Suberin-based dispersions for barrier coating

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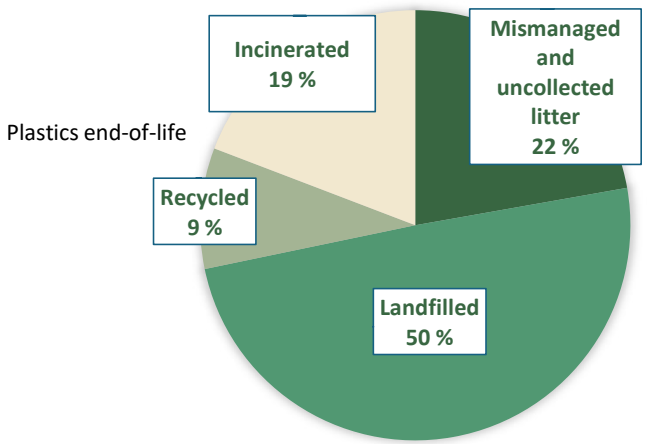
”The plastic problem”

- Annual plastic waste generation*:
  - Europe: 30Mt, 120 lbs/person
  - USA: 34Mt, 232 lbs/person
- Globally only ~9% of plastics is recycled
- Food packaging accounts for almost 60%

→ Growing demand for recyclability and sustainability



OECD Global Plastics Outlook Database

*Kara Lavender Law *et al. Sci. Adv.***6**, eabd0288(2020).DOI:10.1126/sciadv.abd0288

Why paper-based packaging?

- Paper recycling rate is high: Europe 71%[1], USA 68%[2]
- Up to 25% of plastics in packaging can be replaced with fiber-based packaging (35 Mt globally)[3]
- Plastic substitution by paper (”paperization”) driven by:
  - Major brand owners’ and retailers’ commitments to “All packaging recyclable, reusable, (compostable)”
  - Legislation (SUPD[4], PPWR[5], Indian plastic ban, etc.)
  - EPR[6] modulation
  - Regional consumer preferences

[1] CEPI
[2] American Forest & Paper Association
[3] StoraEnso, Reaching for Renewables:
Five Reasons for Surging Demand for Sustainable Packaging Materials, 2023

[4] Single Use Plastics Directive, EU
[5] Plastic and Plastic Waste Regulation, EU
[6] Extended Producer Responsibility fees, EU

Fiber-based packaging (=paper- and paperboard-based packaging)

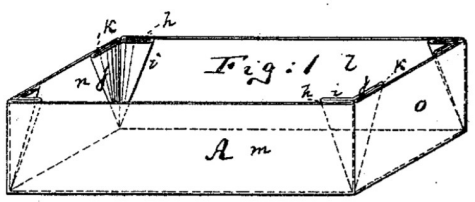
- Barrier coatings are essential, but conventional barrier materials often rely on synthetic polymers, which have limited recyclability and biodegradability

→ Need for environmentally friendly alternatives has led to research into biopolymer-based coatings

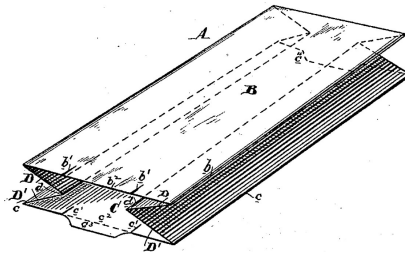
- Key challenges include ensuring:
  - effective barrier properties (moisture, oil/grease, oxygen)
  - compatibility with existing converting machinery
  - heat sealability
  - cost-competitiveness

… all while preserving recyclability

Not a new concept!



