Greener Solutions: Improving performance of mycelium-based leather

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MycoWorks Team

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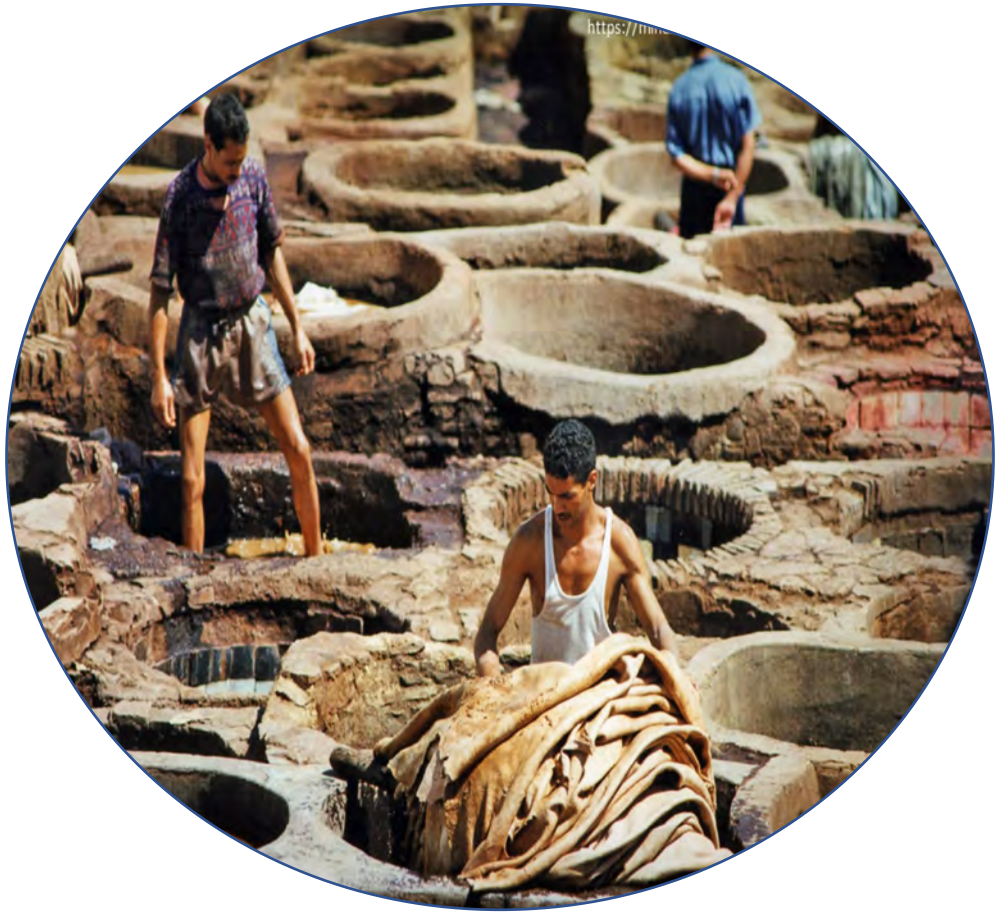
Leather is desirable but problematic

Source: wayfair.com



Source: nature.com

Source: blueskypapers.com

Source: soulrevolver.com

Leather production harms humans and the environment


http://products.mercola.com/grass-fed-beef/


https://en.wikipedia.org/wiki/Chromium(III)_sulfate


http://www.punjabics.com/Islamabad/

MycoWorks presents a promising alternative, but needs more:

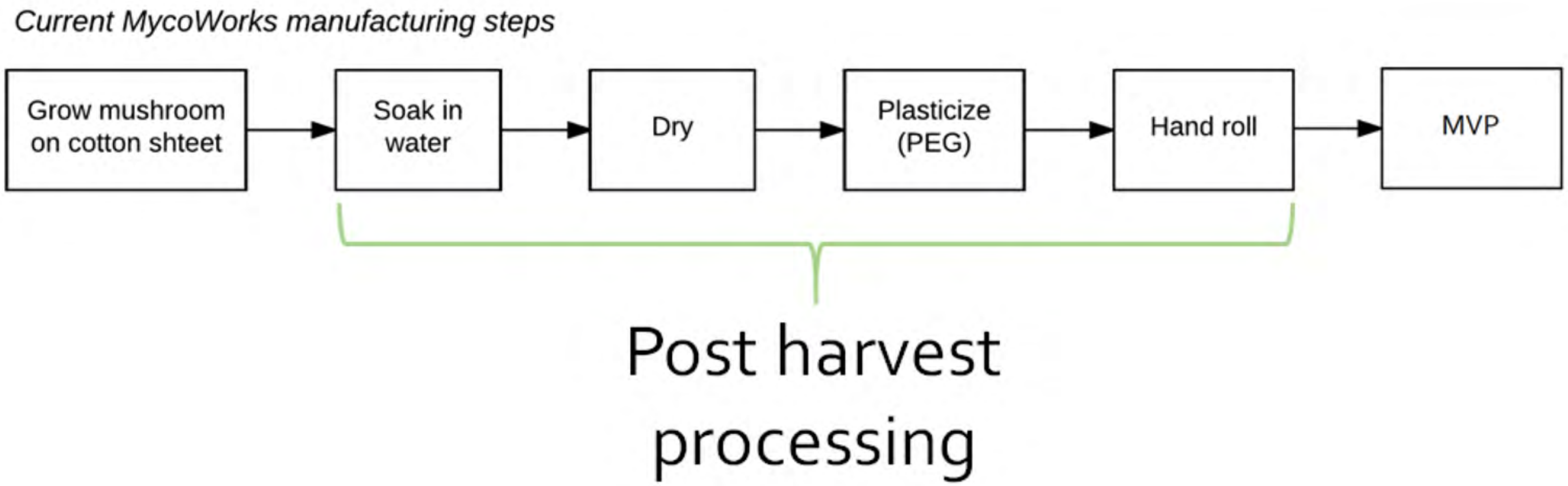
Strength

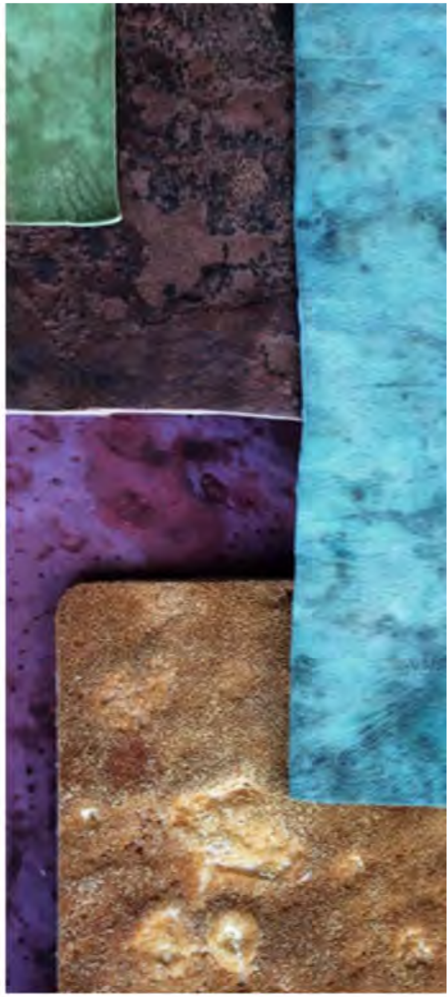
Flexibility

Durability

Source: MycoWorks

There are a few restrictions:





Source: MycoWorks

There are a few restrictions:

Scaleable

Sustainable

Biodegradeable

Source: MycoWorks

Source: MycoWorks

Source: vecteezy.com

Outline

- Approaches and inspiration
- Cross-linking strategies
- Moisture barrier strategy
- Technical performance
- Hazard assessment
- Recommendations and next steps

Source: MycoWorks

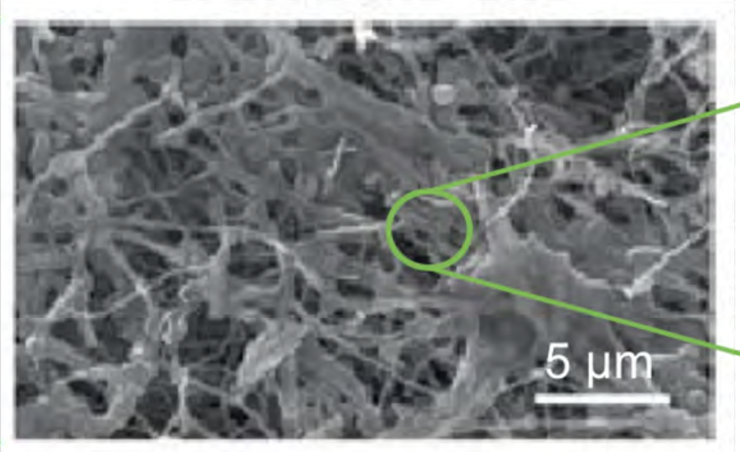
Approaches and Inspiration

What does the MycoWorks material consist of?

