

Supporting information

Lyotropic liquid crystal to measure residual dipolar couplings in dimethyl sulfoxide based on modified cellulose nanocrystals

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Experimental Section

Materials: α -cellulose was bought from Aladdin. Acrylic acid (AA) with a purity of 97% was provided by Aladdin. Sulfuric acid (H_2SO_4) was obtained from Sinopharm Chemical Reagent Co., Ltd. Potassium persulfate (KPS) was obtained from Sinopharm Chemical Reagent Co., Ltd.

Preparation of cellulose crystallite Suspension: The cellulose crystallite suspension was prepared from α -cellulose power according to the previous literature.¹ In detail, the α -cellulose power (20 g) was mixed with sulfuric acid (175 mL, 64%) and stirred at 45 °C for 1 h. Then, a plenty of iced distilled water was added and the residual acid was removed through centrifugation. The sample was repeatedly centrifuged at 8000rpm for 10 min, and turbid supernatant was collected. 100 mL of the cellulose suspension (concentration: 0.7 mg mL^{-1}) was mixed with 311 mg of acrylic acid and 108 mg of $\text{K}_2\text{S}_2\text{O}_8$. The mixture was then kept at 80 °C in a nitrogen atmosphere for 6 h (Fig 1a). After the incubation, the solution was transferred into centrifuge tubes and centrifuged at a speed of 15000 rpm for 2 h. The precipitate was collected. Finally, [D6]-DMSO was used to remove residual water for at least 6 times by centrifugation.

SEM characterization: Scanning electron microscopy (SEM) images of cellulose crystallite suspension at a low concentration of 0.1 wt% were obtained on a Nova NanoSEM FEI (Holland) instrument with an accelerating voltage of 30 Kv.

FT-IR spectroscopy: The FT-IR Spectra of CNC and CNC-g-AA were obtained by IRTracer-100 (Shimadzu, Kyoto, Japan). The samples were dried and pressed into pellets with KBr powder before the measurement.

Polarized Optical Microscopy (POM): POM graphs were performed on a XPV-203E polarized microscope that was purchased from Shanghai Changfang Optical Instrument Co. The CNC-g-AA fluid samples were loaded into the planar cells.

NMR analysis: All ^1H NMR and ^2H NMR data were obtained on a Bruker Avance III NMR spectrometer (600.11 MHz for ^1H NMR; 92.12 MHz for ^2H NMR; 150.91 MHz for ^{13}C NMR, respectively) equipped with a 5-mm BBO Prodigy cryo-probe, BB-(H-F)-D-05-Z (Bruker Instruments Inc., Germany) at 295 K. The ^2H NMR acquisition was recorded using the lock channel. The *J*-Resolved HSQC experiment used homonuclear decoupling (pure-shift). All couplings could be extracted from the *J*-resolved spectra. All data were analyzed and processed using Bruker Top-spin 3.5pl 6 software.

Structure optimization: The initial structures were obtained from the Cambridge Crystallographic Data Centre (CCDC), and the optimization and frequency calculations were performed by Gaussian 09 software package² using B3PW91/6-311 g (d) level of theory under the IEFPCM solvation model with DMSO parameters.

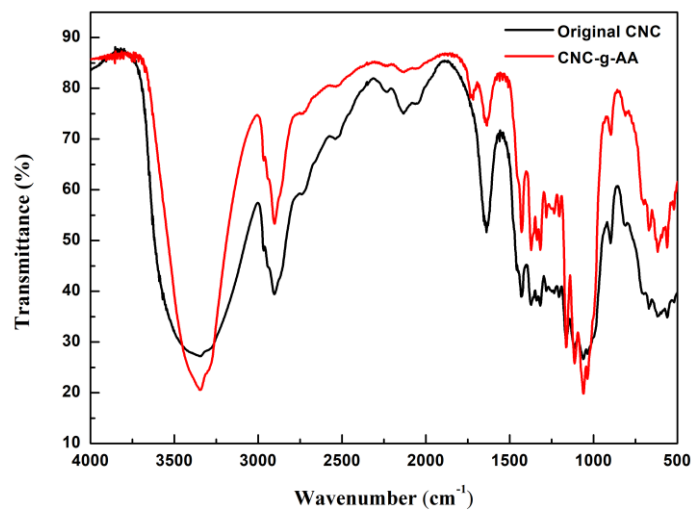


Fig. S1 FT-IR spectra of CNC (black) and CNC-g-AA (red)