Paperboard tray, US Patent 170’991, **1875**



Paper bag, US Patent 405’616, **1889**

Objectives

- Understand the potential of suberin*, a natural polyester found in birch outer bark, as an alternative barrier material:
  - Isolate suberin from birch outer bark
  - Characterize the chemical properties of suberin
  - Develop approaches for creating suberin dispersions
  - Coat and compare to commercial reference barrier coatings

”tuokkonen”/”rove”

*Theoretical availability in Finland: 82500 tons/year, LUKE, personal communication

Overview of the work flow

Birch outer bark

Extraction and hydrolysis

Solid suberin extract

Thermo-mechanical dispersion

Suberin aqueous dispersion

Pilot coating trials

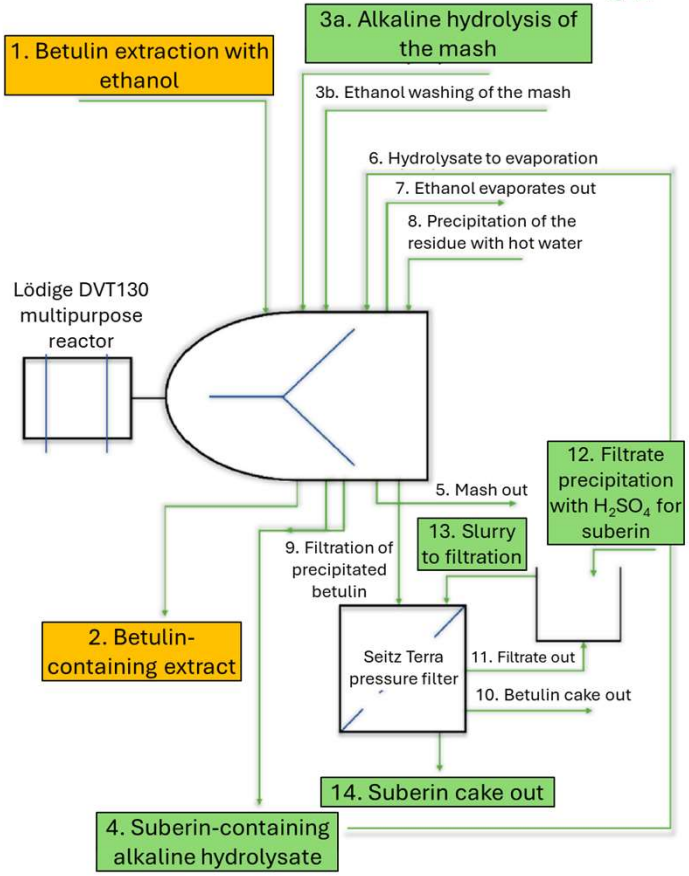
Suberin coated paper

Suberin isolation from birch outer bark

- Ethanol-water fractionation + alkaline hydrolysis in laboratory and pilot scale
- Molecular weight*: 385-430 g/mol
- Melting point: 55-75 °C
- Chemical composition:
  - Fatty acids and their derivatives, which form a crosslinked hydrophobic network:

Sample	Group compositions (mg/g)						Sum (mg/g)
	Short chain fatty acids	Long chain fatty acids	Triterpenyl alcohols	Dimers 1	Dimers 2	Trimers	
Suberin.1	11.9	564.7	72.6	32.7	9.9	9.8	701.7
Suberin.2	28.6	868.6	14.7	28.4	9.5	19.2	969.0

  - Phenolic and polyaromatic compounds



Korpinen, R. I. et al., *Molecules* 2019, 24 (23), 4391

*Measured with size exclusion chromatography (SEC)