Ganoderma lucidum

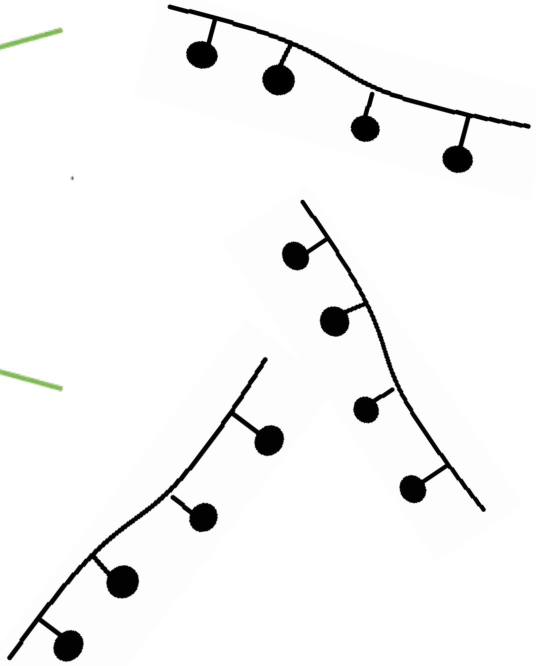
Source: Wikipedia

Mycelium

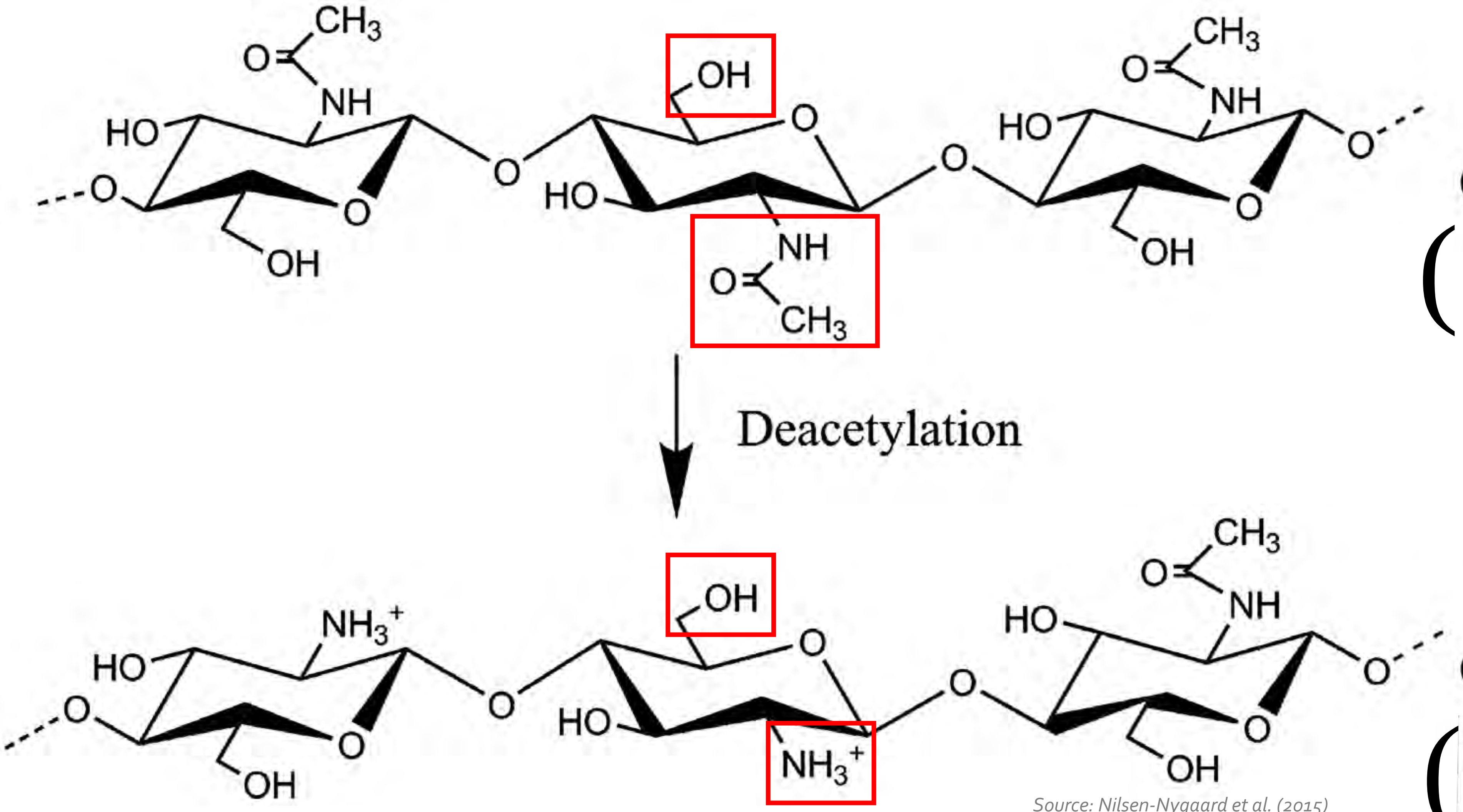


Source: Haneef et al. (2017)

