

Evaluation of Starch-Derived Hydrogel Systems for Artifact-Cleaning Applications

Nicola Razza ¹, Maduka L. Weththimuni ^{2,*}, Matteo Ferretti ², Alessandro Girella ^{1,2,3}, Barbara Vigani ⁴, Pietro Galinetto ⁵ and Maurizio Licchelli ^{1,2,*}

¹ Research Centre for Cultural Heritage (CISRIC), University of Pavia, via A. Ferrata 3, 27100 Pavia, Italy; nicola.razza01@universitadipavia.it (N.R.); alessandro.girella@unipv.it (A.G.)

² Department of Chemistry, University of Pavia, via T. Taramelli 12, 27100 Pavia, Italy; matteo.ferretti02@universitadipavia.it (M.F.)

³ Centre for Colloid and Surface Science (C.S.G.I.), Pavia Unit, Department of Chemistry, University of Pavia, via T. Taramelli 16, 27100 Pavia, Italy

⁴ Department of Drug Sciences, University of Pavia, via T. Taramelli 14, 27100 Pavia, Italy; barbara.vigani@unipv.it (B.V.)

⁵ Department of Physics, University of Pavia, via Agostino Bassi, 6, 27100 Pavia, Italy; pietro.galinetto@unipv.it (P.G.)

* Correspondence: madukalankani.weththimuni@unipv.it (M.L.W.); maurizio.licchelli@unipv.it (M.L.)

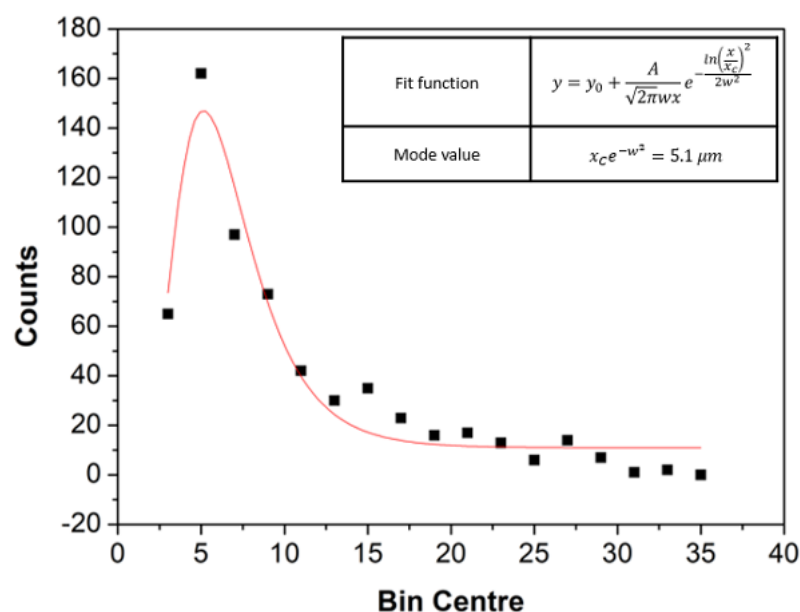


Figure S1. Porosity distribution of S-SB hydrogel.

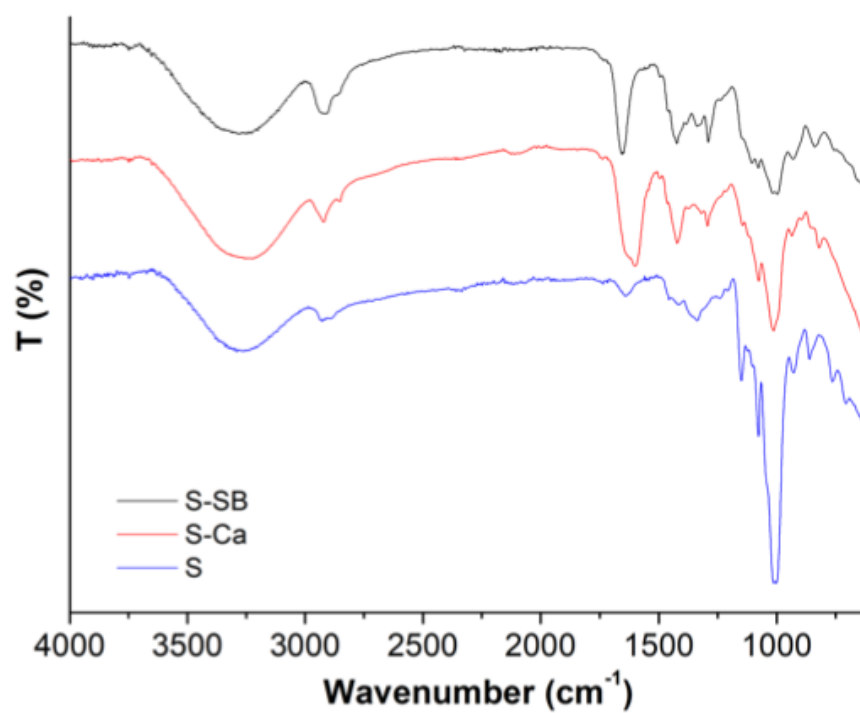


Figure S2. FTIR spectrum of starch biopolymer with hydrogels S-SB and S-Ca.

