**Supplementary material**

**Lacunarity exponent and Moran’s Index: a complementary methodology to analyze AFM images and its application to chitosan films**

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FIG. 1.Linear fit of the fractal lacunarityfor the simulated self-similar fractal (Sierpinski carpet): (a) 81 x 81 pixels, (b) 243 x 243 pixels, (c) 729 x 729 pixels.



FIG. 2.Simulated self-affine rough surfaces: (a-c) H = 0.10, (d-f) H = 0.30, (g-i) H = 0.50, (j-m) H = 0.70, and (n-p) H = 0.90.



FIG. 3.Linear fit of the fractal lacunarity for the simulated self-affine rough surfaces: (a-c) H = 0.10, (d-f) H = 0.30, (g-i) H = 0.50, (j-m) H = 0.70, and (n-p) H = 0.90.



FIG. 4.AFM images of the chitosan films: (a-d) 0% of glycerol, (e-h) 3% of glycerol, and (i-m) 25% of glycerol. Mass percentage of glycerol per mass of chitosan.



FIG. 5.Linear fit of the fractal lacunarity for AFM images of the chitosan films: (a-d) 0% of glycerol, (e-h) 3% of glycerol, and (i-m) 25% of glicerol.

TABLE I.Parameters values for all simulated surfaces.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | I | Df | W0 (%) | W1 (%) | μ0 (nm) | μ1 (nm) | Z (nm) | ηmáx | β |
| H = 0.10 | 0.800212253 | 2.48368 | 50.2 | 49.8 | 0.031649778 | 0.047392609 | 0.015742831 | 0.6372434 | 0.150483 |
| H = 0.10 | 0.79396304 | 2.50795 | 52.3 | 47.7 | 0.031568542 | 0.04734255 | 0.015774008 | 0.6382869 | 0.142815 |
| H = 0.10 | 0.826766736 | 2.48472 | 47.3 | 52.7 | 0.032494952 | 0.048387224 | 0.015892272 | 0.6408186 | 0.13804 |
| H = 0.30 | 0.936460391 | 2.39629 | 48.6 | 51.4 | 0.031656696 | 0.047429589 | 0.015772893 | 0.6478574 | 0.104132 |
| H = 0.30 | 0.91045894 | 2.42252 | 50.2 | 49.8 | 0.030109707 | 0.046065769 | 0.015956062 | 0.6515898 | 0.127278 |
| H = 0.30 | 0.924362638 | 2.40284 | 45.5 | 54.5 | 0.031430541 | 0.04751442 | 0.016083879 | 0.656588 | 0.127602 |
| H = 0.50 | 0.970309728 | 2.33968 | 45.9 | 54.1 | 0.030058598 | 0.045985971 | 0.015927373 | 0.6349701 | 0.096442 |
| H = 0.50 | 0.96769215 | 2.3472 | 48.2 | 51.8 | 0.024958398 | 0.040558452 | 0.015600054 | 0.6331647 | 0.109053 |
| H = 0.50 | 0.969593495 | 2.333 | 53.5 | 46.5 | 0.025947751 | 0.041514462 | 0.015566711 | 0.6298432 | 0.098964 |
| H = 0.70 | 0.981813451 | 2.30191 | 49.8 | 50.2 | 0.026543279 | 0.042446879 | 0.0159036 | 0.636467 | 0.097671 |
| H = 0.70 | 0.983067334 | 2.29348 | 52.5 | 47.5 | 0.021104538 | 0.036143951 | 0.015039413 | 0.6342965 | 0.09859 |
| H = 0.70 | 0.989482386 | 2.25997 | 48.2 | 51.8 | 0.023382328 | 0.039400425 | 0.016018097 | 0.6513355 | 0.081219 |
| H = 0.90 | 0.993343055 | 2.23602 | 50.7 | 49.3 | 0.020122909 | 0.034651583 | 0.014528674 | 0.6632752 | 0.059875 |
| H = 0.90 | 0.991542262 | 2.23077 | 51.2 | 48.8 | 0.02305504 | 0.038820029 | 0.015764989 | 0.6358768 | 0.084797 |
| H = 0.90 | 0.994864615 | 2.1993 | 47.6 | 52.4 | 0.023831377 | 0.03962509 | 0.015793713 | 0.6439294 | 0.082528 |