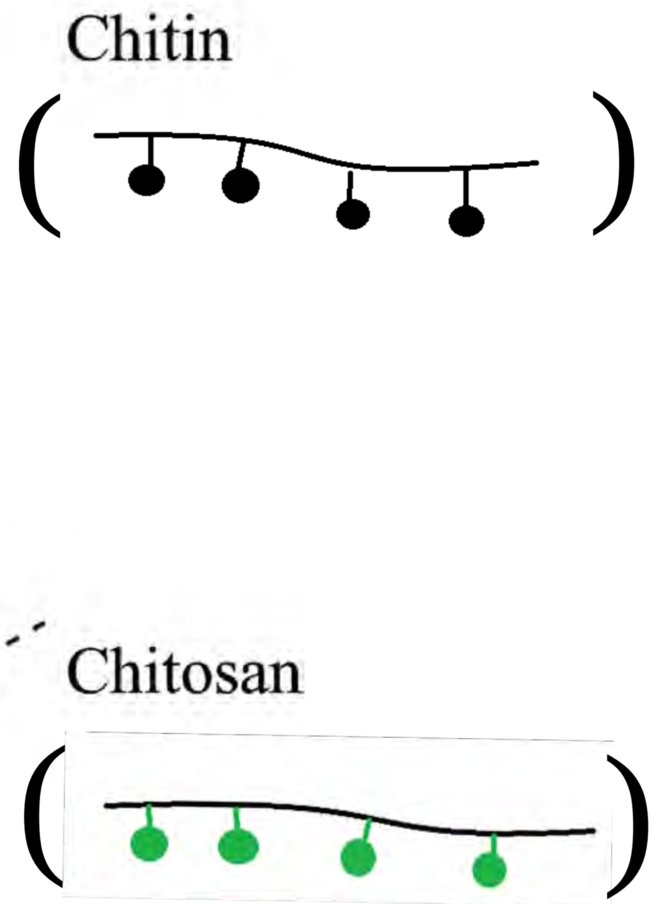
Chitin



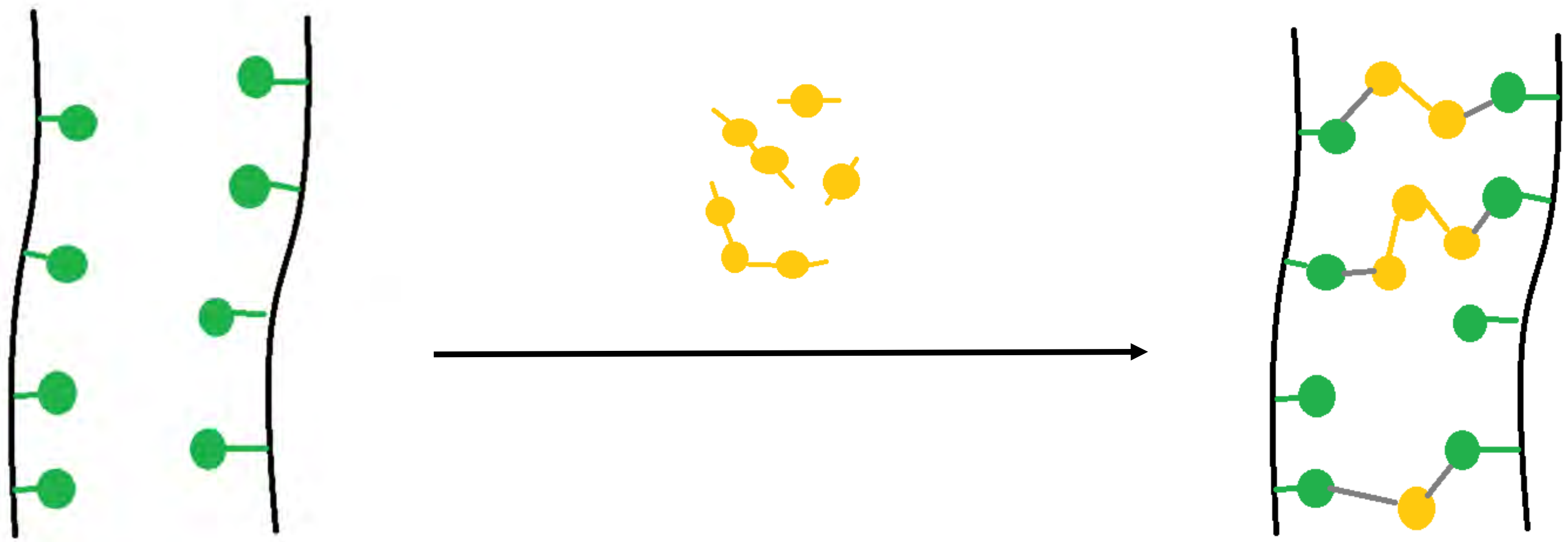
Chitin and chitosan functional groups



Source: Nilsen-Nygaard et al. (2015)



Approach #1: incorporate cross-linking like in animal leather



	Long-chain fibers	Cross-linkers	Cross-linked material
Animal leather:	Collagen	Chromium(III) compounds or aldehydes	Leather
MycoWorks material:	Chitosan	**Our proposed strategies**	A stronger, more flexible material

Approach #2: introduce a moisture barrier

MycoWorks currently uses PEG successfully as a plasticizer, but it leaches out when the material is washed with water.

Source: MycoWorks

Current MycoWorks manufacturing steps

Grow mushroom on cotton shteet → Soak in water → Dry → Plasticize (PEG) → Apply moisture barrier → Hand roll

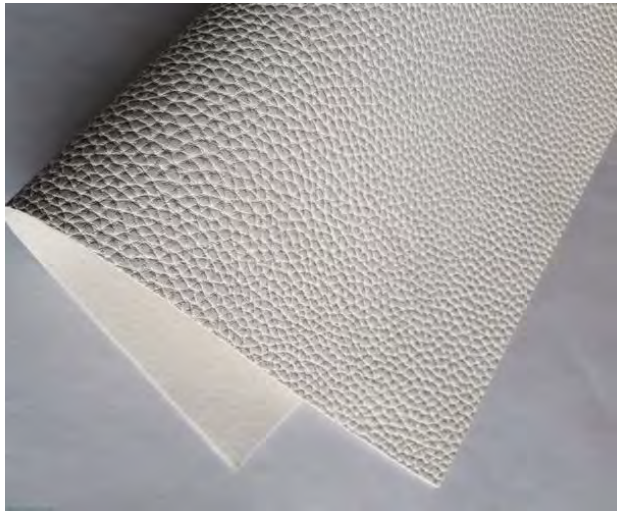
Baselines for guiding strategy development

