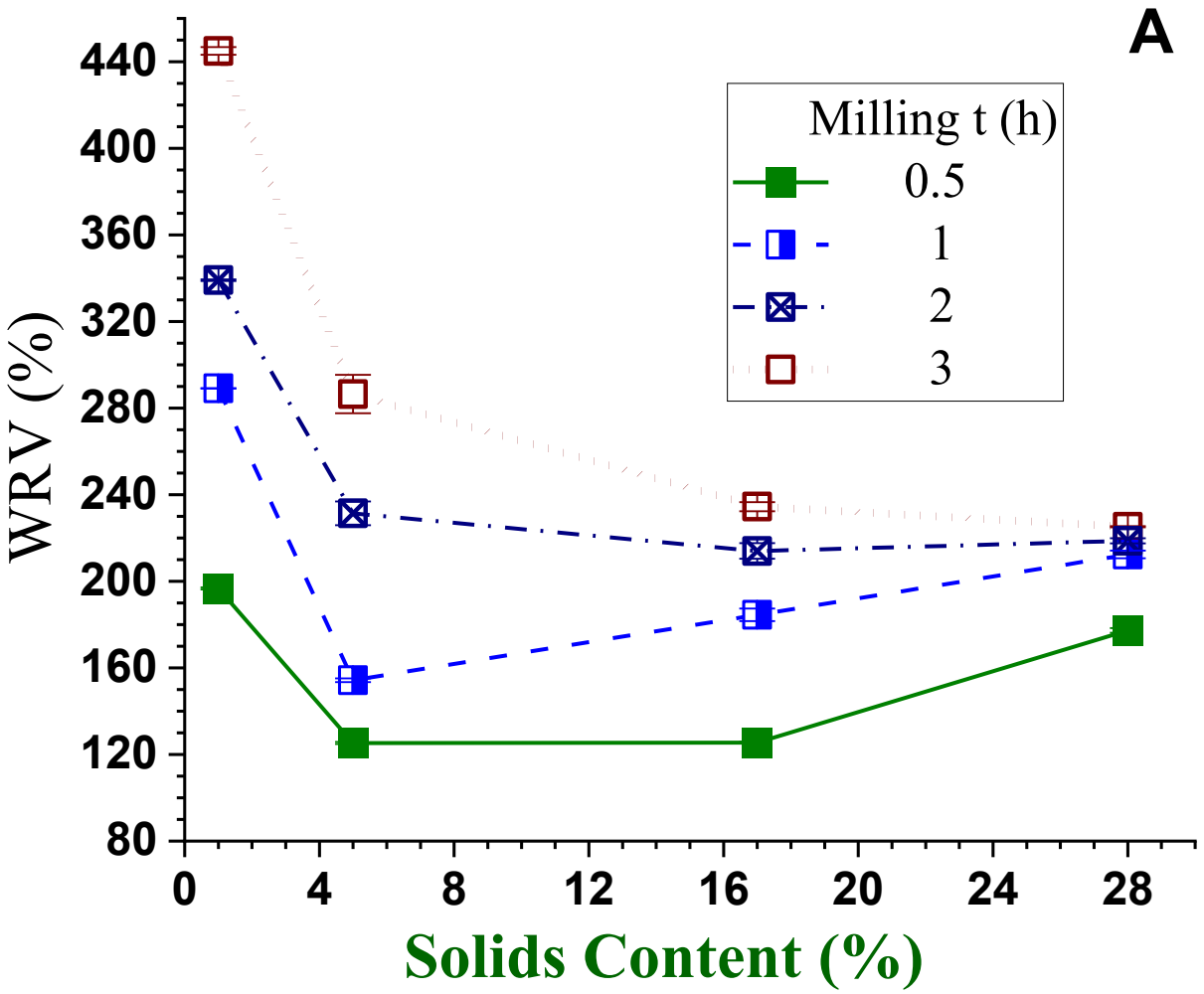
Zhang et al (2024)
Biomacromolecules **25**:2509