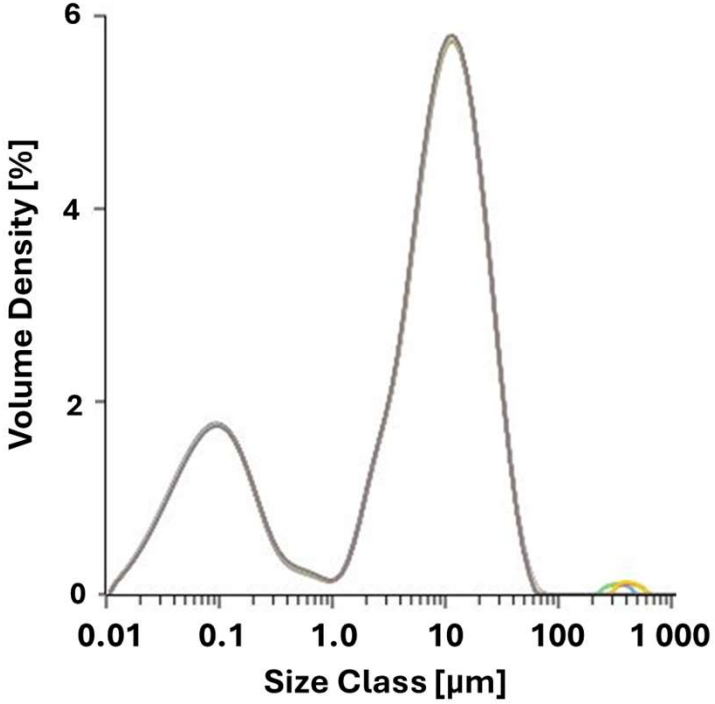
Suberin dispersion

- PVOH (Poval 40-88) as dispersant: 10-20 wt-%
- Thermomechanical dispersion:
  - Suberin is heated to 75 °C to melt it
  - Preheated (70 °C) 7% aqueous PVOH solution added stepwise while mixing
  - Dilution with 50 °C water to final solids content of 20-30%
  - Post-treatment with Ultra Turrax homogenization @12-14000 rpm for 15 minutes
  - Filtering through fine metallic sieve

Molten suberin at 75 °C

Typical suberin dispersion properties

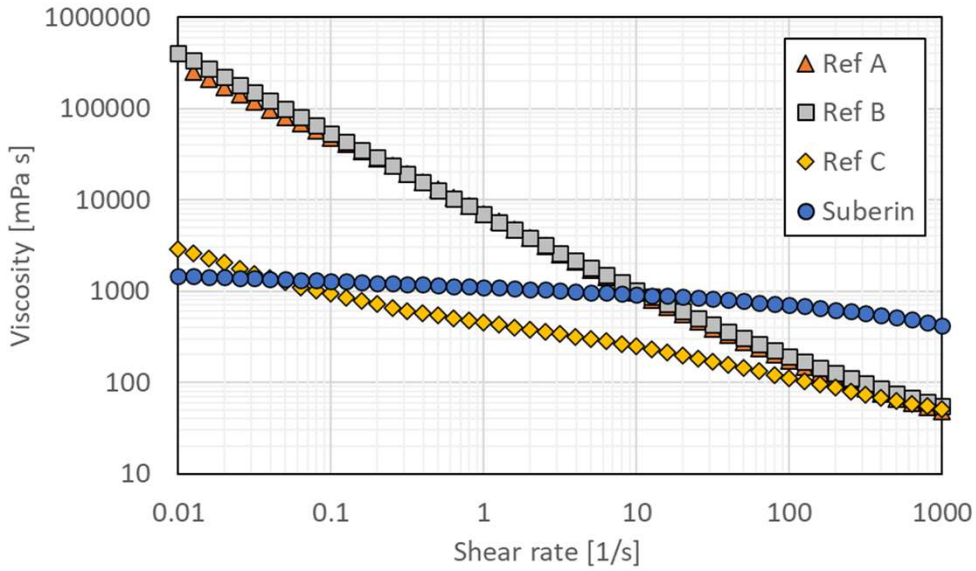
- Brownish color
- Volume-based particle size 1-100 µm
- Brookfield viscosity (100 rpm) 1390-2830 mPa s
- pH 4.0-6.5
- Conductivity 325-380 µS/cm



Materials

- Substrates:
  - Paper (UPM Prego, barrier base paper for packaging of baked goods and food), 53 g/m^2
  - Paperboard (MetsäBoard Prime FBB Bright), 202 g/m^2