Technical performance: baseline is the MycoWorks MVP

Hazards: baselines are animal leather and vegan leather

Source: MycoWorks

Source: http://michelleayres.com

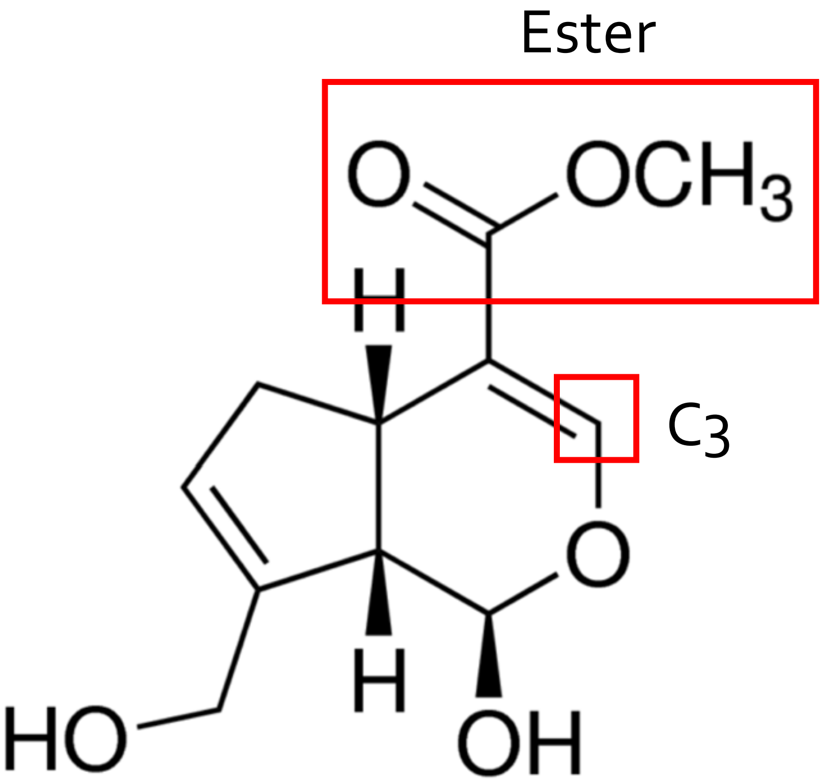


Source: Green Mountain Outlook

Cross-linking Strategies

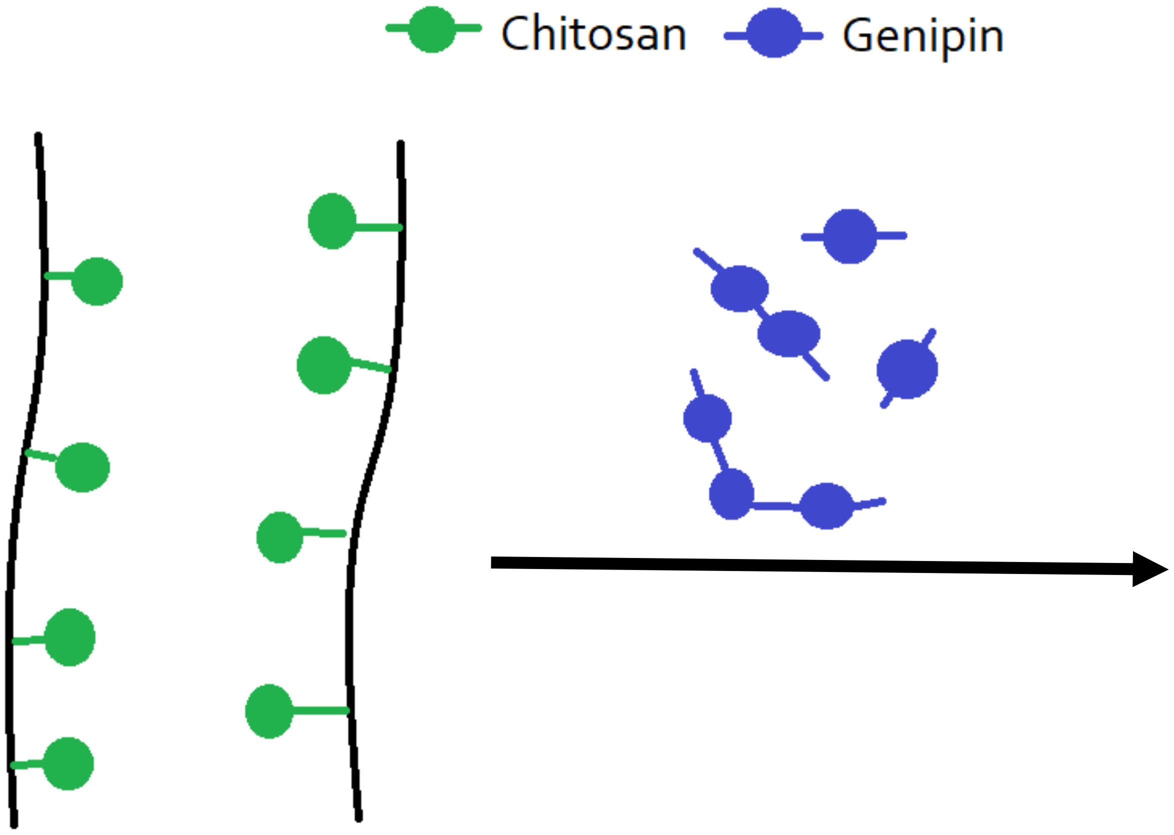
Natural cross-linker: genipin

Source: https://www.thesynergycompany.com/



Source: Sigma-Aldrich, Butler et al. (2003)

Genipin directly cross-links chitosan fibers



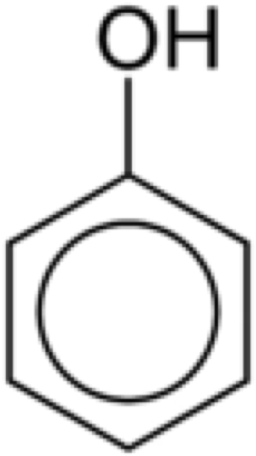
BLUE

Source: Butler et al. (2003), Gorczyca et al. (2013)

Chitosan in acetic acid bath → Add dissolved genipin to the bath → Leave at room temp + agitate → Leave for 40 mins to a few hours → Wash

BID enzymatically driven crosslinking

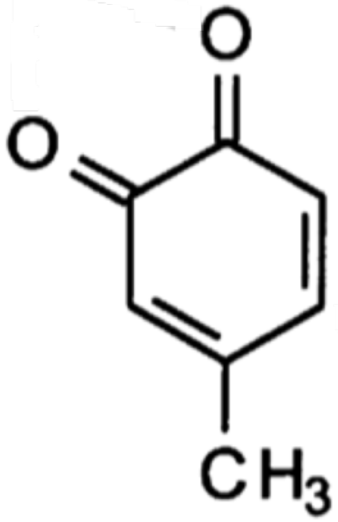
Tyrosinase catalyzed cross-linking



enzyme

Tyrosinase

phenol → o-quinone

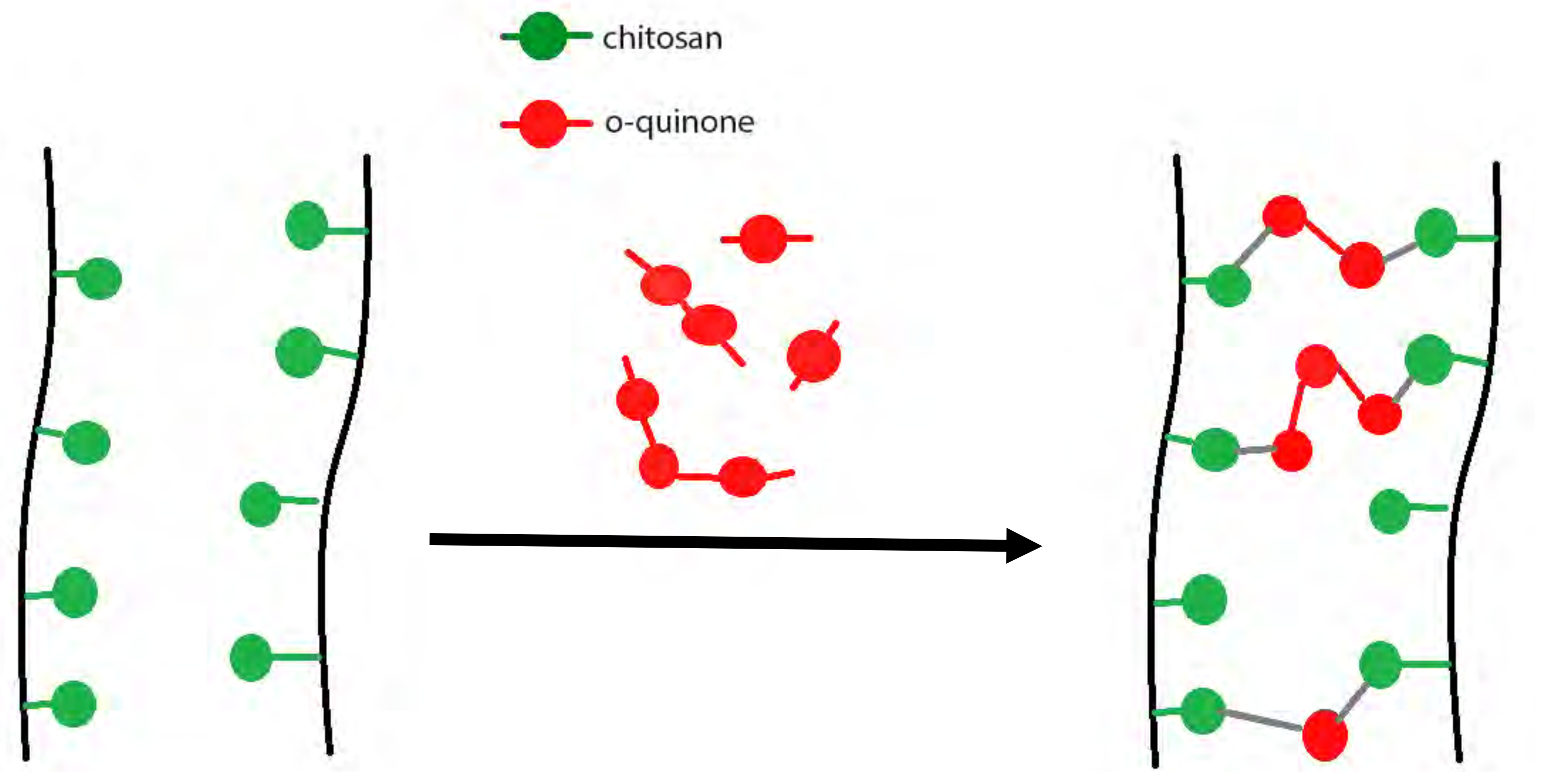


substrate

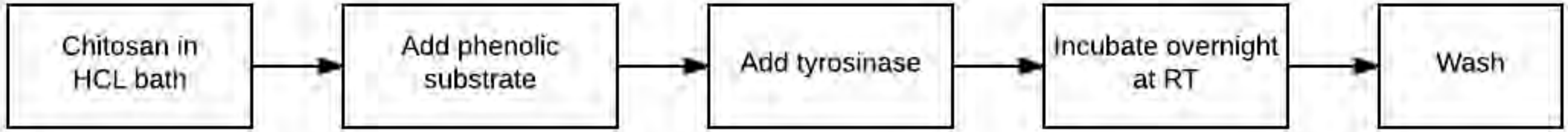
cross-linker

Source: Kumar (1999)