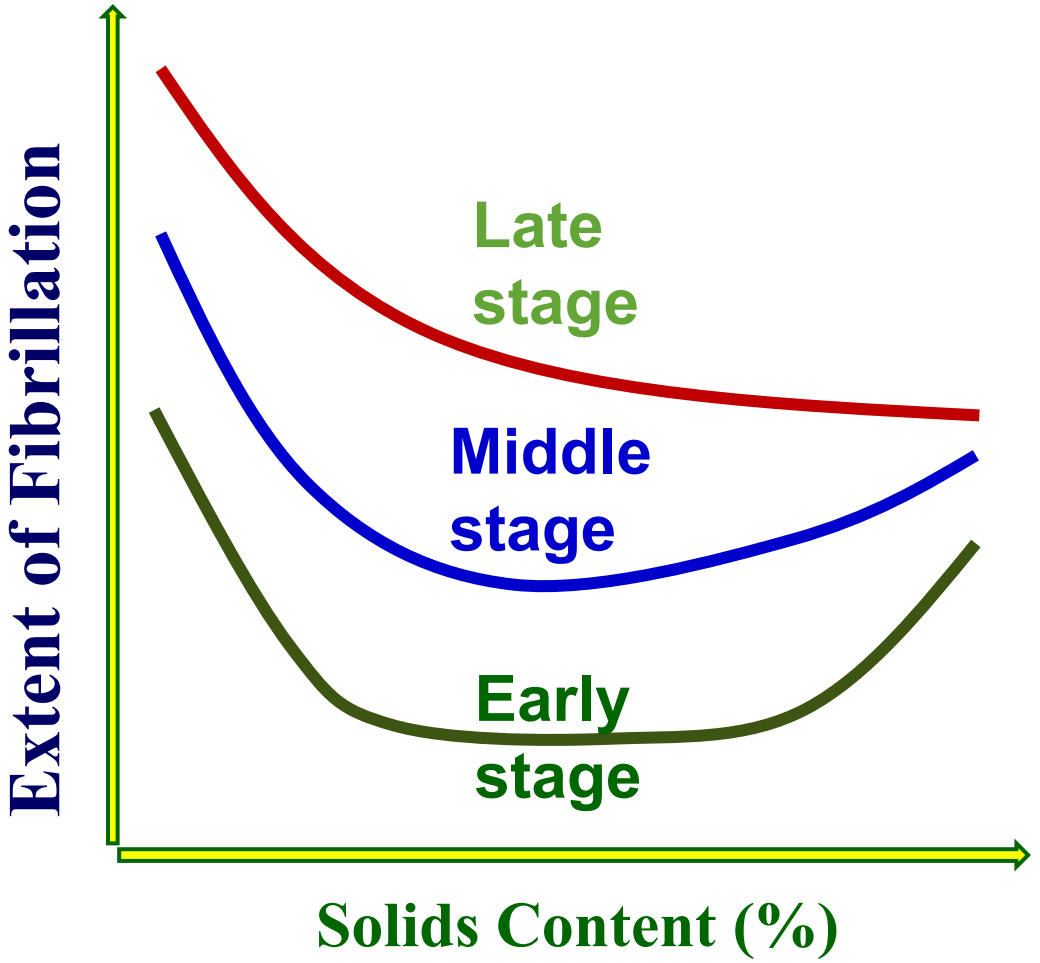


High Solids Fibrillation - Objective 3

Zhang et al (2024) *Biomacromolecules* **25**:2509

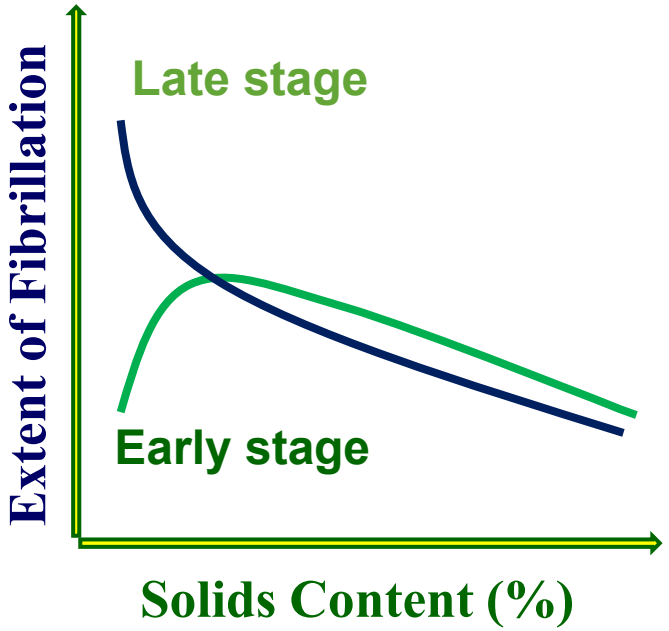
Verification with WRV

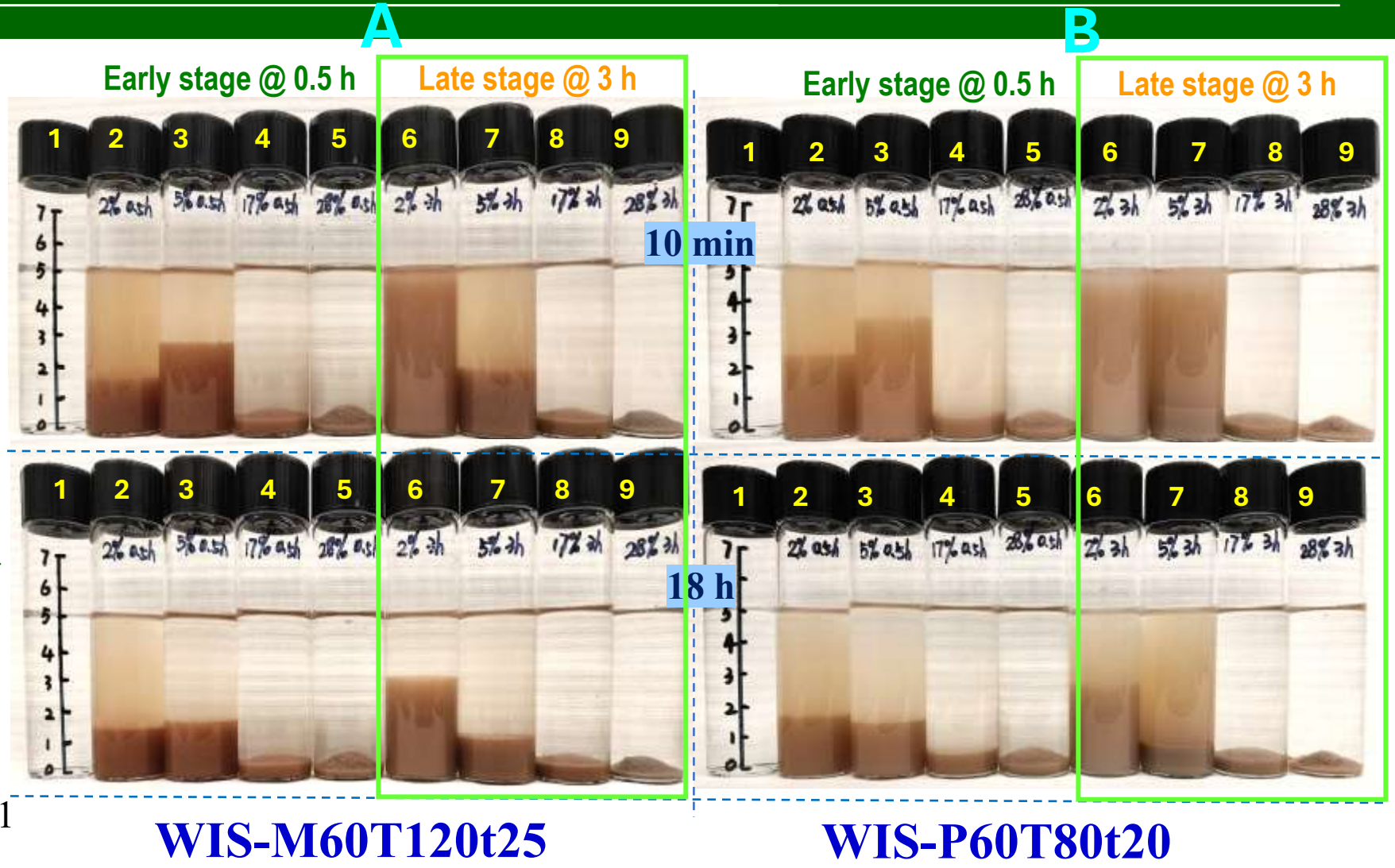




High Solids Fibrillation of Lignocelluloses

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Zhang et al. (2026)
ACS Sustain Chem. Eng. **14**:8421
doi:10.1021/acssuschemeng.6c01405

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Summary – Objective 3

- A very low solids content of 1-2% facilitated the impacting interactions between the mill(balls) and fibers/fibrils – the primary mechanism.
- A high solids content improved fibrillation compared with medium solids contents in the early stage due to the enhanced frictional and tensional interactions among fibers/fibrils – the secondary mechanism.
- However, the effectiveness of this secondary mechanism diminished in the late stage toward nano-fibrillation.
- High solids loading is beneficial for producing MFC. Needs scale-up and verification using energy input data.

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Future Work

- Analyze lab data on Mangos and Avocados
- Analyze field trial study data on using Avocados
- Work with partners on FDA approval
- Find industry partners (packing houses, farmers) for commercialization
- Secure funding for high-solids fibrillation using the New twin-shaft mixer