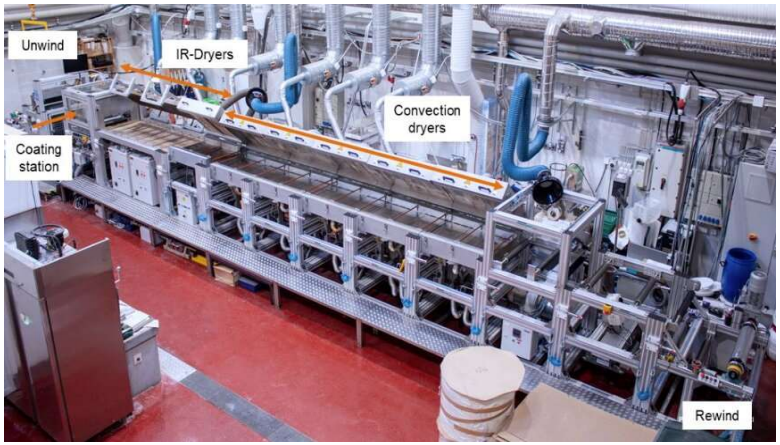
- Barrier dispersions:
  - Suberin dispersion stabilized with 20 wt-% PVOH, total dispersion solids content 20%, pH 6.5
  - Three commercial reference barrier dispersions:
    - Ref A and Ref B: styrene acrylate-based dispersions, solids content 50%, supplied by CH-Polymers Oy, Finland
    - Ref C: TEKNOPACK MJ 09, solids content 45%, supplied by Teknos Group Oy, Finland

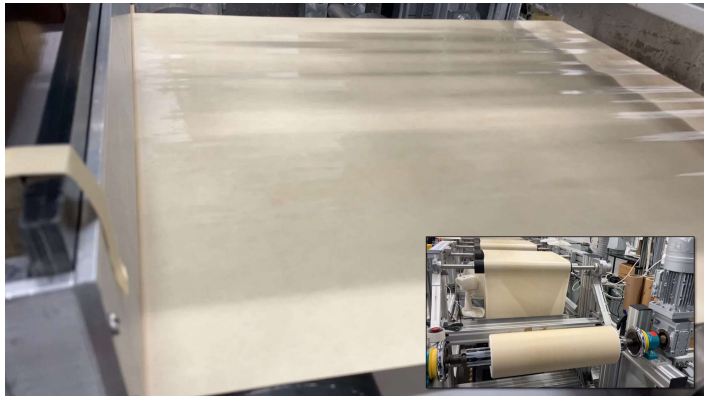


Pilot coating

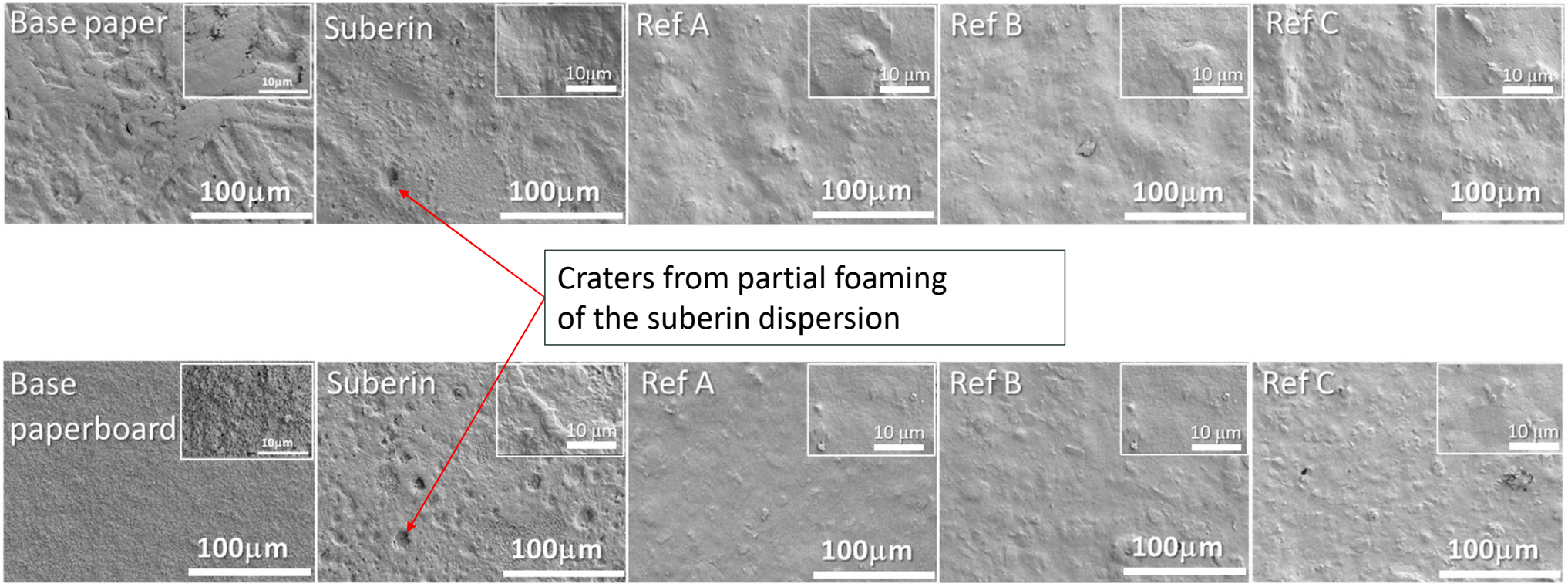
- VTT SUTCO pilot line:
  - 500 mm web width
  - Coater speed 5-10 m/min
  - 3 x IR drying: surface temperatures after each: 60/70/ 90°C
  - Hot air drying: set points 130-150°C, actual temperature 110-130°C
  - Rod metering, nominal wet coating thickness 32 µm (Suberin) / 28 µm (Ref A/B/C)