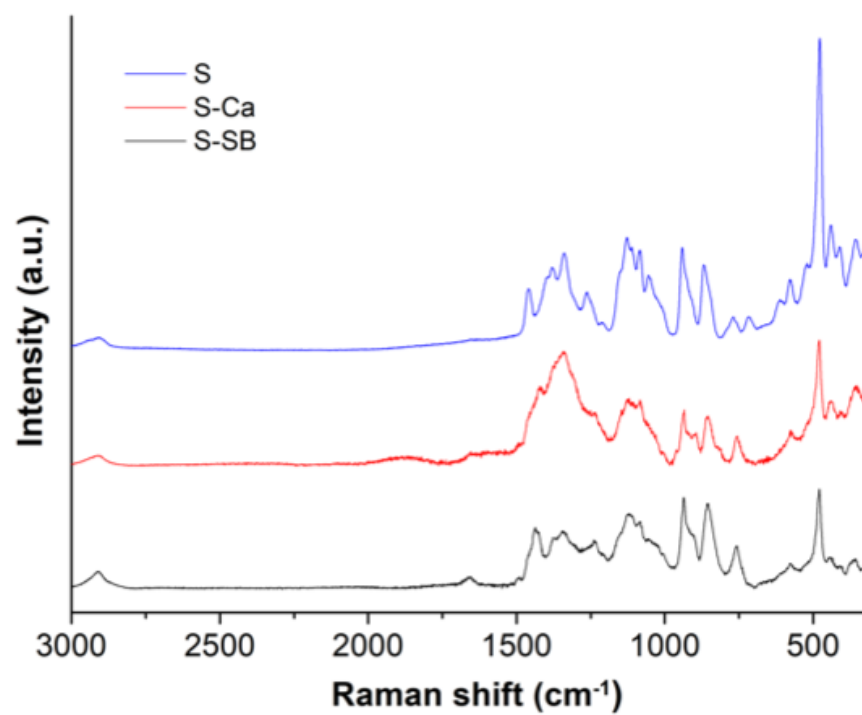


Figure S3. Raman spectrum of starch biopolymer with hydrogels S-SB and S-Ca.