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Publications

1. Zhang, X., Yelle, D., Kitin, P., Tong, G., **Zhu, J.Y.** (2024) "Producing cellulose microfibrils (CMF) at high solids content with and without mechanical or enzymatic pre-treatment" *Biomacromolecules* **25**:2509−2519 DOI: 10.1021/acs.biomac.3c01457
2. Geng, J., Stark, N., Zhang, X., Zhang, X., **Zhu, J.Y.** (2024) "Microfibrillated cellulose (MFC) barrier coating for extending banana shelf life" *Food Hydrocolloids* **150:**109671, DOI: 10.1016/j.foodhyd.2023.109671
3. Geng, J., Stark, N., Kitin, P., Zhang, X., **Zhu, J.Y.** (2025) "Incorporating Carboxymethyl Cellulose into Microfibrillated Cellulose for Barrier Coating to Delay Banana Browning and Extend Shelf Life" *Food Chem.* **486:**144664 DOI:10.1016/j.foodchem.2025.144664
4. Geng, J., Baez, C.L., Kitin, P., Plaza, N.Z., Zhang, X., Lundberg, B., **Zhu, J.Y**., (2026) "Barrier coating of bananas using plant cellulose and edible lemon peel fibrils to extend shelf-life" *Int J. Bio. Macromol.* **338**:149666 doi:10.1016/j.ijbiomac.2025.149666
5. Zhang, X., Kitin, P., Geng, J., Kim, H., Gleisner, R., Yelle, D., **Zhu, J.Y.** (2026) "Carboxylated Lignin-Containing Cellulose Microfibrils (L-CMF) Produced from Wood at High Solids through Maleic Acid Hydrotropic Fractionation (MAHF)" *ACS Sustainable Chem. Eng.* **14**:8421 doi:10.1021/acssuschemeng.6c01405
6. Geng, J., Crane, J.H., Kitin, P., Li, Y.C., Stark, N., Zhang, X., **Zhu, J.Y.** (2026) "Cellulosic sol barrier coating for nonclimacteric Star apple (*Chrysophyllum cainito* L.) preservation" Sustainable *Sustain. Food Technol,* **4**:5051 – 5062 DOI: 10.1039/D6FB00169F
7. Geng, J., Perzynski, K., Kitin, P., Stark, N., Zhang, X., **Zhu, J.Y.,** (2026) "A Simple Two-Component CNF/HCO Pickering Emulsion Improves Barrier Coating for Fuji Apples" *Carbohydrate Polymer Technol. Appl.* (Revised resubmitted)

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Contact Information & Acknowledgement

J.Y. Zhu
USDA Forest Products Lab.
junyong.zhu@usda.gov
608 231 - 9520

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Washington State University

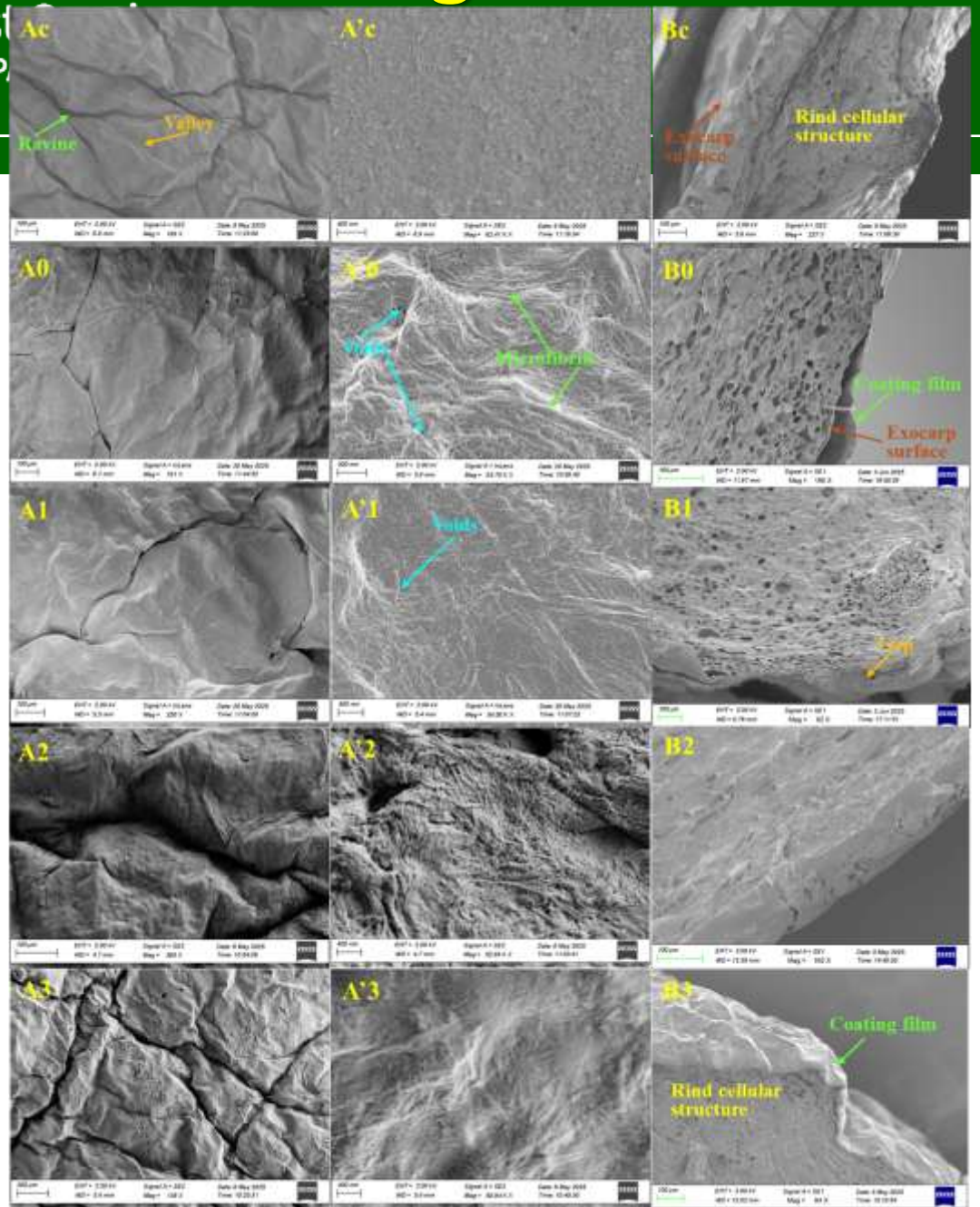




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Coating Film on Star Apple Pericarp