TABLE II.ANOVA test for data in Table I.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source | DF | I | Df | W0 | W1 | μ0 | μ1 | Z | ηmax | β |
| Mean square | 4 | 0.01767 | 0.03312 | 2.08 | 2.08 | 0.000055 | 0.000060 | 1.37062\*10-7 | 0.000173 | 0.002048 |
| Error | 10 | 0.00010 | 0.00026 | 7.15 | 7.15 | 0.000004 | 0.000005 | 1.75653\*10-7 | 0.000063 | 0.000110 |
| Total | 14 | - | - | - | - | - | - | - | - | - |
| F-value | - | 178.7 | 126.2 | 0.292 | 0.292 | 14.030 | 11.306 | 0.78 | 2.76 | 18.604 |
| P-value | - | 2.9619\*10-9 | 1.63024\*10-8 | 0.876807¥ | 0.876807¥ | 0.000415 | 0.000992 | 0.562927¥ | 0.087524¥ | 0.000126 |

¥No significance according to ANOVA at 5% significant level. DF: degree of freedom; I: Moran Index for the first neighborhood; Df: fractal dimension; W0: percent of pixels corresponding to valleys; W1: percent of pixels corresponding to peaks; µ0: valleys’ average height; µ1: peaks’ average height; Z: mean effective height; ηmáx: maximum separability; β: lacunarity exponent.

TABLE III.Height parameters values for all AFM images of the chitosan films.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Samples | Sq (nm) | Sa (nm) | Ssk | Sku |
| #1 | 3.4853 | 2.4649 | 0.5435 | 8.2658 |
| #1 | 2.7824 | 2.0957 | 0.7736 | 7.2808 |
| #1 | 5.4053 | 3.9289 | 0.7396 | 6.1024 |
| #1 | 4.1768 | 3.1667 | 0.3816 | 4.8325 |
| #2 | 2.8077 | 2.0251 | -0.7884 | 9.7704 |
| #2 | 1.9361 | 1.4852 | -0.1465 | 4.3515 |
| #2 | 1.9533 | 1.489 | -0.0598 | 4.7059 |
| #2 | 2.8384 | 1.9695 | -1.0479 | 11.114 |
| #3 | 15.4947 | 11.1055 | 0.2656 | 7.114 |
| #3 | 15.2791 | 11.3195 | 0.0058 | 5.8262 |
| #3 | 10.0879 | 7.7854 | 0.4257 | 3.8883 |
| #3 | 9.3485 | 7.1222 | 0.7257 | 4.5951 |

TABLE IV.ANOVA test for data in Table III.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | DF | Sq | As | Ssk | Sku |
| Mean square | 2 | 119.7891 | 66.8004 | 1.379946 | 4.5882 |
| Error | 9 | 4.1056 | 1.8442 | 0.119350 | 5.3987 |
| Total | 11 | - | - | - | - |
| F-value | - | 29.1767 | 36.2221 | 11.56217 | 0.84987 |
| P-value | - | 0.000117 | 0.000050 | 0.003261 | 0.459106¥ |

¥No significance according to ANOVA at 5% significant level. DF: degree of freedom; Sq: RMS roughness; Sa: mean roughness; Ssk: skewness coefficient; Sku: kurtosis.