Cross-linking between fibers via quinones

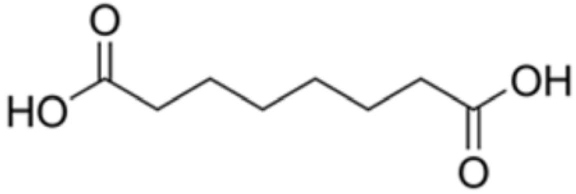


Source: Kumar (1999)

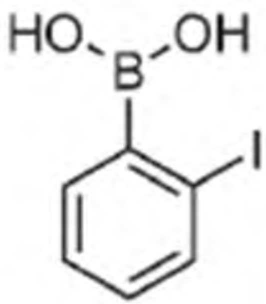


Composite-based material: chitin nanowhiskers

Filler:
Chitin nanowhiskers



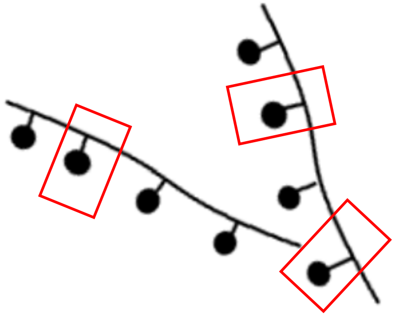
Crosslinker:
Suberic acid



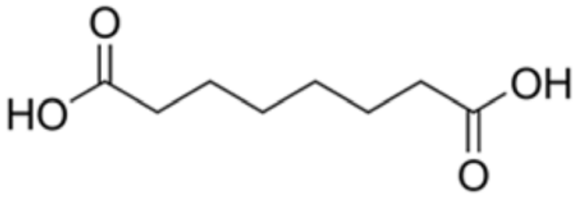
Catalyst:
2-iodophenylboronic acid
(IPBA)

Sources:
Araki (2012)
Al Zoubi (2008)

Composite-based material: chitin nanowhiskers



Filler:
Chitin nanowhiskers



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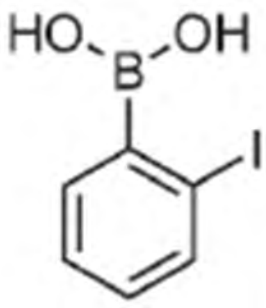

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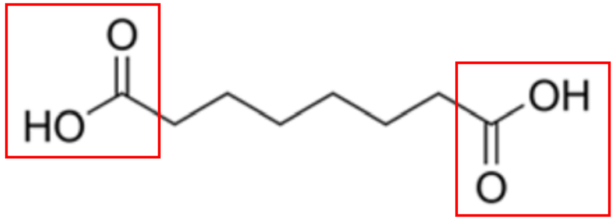

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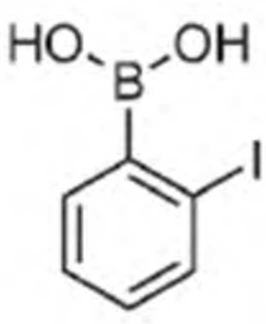
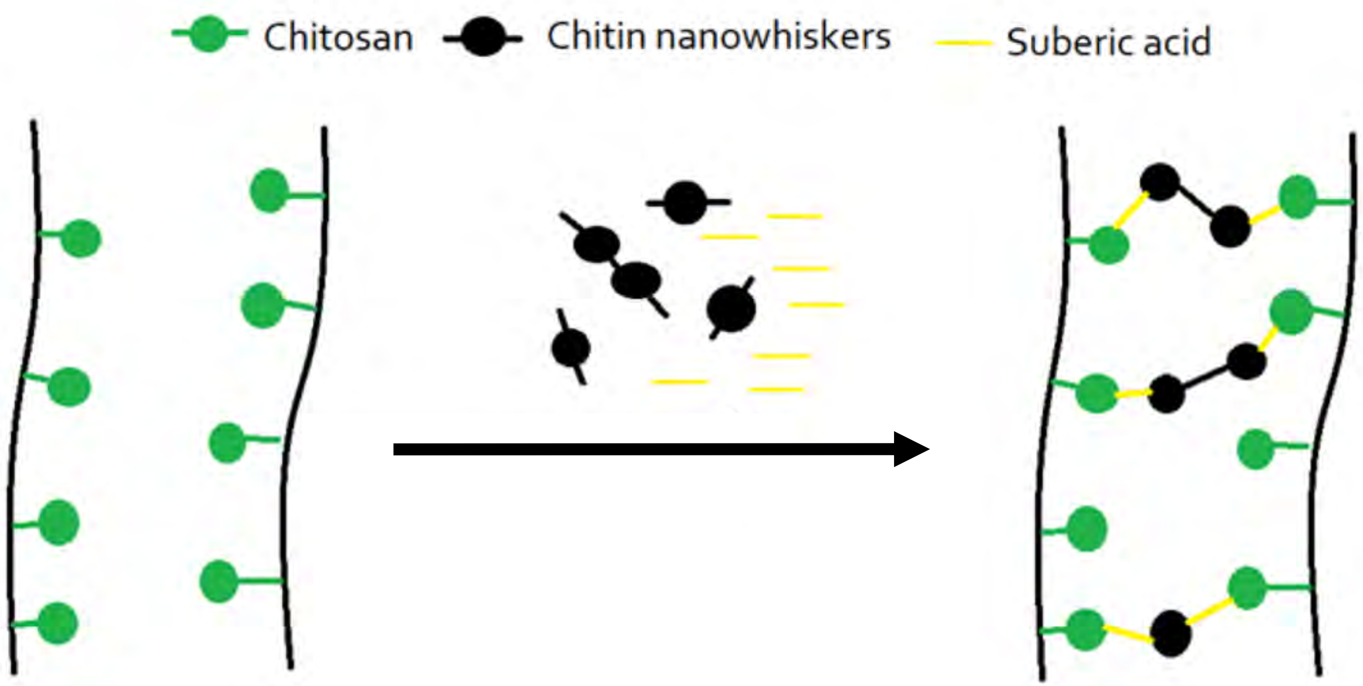
Suberic acid



Catalyst:
2-iodophenylboronic acid
(IPBA)

Sources:
Araki (2012)
Al Zoubi (2008)

Nanowhiskers crosslink fibers



Synthesize chitin nanowhiskers → Soak nanowhiskers into harvested MW material at RT → Add crosslinker and catalyst → Incubate with agitation for 2 days at RT

Sources:
Araki (2012)
Al Zoubi (2008)