	Dry coat weight (g/m²)	
	Paper	Paperboard
Suberin	10 ± 1.0	13.4 ± 3.8
Ref A	21 ± 0.3	29.5 ± 0.8
Ref B	19 ± 1.0	28.5 ± 0.8
Ref C	15 ± 0.3	26.1 ± 1.0





SEMs of uncoated and barrier-coated substrates



Barrier testing

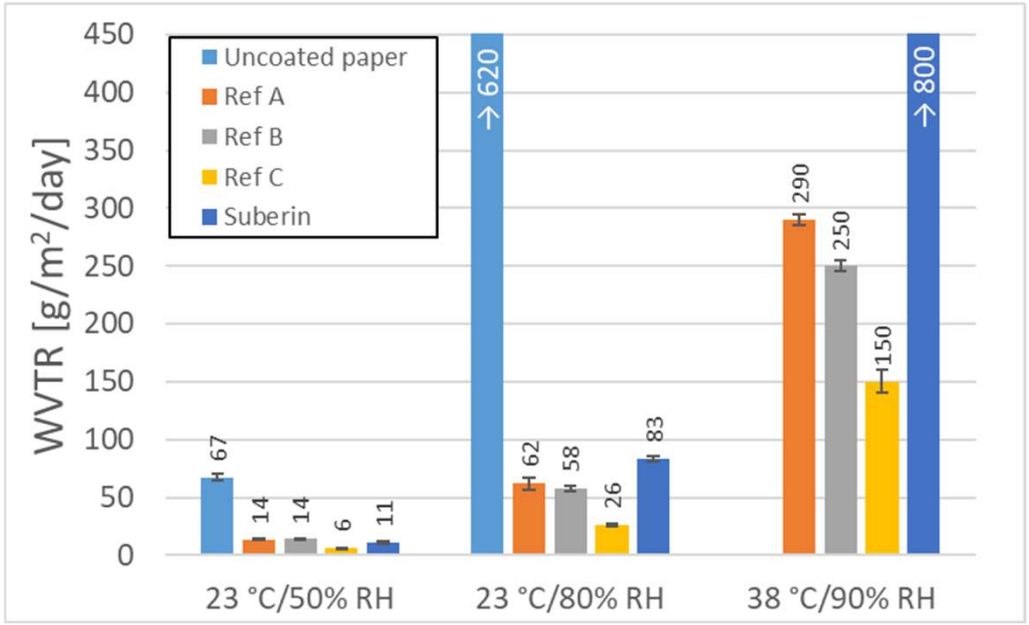
- Air permeability (L&W SE-166) below the detection limit (0.003 µm/Pa s) for all the coatings
- KIT test (TAPPI T 559)
- Grease barrier ASTM F119-82 standard using olive oil at 40 °C
- Heptane vapor transmission test: cup test at 23 °C, 50% RH