No-coating

MFC 0.75%

MFC/CMC 0.65:0.1%

MFC/CMC 0.55:0.2%

MFC/CMC 0.45:0.3%

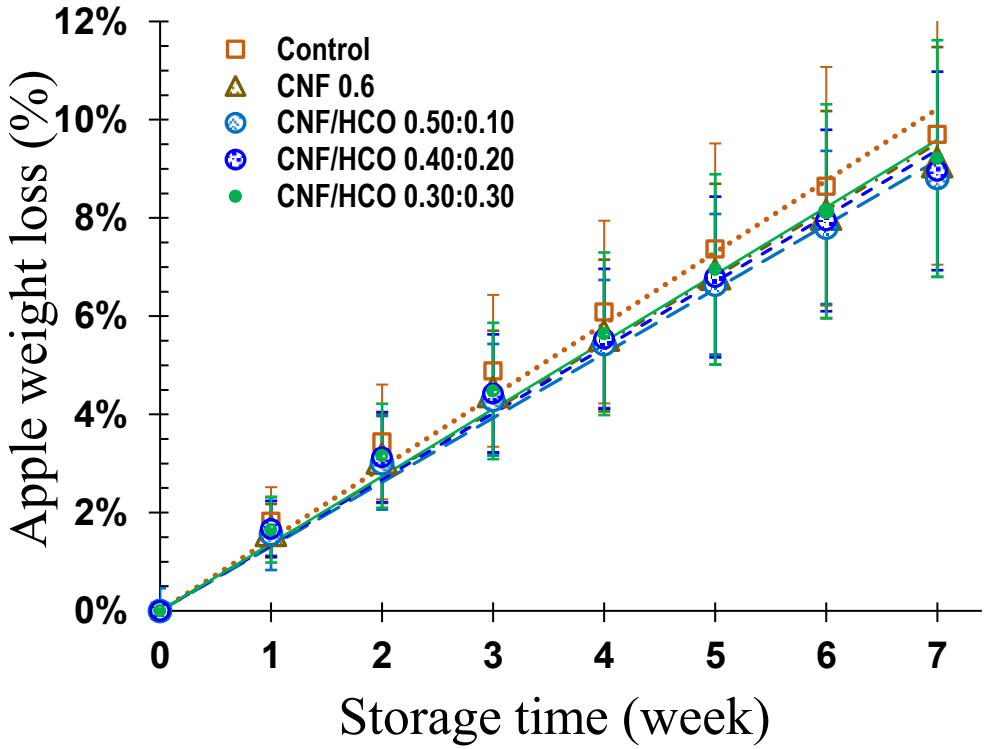
Geng et al (2026)

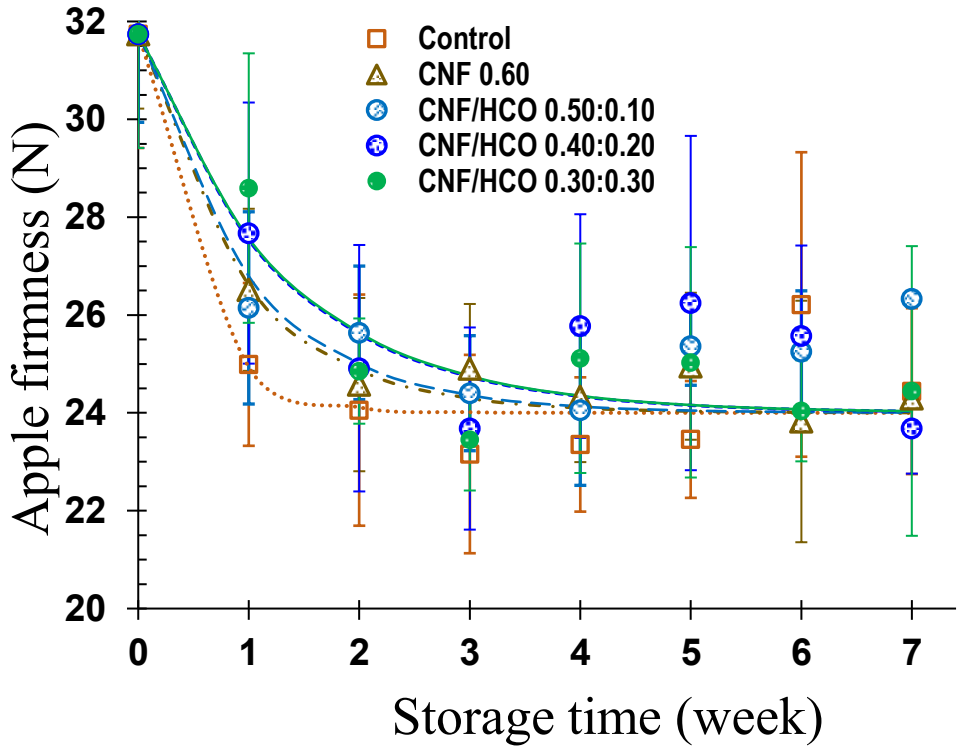
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DOI: 10.1039/D6FB00169F