Moisture Barrier Strategy

Water-insoluble proteins can be extracted from agricultural byproducts

Source: Pixabay.com

Corn zein

Wheat gluten

Fish myofibrillar protein

Water-insoluble proteins can be extracted from agricultural byproducts

Source: Pixabay.com

Corn zein

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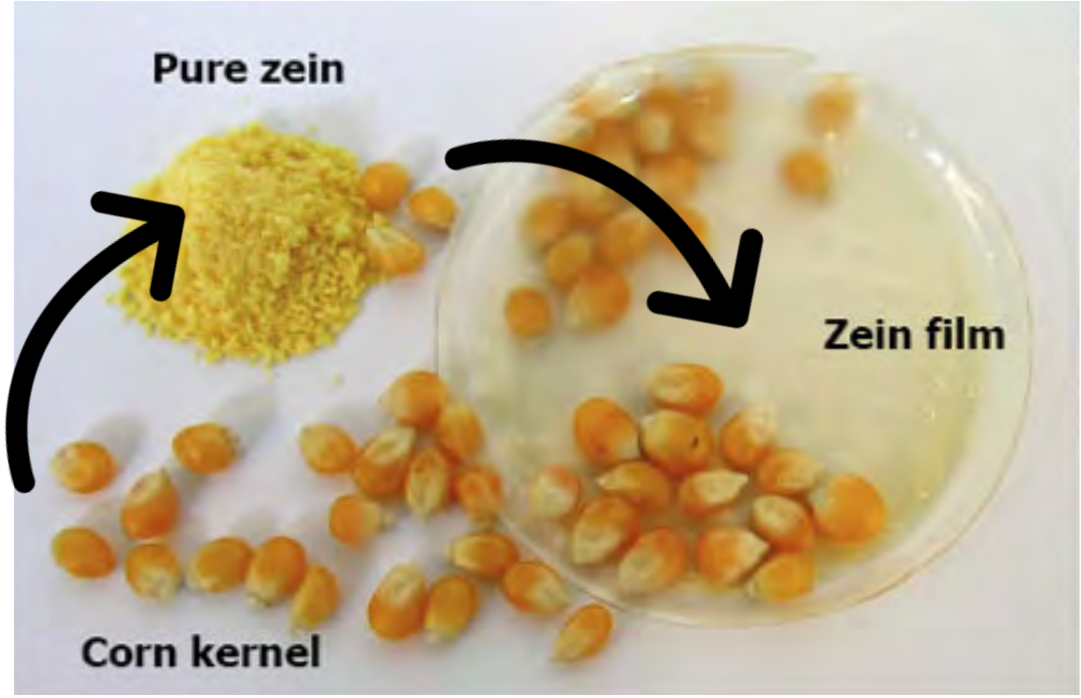
Fish myofibrillar protein

Corn zein forms water-resistant films



Source: Global Protein Products, Inc., globalprotein.com

Corn zein films are demonstrated moisture barriers

Material	**Water vapor permeability** (g•mm/m²•h•kPa at 25 ˚C and 0/90% relative humidity gradient)
Corn zein film*	0.06
Corn zein film* + tung oil coating	0.005
Cellophane (a hydrophilic biopolymer)	0.3
LDPE film	0.003

*Without PEG

Source: Gennadios A. Protein-Based Films and Coatings. CRC Press (2002)

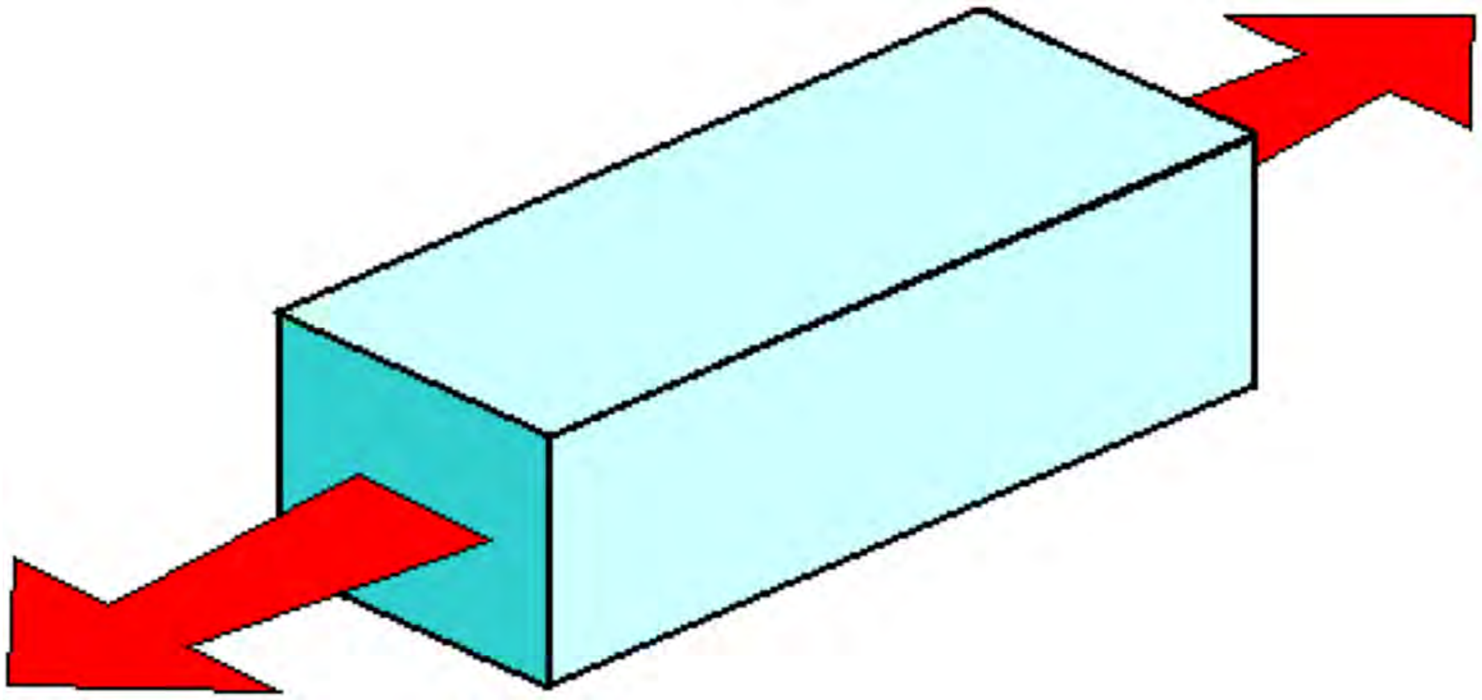
We propose applying a corn zein coating to the MycoWorks material

Dissolve corn zein in warm ethanol with PEG → Cool → Dip material into solution or brush or spray it on → Allow solvent to evaporate → Optional: add a drying oil coating