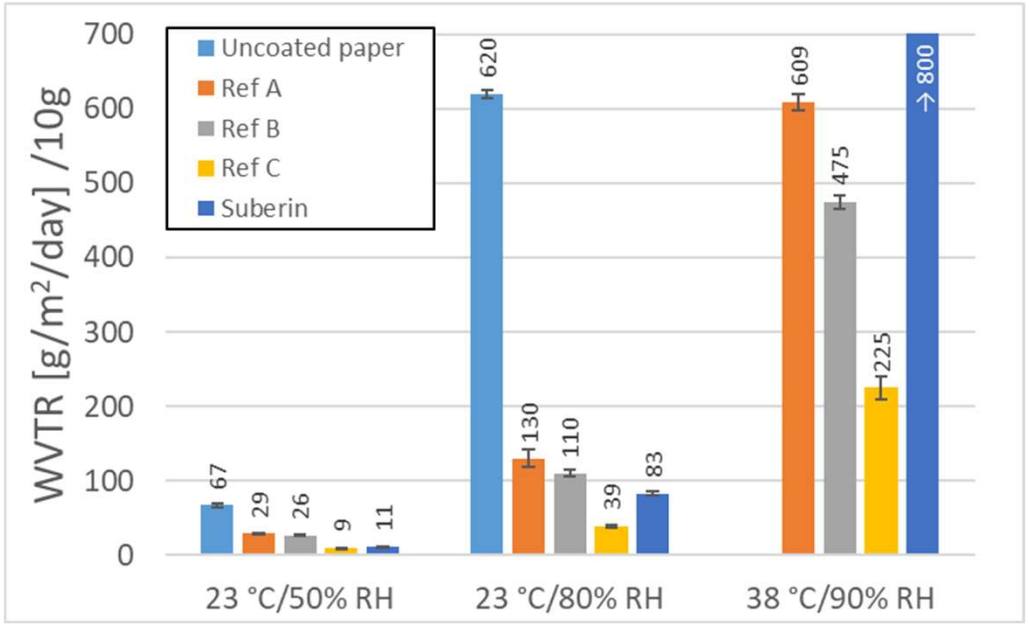
	Coatings on paper					Coatings on paperboard				
Barrier coating	Base paper	Ref A	Ref B	Ref C	Suberin	Base paperboard	Ref A	Ref B	Ref C	Suberin
Coat weight (g/m^2)	-	21 ± 0.3	19 ± 1.0	15 ± 0.3	10 ± 1.0	-	29.5 ± 0.8	28.5 ± 0.8	26.1 ± 1.0	13.4 ± 3.8
KIT	2	12	12	8	6	5	12	12	12	12
Grease barrier* (hours)	< 0.5 h	72-168 h	24-168 h	24-168 h	0.5-5 h	3-7 h	150-168 h	72-168 h	24-168 h	24-168h
HVTR (g/m^2/day)	100 ± 15	69 ± 1	93 ± 2	83 ± 7	15 ± 1	No barrier	370 ± 30	290 ± 10	420 ± 10	Below detection limit

*Starting value indicates failure of the 1st sample, the end value failure of the 5th sample. Test stopped at 168 h.