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CNF/HCO Coating on Fuji Apples



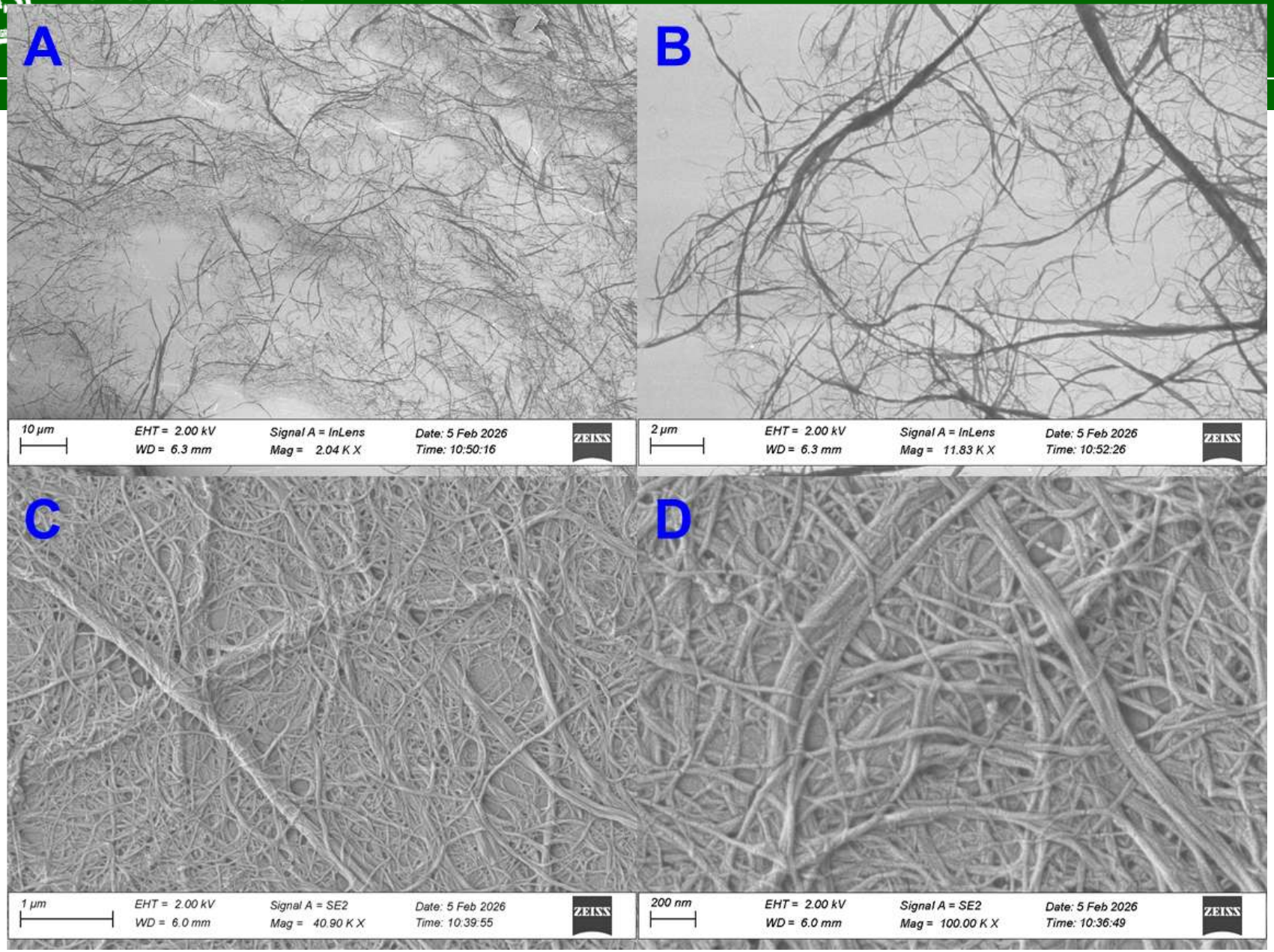


Barrier Coating Fuji Apple: CNF Morphology

USDA Forest Service

SAPPI CNF

Valida S+ 8%



RESEARCH & DEVELOPMENT

- Is there a civilian scientist aspect to this work?
- Can audience members assist/test in your work?
- Where can audience members go to experience/see your work?
- Do you have any public demonstrations of your work?