Technical Performance

Strength: ultimate tensile strength

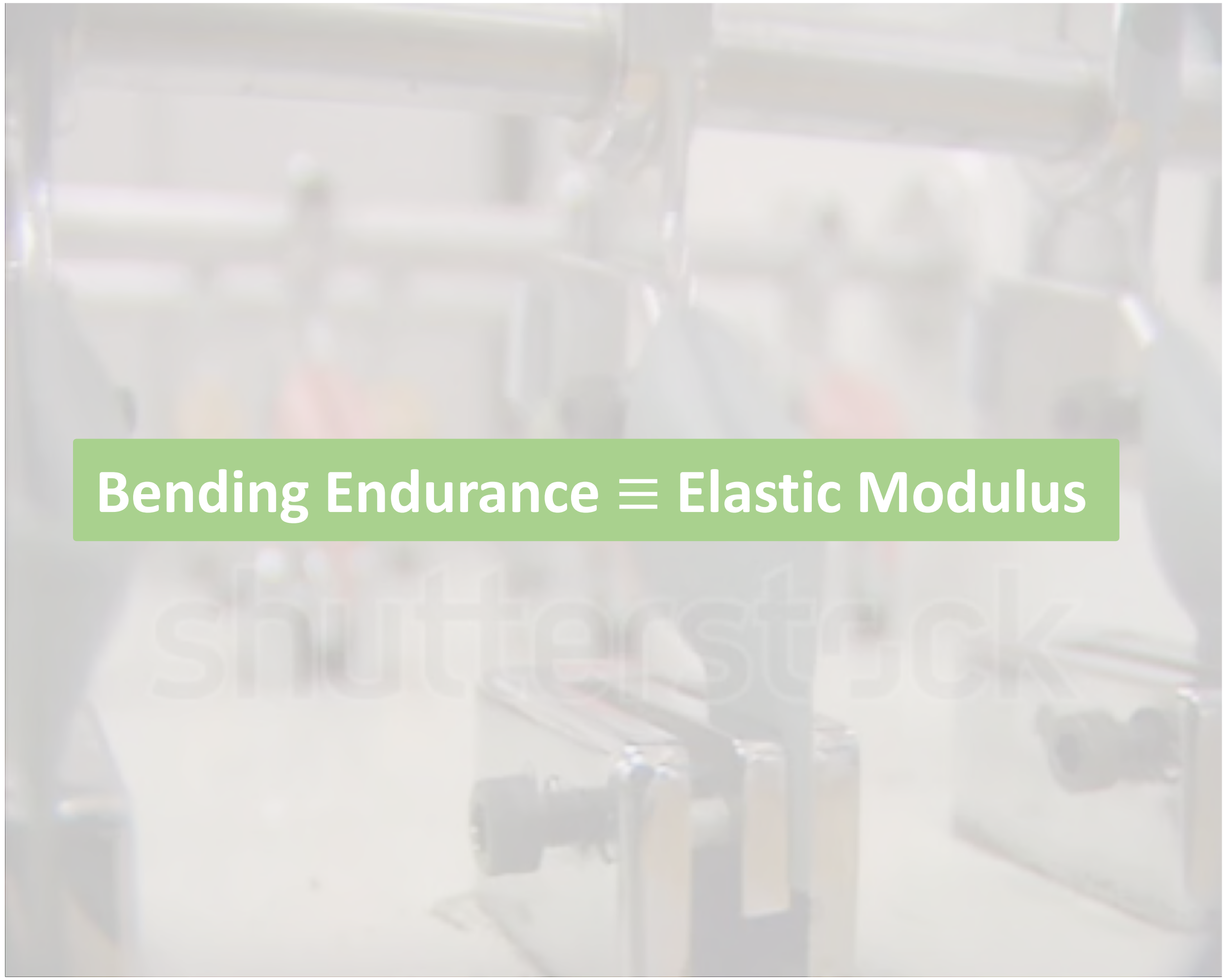
Source: Giphy.com



Flexibility: bending endurance

Source: StockShots

Flexibility: bending endurance



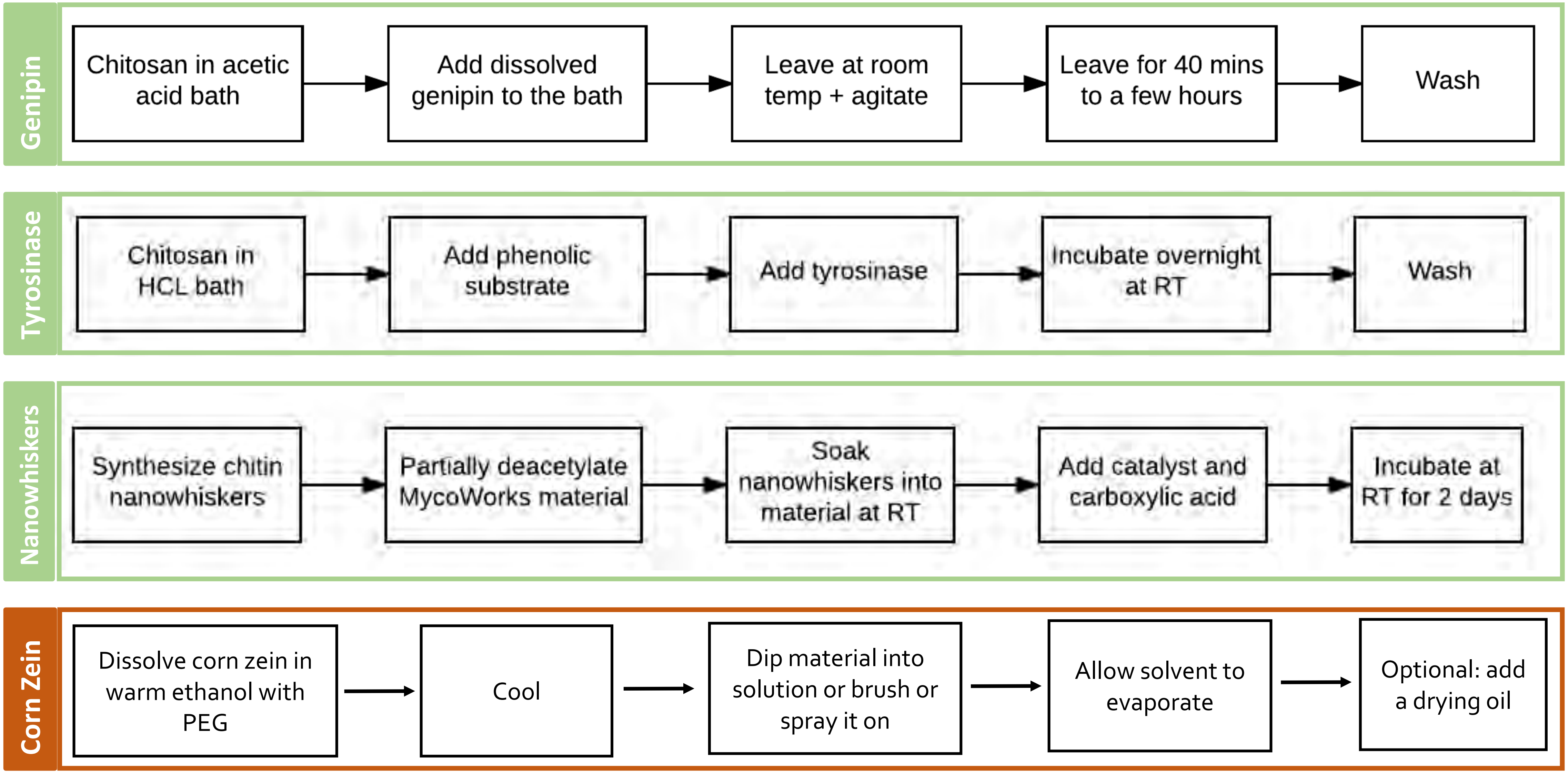
Technical performance framework

	Categories	0	xxx	xx	x
Performance	Strength	Unknown	<= 0.5x	Similar to MycoWorks	>=2x
	Water Resistance	Unknown	Lower	Similar to MycoWorks	Higher
	Flexibility	Unknown	Lower	Similar to MycoWorks	Higher
	Longevity Through Washes	Unknown	Lower	Similar to MycoWorks	Higher
	Handfeel	Unknown	Worse	Similar to MycoWorks	Better
	Discoloration	Unknown	Negative color change	-	Positive or no color change
Feasibility	Post-processing	Unknown	No	-	Yes
	Process Complexity	Unknown	High	Medium	Low
	Material Availability	Unknown	Few commercially available materials (<10%) or hard to synthesyze	Some synthesis required	Most materials commercially available (>90%)
	Thermal Energy Requirement	Unknown	High	Medium	Room temp
	Innovation Requirement	Additional research needed	Major hurdles anticipated	Minor hurdles anticipated	Process optimization only

Technical performance across strategies

	Strategy	Technical Performance: Physical Properties: Strength	Physical Properties: Water Resistance	Physical Properties: Flexibility	Physical Properties: Longevity Through Washes	Cosmetic Side Effects: Handfeel	Cosmetic Side Effects: Discoloration	Technical Feasibility: Integration: Post-processing	Integration: Process Complexity	Integration: Material Availability	Integration: Thermal Energy Requirement	Innovation
Existing Strategies	MycoWorks MVP	xx	xx	xx	xx	xx	xxx	N/A	N/A	N/A	N/A	N/A
	Animal leather	x	x	x	x	x	N/A	N/A	N/A	N/A	N/A	N/A
	Vegan leather	xx	x	o	x	xxx	N/A	N/A	N/A	N/A	N/A	N/A
Proposed Strategies	Genipin	x	x	xx	o	o	xxx	x	xx	x	x	x
	Tyrosinase	o	o	o	o	o	o	x	xx	xx	x	xxx
	Nanowhiskers	x	o	xx	o	o	o	x	xxx	xx	x	xx
	Corn zein + PEG	xx	x	x	o	o	o	x	xx	x	xx	xxx