Water vapor transmission rate

Coatings on paper





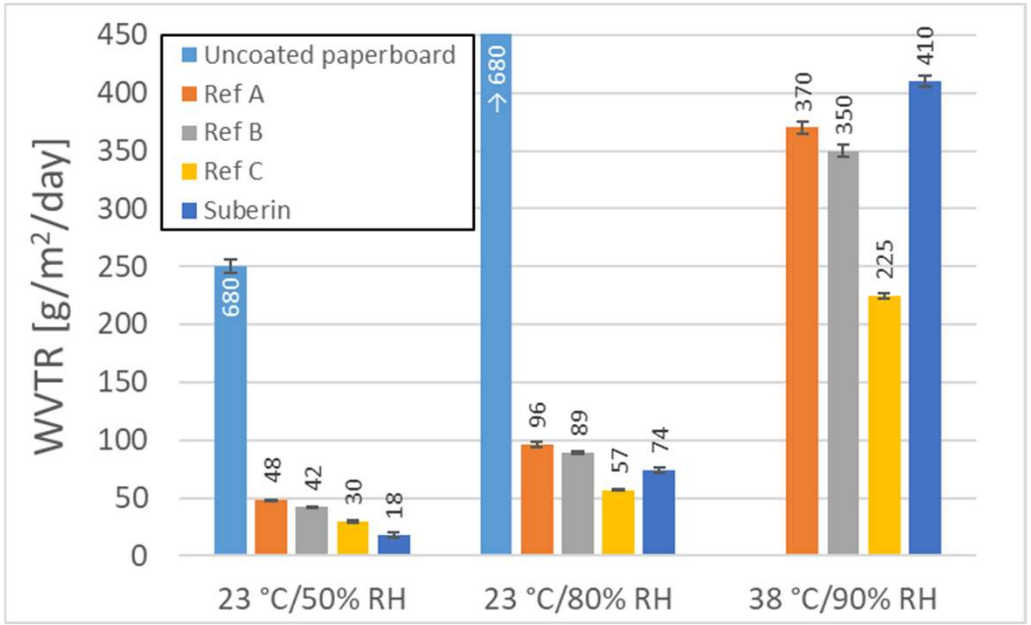
	Ref A	Ref B	Ref C	Suberin
Coat weight (g/m²)	21 ± 0.3	19 ± 1.0	15 ± 0.3	10 ± 1.0

