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Hydrogen-Bond Organization and Porous Architecture Govern Water Transport and Germination in Cellulosic Membranes

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Introduction

Water scarcity in semi-arid regions such as La Guajira (Colombia) limits seed germination and early crop establishment. Polyethylene mulch films conserve moisture, but they persist in soil and release microplastics. Cellulose membranes from agro-industrial residues are a biodegradable alternative, yet how the biomass source shapes their hydrogen-bond network, porous architecture and agronomic function is poorly understood.

Objective

To compare porous cellulose membranes from rice husk (RH), banana pseudostem (BP) and sugarcane bagasse (SB), produced under identical conditions, and to relate their structure to water transport, seed germination and biodegradation.

Methodology

- **Extraction:** alkaline delignification (5% NaOH, 80 °C, 4 h) and bleaching (3% H_2O_2).
- **Membranes:** 2 wt.% suspension, high-shear homogenization (15,000 rpm), 10% glycerol, casting at 40 °C (≈95 µm).
- **Characterization:** ATR-FTIR, SEM, compressive strength, elongation and water vapor transmittance (WVT).
- **Function:** soil water retention, germination of *Brassica oleracea* under water stress (controls: bare soil and LDPE mulch) and 56-day soil burial.
- **Statistics:** ANOVA and Tukey test (n = 5, $p < 0.05$).

Table 1. Properties of the cellulose membranes (mean, n = 5).

Property	RH	BP	SB
Compressive strength (MPa)	**8.16**	2.81	5.39
Elongation (%)	2.33	**9.83**	5.65
WVT (g m^{-2} day^{-1})	170	**400**	300
Water retention (%)	92.1	145.3	**215.7**
Germination (%)	86.5	87.0	**90.5**
Degradation half-life (days)	16.1	15.0	15.4

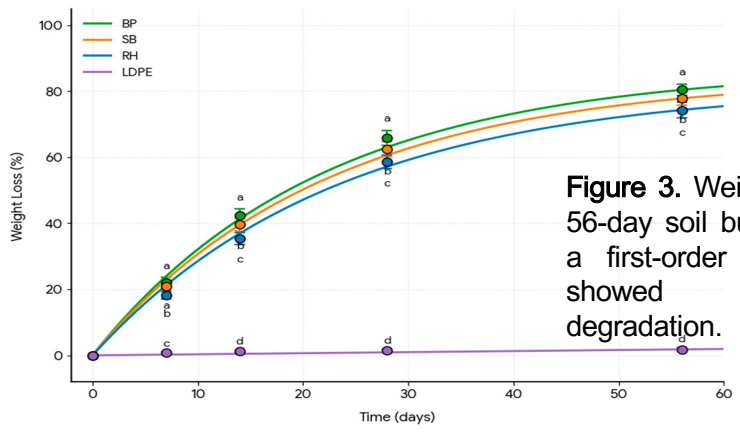


Figure 3. Weight loss during 56-day soil burial, fitted with a first-order model. LDPE showed almost no degradation.

Results and Discussion

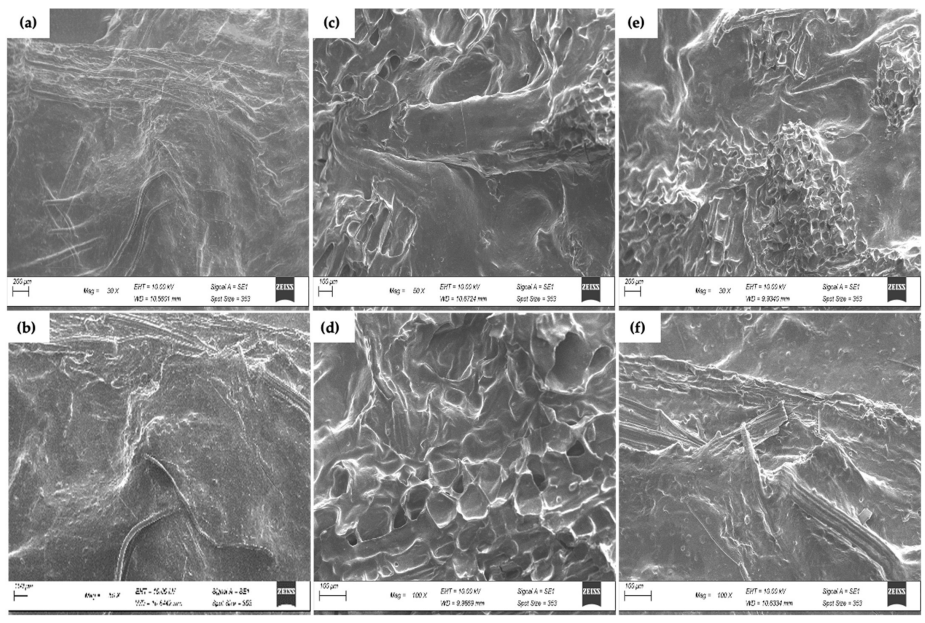


Figure 1. SEM micrographs of RH (a, b), BP (c, d) and SB (e, f) membranes at 500× and 2000×.

- FTIR confirmed removal of lignin and hemicellulose; biogenic silica (Si–O–Si) was preserved in RH.
- **RH:** compact, silica-reinforced matrix (pores < 5 µm) with the highest strength.
- **BP:** open, interconnected network (10–30 µm) with the highest elongation and vapor transport.
- **SB:** intermediate pores (5–15 µm) with the highest water retention and germination.

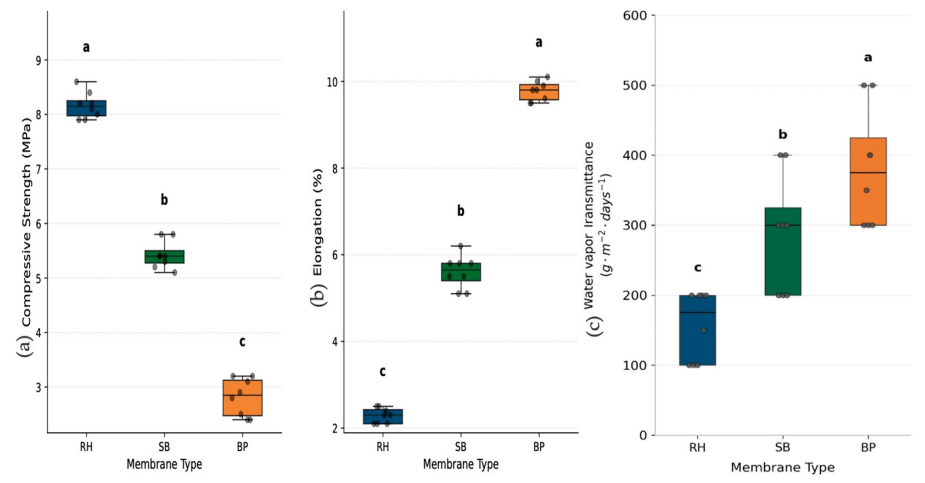


Figure 2. (a) Compressive strength, (b) elongation and (c) water vapor transmittance. Different letters indicate $p < 0.05$.

Conclusions

- Biomass origin determines hydrogen-bond organization and pore architecture and, through them, mechanical, transport and biological performance.
- All membranes outperformed LDPE mulch and bare soil in germination.
- Sustained water availability (SB) is more decisive than maximum transport rate (BP).
- All membranes degraded in soil with first-order kinetics ($R^2 \geq 0.995$; half-life of 15–16 days).
- Biomass selection is a design tool for biodegradable membranes in water-limited agriculture.

References and Acknowledgments

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