Technical feasibility



Hazards Assessment

Hazards assessment framework

Green Screen (v.1.2) Hazard Profile Summary Table																				
			Human Health Effects												Ecotox.		Fate		P-Chem	
			Group I					Group II												
	Chemical	CAS #	Carcinogenic (C)	Mutagenic/ Genotoxic (M)	Reproductive (R)	(Neuro) Developmental (D)	Endocrine Activity (E)	Acute Mammalian Tox (AT)	Systemic Tox/Organ Effects (incl. Immune System) (ST)	Neurotoxicity (N)	Skin Sensitization (SnS)	Respiratory Sensitization (SnR)	Irritation/ Corrosivity Skin (IrS)	Irritation/ Corrosivity Eye (IrE)	Acute Aquatic Toxicity (AA)	Chronic Aquatic Toxicity (CA)	Persistence (P)	Bioaccumulation (B)	Reactivity (Rx)	Flammability (F)
Animal leather*	Chromium(III) Sulfate	13825-86-0	O	H	O	O	O	L	M	O	H	M	H	M	M	M	O	O	M	M
	Sulfuric acid	7664-93-9	H	L	L	M	O	H	H	O	L	H	H	H	M	H	H	L	M	M
	Acetic acid	64-19-7	L	L	O	L	O	M	L	L	M	M	H	H	M	L	L	L	M	M
	Sodium bicarbonate	144-55-8	L	L	M	L	M	H	M	O	O	L	M	M	L	L	H	O	M	L

Green Screen (v.1.2) Hazard Profile Summary Table					
Strategy	Chronic Human Health Endpoints	Acute Human Health Endpoints	Ecotoxicity	Fate	Physical
Animal Leather	H	H	M	H	M

Hazards assessment summary across strategies

Legend:

High Hazard
Moderate Hazard
Low Hazard
Data Gap

Green Screen (v.1.2) Hazard Profile Summary Table					
Chemical/ Strategy	**Chronic Human Health**	**Acute Human Health**	**Ecotoxicity**	**Fate**	**Physical**
Animal Leather	**H**	**H**	**M**	**H**	**M**
Genipin	**M**	**M**	**O**	**L**	**L**
Tyrosinase	**L**	**M**	**O**	**O**	**L**
Nanowhiskers	**M**	**H**	**L**	**O**	**L**
Corn zein	**L**	**L**	**O**	**L**	**L**

Recommended strategies: genipin + corn zein

Source: https://www.thesynergycompany.com/

Source: Global Protein Products, Inc., globalprotein.com

Source: MycoWorks

Strength
+
Flexibility

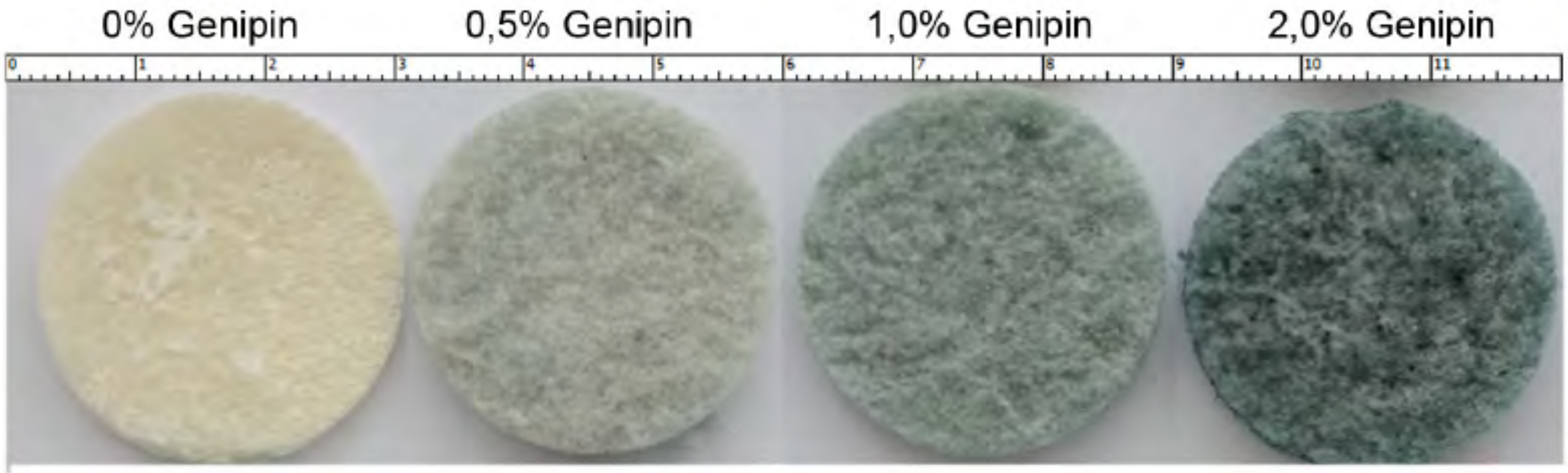
Hydrophobicity
+
PEG

Flexibility

Next steps: adding a cross-linker - genipin

- Understand the impact to material at each step in the process

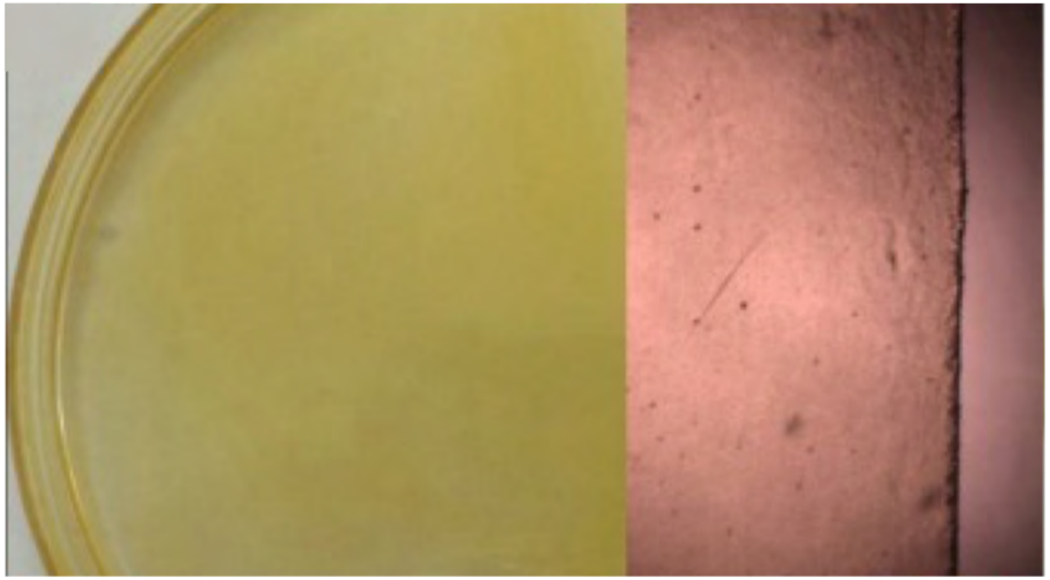
- Optimize the process for cross-linking
  - De-colorization strategy



Source: Gorczyca et al. (2013)

Next steps: adding a moisture barrier - corn zein

- Test the durability through washing
- Determine the effect of temperature and humidity on performance
- Optimize corn zein:PEG ratio



Corn zein film: macroscopic (left) and microscopic (right)

Source: Bisharat et al. (2018)


THANKS!
www.thesunandtheturtle.com