TABLE V.Parameters values for all AFM images of the chitosan films.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Samples | H | I | Df | W0 (%) | W1 (%) | μ0 (nm) | μ1 (nm) | Z (nm) | ηmáx | β |
| #1 | 0.1174 | 0.836199986 | 2.394 | 60.17 | 39.83 | 17.0877 | 22.15232 | 5.06462 | 0.5060532 | 0.2231 |
| #1 | 0.1263 | 0.759262382 | 2.423 | 47.3 | 52.7 | 10.12674 | 14.3261 | 4.19936 | 0.5677885 | 0.1822 |
| #1 | 0.2567 | 0.927330971 | 2.366 | 57.4 | 42.6 | 26.79683 | 34.76499 | 7.96816 | 0.531315 | 0.1846 |
| #1 | 0.22035 | 0.864556669 | 2.387 | 42.6 | 57.4 | 22.93891 | 29.36232 | 6.42341 | 0.5785541 | 0.1485 |
| #2 | 0.50095 | 0.864660969 | 2.333 | 56 | 44 | 21.13155 | 25.22023 | 4.08868 | 0.5225207 | 0.2058 |
| #2 | 0.5252 | 0.89834512 | 2.373 | 50.5 | 49.5 | 9.572482 | 12.54302 | 2.970538 | 0.5884284 | 0.2086 |
| #2 | 0.53665 | 0.887643702 | 2.37 | 48.5 | 51.5 | 10.00823 | 12.98792 | 2.97969 | 0.5812508 | 0.1987 |
| #2 | 0.5449 | 0.859053638 | 2.346 | 62.8 | 37.2 | 19.05149 | 23.15999 | 4.1085 | 0.4896829 | 0.2786 |
| #3 | 0.747 | 0.984260134 | 2.19 | 52.6 | 47.4 | 58.85503 | 81.10374 | 22.24871 | 0.5140913 | 0.1412 |
| #3 | 0.79545 | 0.986234816 | 2.2 | 47.8 | 52.2 | 85.75392 | 108.4206 | 22.66668 | 0.5491752 | 0.1154 |
| #3 | 0.66095 | 0.982207528 | 2.265 | 40.11 | 59.89 | 32.01044 | 47.99545 | 15.98501 | 0.603171344 | 0.1074 |
| #3 | 0.67735 | 0.976125823 | 2.264 | 37.7 | 62.3 | 30.41707 | 45.24978 | 14.83271 | 0.5913732 | 0.1172 |

TABLE VI.ANOVA test for data in Table 5.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Source | DF | H | I | Df | W0 | W1 | μ0 | μ1 | Z | ηmax | β |
| Mean square | 2 | 0.299451525 | 0.020160 | 0.02911 | 105.43 | 105.43 | 1621.128 | 3229.92 | 274.803 | 0.000469 | 0.010757 |
| Error | 9 | 0.003015129 | 0.001742 | 0.00085 | 52.38 | 52.38 | 257.593 | 340.37 | 6.649 | 0.001678 | 0.000846 |
| Total | 11 | - | - | - | - | - | - | - | - | - | - |
| F-value | - | 99.31632194 | 11.575 | 34.21 | 2.0127 | 2.0127 | 6.29337 | 9.48932 | 41.3305 | 0.280 | 12.7164 |
| P-value | - | 7.34955\*10-7 | 0.003250 | 0.000062 | 0.189464¥ | 0.189464¥ | 0.019510 | 0.006073 | 0.000029 | 0.762460¥ | 0.002386 |

¥No significance according to ANOVA at 5% significant level. DF: degree of freedom; H: Hurst exponent; I: Moran Index for first neighborhood; Df: fractal dimension; W0: percent of pixels corresponding to valleys; W1: percent of pixels corresponding to peaks; µ0: valleys’ average height; µ1: peaks’ average height; Z: mean effective height; ηmáx: maximum separability; β: lacunarity exponent.

TABLE VII.Linear fit of the average PSD curve for the AFM images from chitosan films (y = A + B\*x; y = log[PSD] and x = log[q]).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample | A | B | R2 | H |
| #1 | -0.9127 | -2.2348 | 0.9897 | 0.1174 |
| #1 | -0.9694 | -2.2526 | 0.9916 | 0.1263 |
| #1 | -1.1033 | -2.5134 | 0.9818 | 0.2567 |
| #1 | -1.1461 | -2.4407 | 0.9877 | 0.22035 |
| #2 | -2.4967 | -3.0019 | 0.9925 | 0.50095 |
| #2 | -2.9832 | -3.0504 | 0.9828 | 0.5252 |
| #2 | -3.005 | -3.0733 | 0.98 | 0.53665 |
| #2 | -2.6389 | -3.0898 | 0.9875 | 0.5449 |
| #4 | -2.1708 | -3.494 | 0.8668 | 0.747 |
| #4 | -2.3813 | -3.5909 | 0.8165 | 0.79545 |
| #4 | -2.45 | -3.3219 | 0.97 | 0.66095 |
| #4 | -2.5577 | -3.3547 | 0.9794 | 0.67735 |

R: Pearson correlation coefficient; H: Hurst exponent.