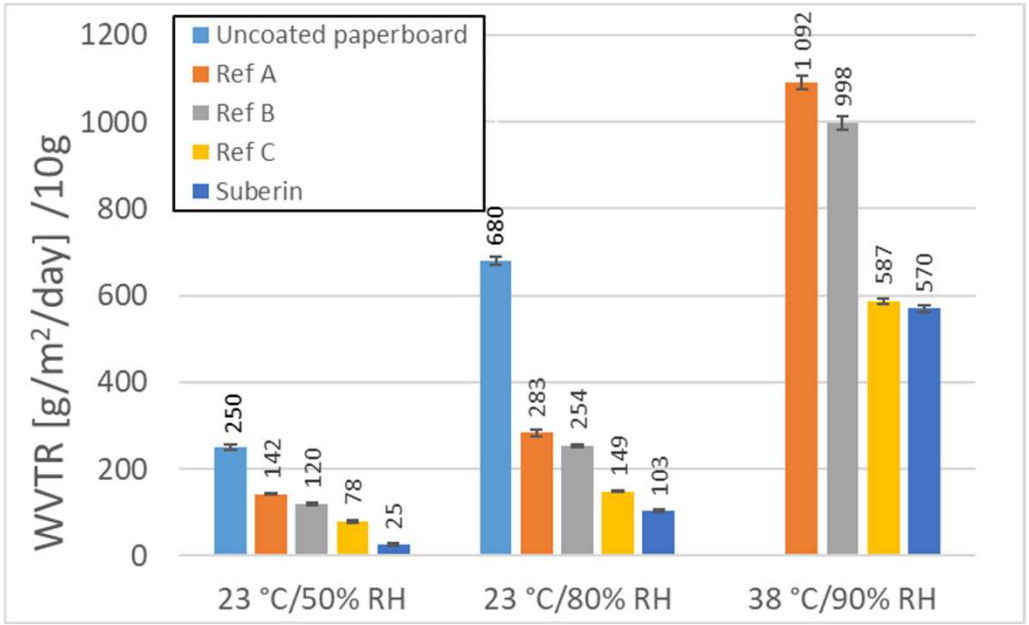
Normalized to 10 g/m²

ASTM standard (E96/E96 M-05), 3 parallel measurements

Water vapor transmission rate

Coatings on paperboard





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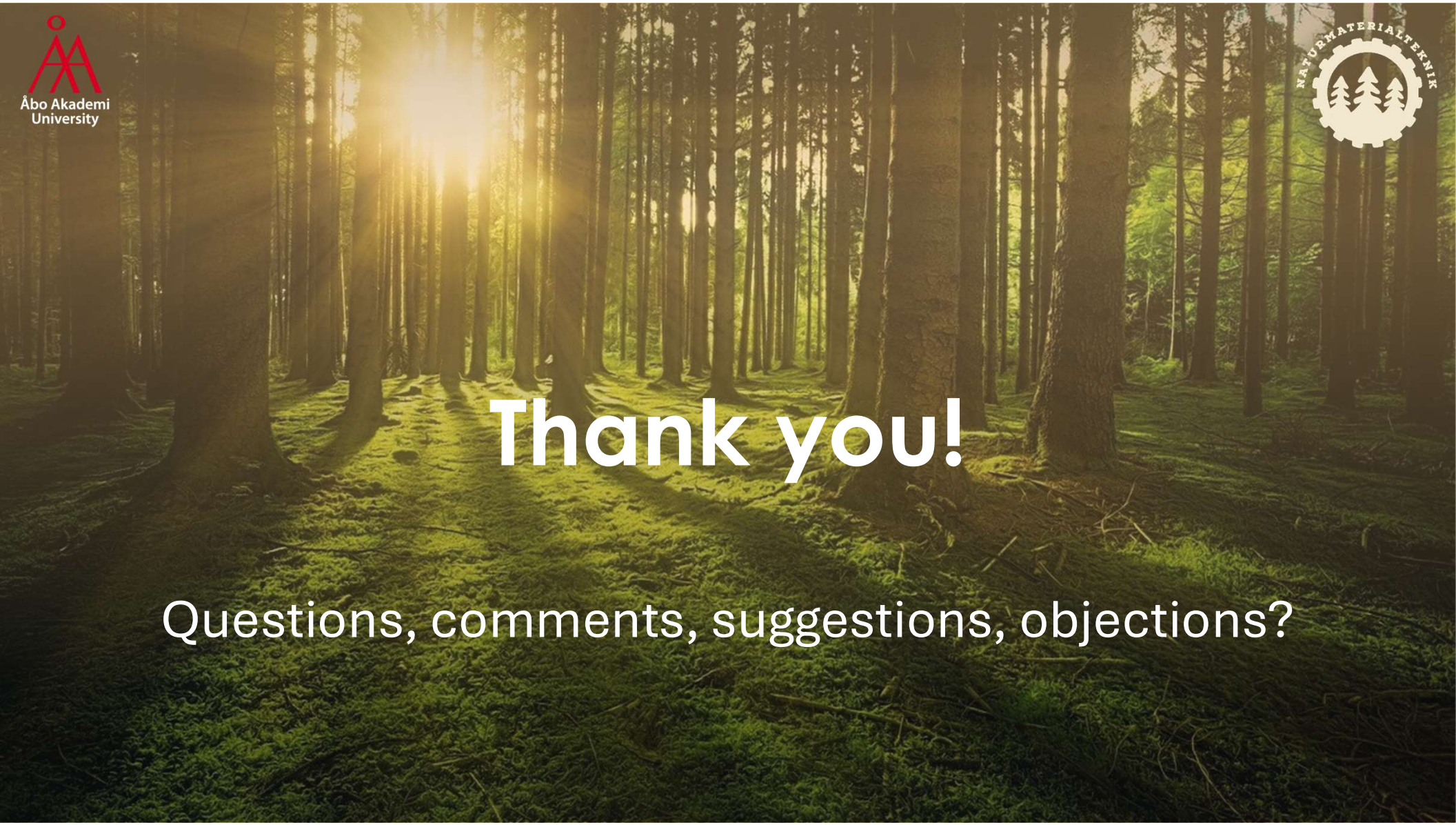
Conclusions

- Solvent-free extraction of suberin is possible from renewable source birch bark
- PVOH can be used to prepare coatable suberin dispersions
- Barrier performance of suberin is promising:
  - Suberin coatings on paperboard show better WVTR & HVTR than the reference dispersions
  - On paper, the WVTR at 50% RH is comparable to the best reference dispersion Ref C, but at higher humidity the suberin barrier is reduced
- Current and future work:
  - Alternative stabilizers to replace PVOH
  - Alternative dispersion techniques
  - Smaller particle size
  - Higher solids content
  - Convertability, foldability, creasability, sealability etc.
  - Cost analysis for scalability


Åbo Akademi
University
NATURMATERIALTEKNIK
Thank you!
Questions, comments, suggestions, objections?