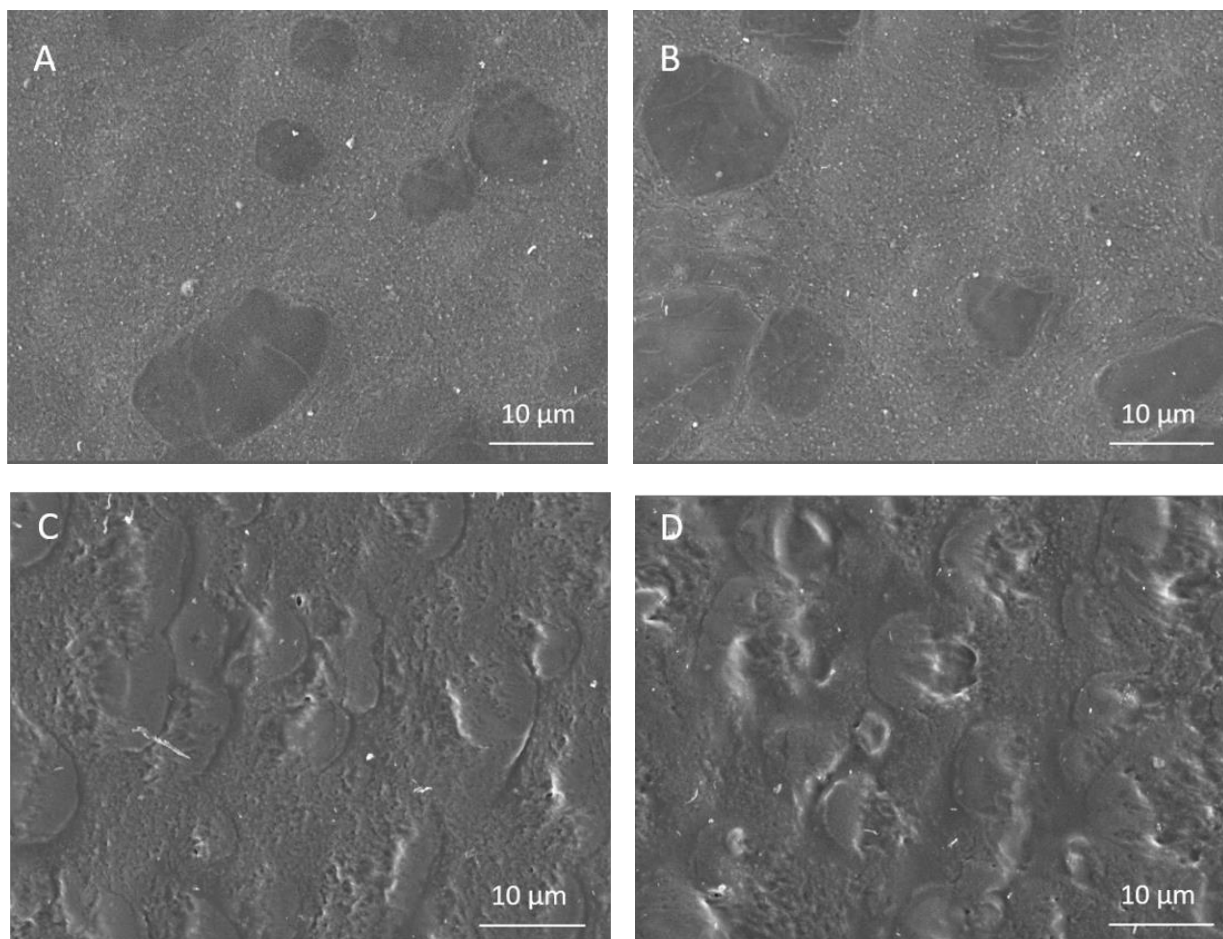


Figure S4. SEM images of non-lyophilized hydrogel films before (left) and after (right) application processes: (A and B) S-Ca and (C and D) S-SB

Table S1. Moisture properties of newly prepared hydrogels: three replicates were used to calculate the statistical data

Gels	Equilibrium water content (EWC, %)	Water releasing capacity (RC, mg/cm²)
S-Ca	83.3 (±3.1)	11.9 (±2.6)
1	85.6	8.9
2	84.6	12.9
3	79.8	13.8
S-SB	86.3 (±2.8)	16.2 (±0.6)
1	83.1	15.7
2	87.8	16
3	87.9	16.9

Table S2. Chromatic variations of the Paraloid B-72 treated mock-ups after ageing and after the cleaning with NSE-loaded hydrogels: three replicates were used to calculate the statistical data. Statistical significance for each chromatic coordinate before and after the hydrogel treatment was assessed by paired Student's t-tests; asterisks indicate significant differences (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$).

Samples	With Aged Paraloid B-72				After cleaning with NSE loaded gels			
	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔL^*	Δa^*	Δb^*	ΔE^*
Marble	-5.3 (± 0.2)	-0.1 (± 0)	0.5 (± 0.2)	5.3 (± 0.3)	-1.3 (0.2)***	-0.1 (± 0)	0.5 (± 0)	1.3 (± 0.2)
1	-5.1	-0.1	0.6		-1.1	-0.1	0.5	
2	-5.5	-0.1	0.7		-1.3	-0.1	0.5	
3	-5.3	-0.1	0.3		-1.5	-0.1	0.5	
Wood	-5.7 (± 0.3)	0.8 (± 0)	5.8 (± 0.4)	17.9 (± 0.9)	0.7 (± 0.1)**	0.3 (± 0.1)*	3.9 (± 0)*	3.9 (± 0.3)
1	-6	0.8	6.2		0.8	0.4	3.9	
2	-5.4	0.8	5.5		0.6	0.2	3.9	
3	-5.7	0.8	5.6		0.7	0.3	3.9	

Table S3. Contact angle measurements of the Paraloid B-72 treated mock-ups after ageing and after the cleaning with NSE-loaded hydrogels: three replicates were used to calculate the statistical data. For marble substrate, different superscript letters (a, b, c) within the same row indicate statistically significant differences between the experimental conditions (untreated, with aged Paraloid B-72, and after cleaning), assessed by one-way ANOVA followed by Tukey's post-hoc test ($p < 0.05$).

Samples	Contact angles, α ($^\circ$)		
	untreated	With aged Paraloid B-72	After cleaning with NSE loaded gel
Marble	81 (± 1) ^a	115 (± 4) ^b	88 (± 3) ^c
1	82	111	85
2	80	115	91
3	81	119	88
Wood	-	108 (± 2)	-
1	-	110	-
2	-	108	-
3	-	106	-