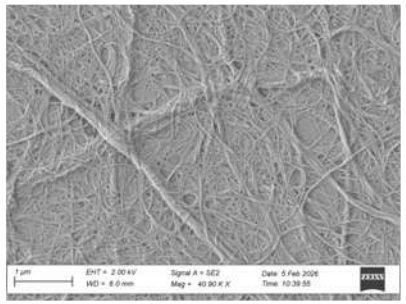
Scale-up MFC Production





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Lab Study: Barrier Coating of Fruits – Objective 1

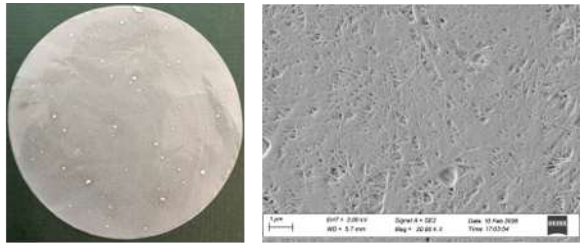


AQUEOUS CNF SUSPENSION

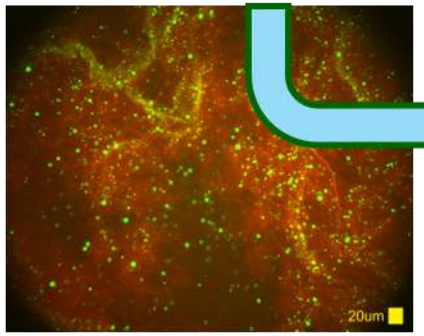
HCO

SHEAR EMULSIFYING

FILM CASTING & DRYING



CNF/HCO film



DIP COATING

STORAGE without COATING



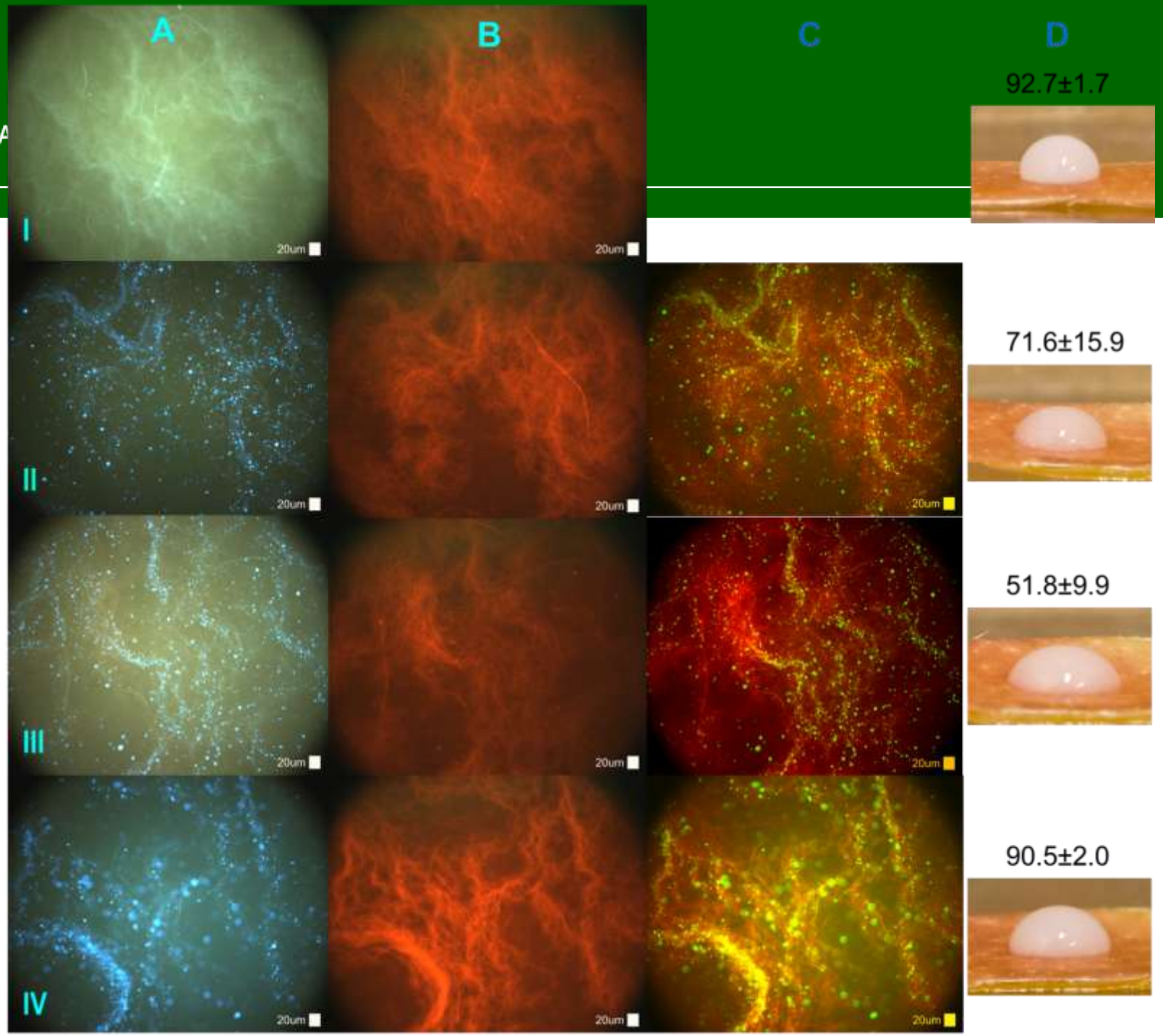
DRYING

STORAGE

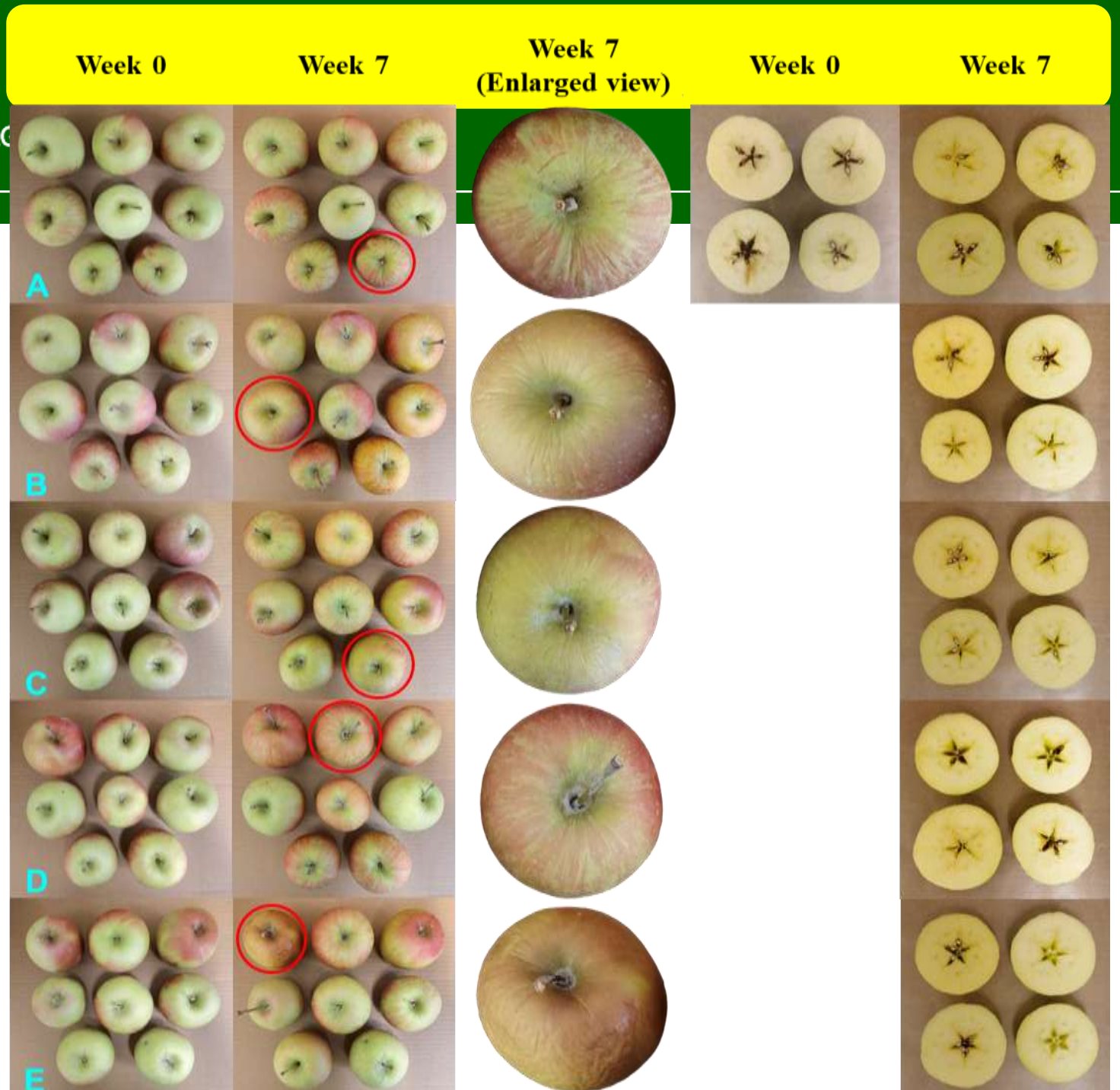


CNF + HCO Emulsion Stability

System: CNF/HCO	Before centrifugation (µm)	After centrifugation (µm)
0.5:0.1	1.160±0.048	1.123±0.070
0.4:0.2	1.689±0.087	
0.3:0.3	2.032±0.064	1.511±0.066



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No coating

CNF 0.6

CNF/HCO 0.5:0.1

CNF/HCO 0.4:0.2

CNF/HCO 0.3:0.3