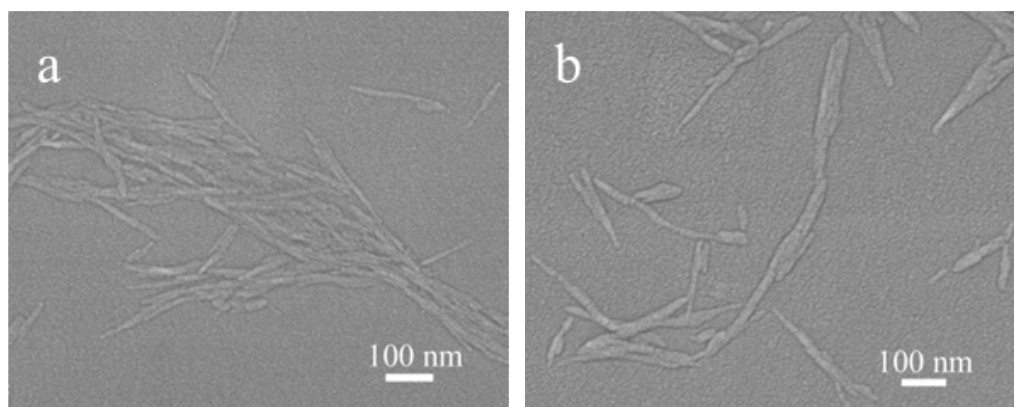


Fig. S2 SEM images of unmodified CNC (a) and CNC-g-AA (b).

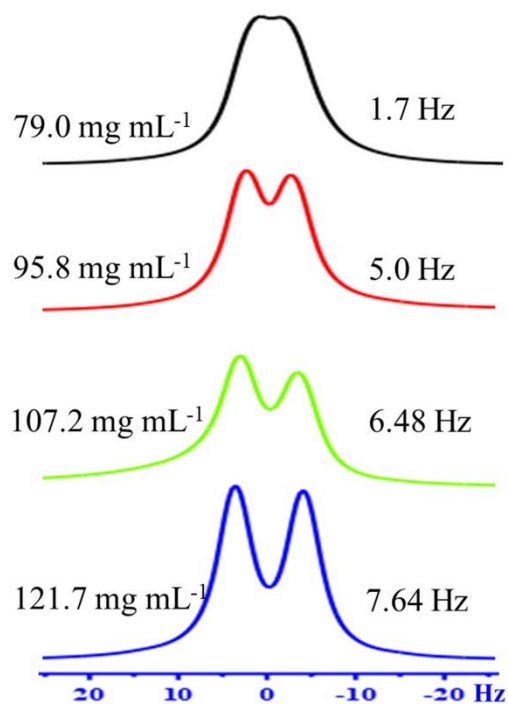


Fig. S3 1D ^2H spectra of CNC-g-AA LCs in dependence on concentration (79.0, 95.8, 107.2 and 121.7 mg mL $^{-1}$) in [D6]-DMSO collected at 22 °C.

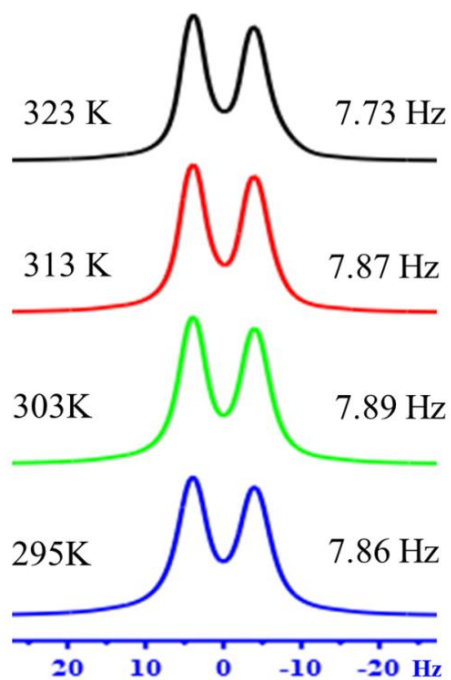


Fig. S4 1D ^2H spectra of the CNC-g-AA LCs (116 mg mL $^{-1}$) sample were recorded at various temperatures.

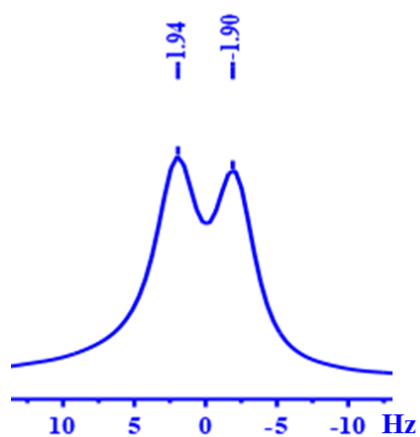


Fig. S5 1D ^2H NMR spectrum of the anisotropic sample containing 2.0 mg artemisinin in 85 mg mL^{-1} CNC-g-AA LCs phase resolved in DMSO showing quadrupolar couplings of 3.84 Hz with the linewidth of 1.81 Hz.

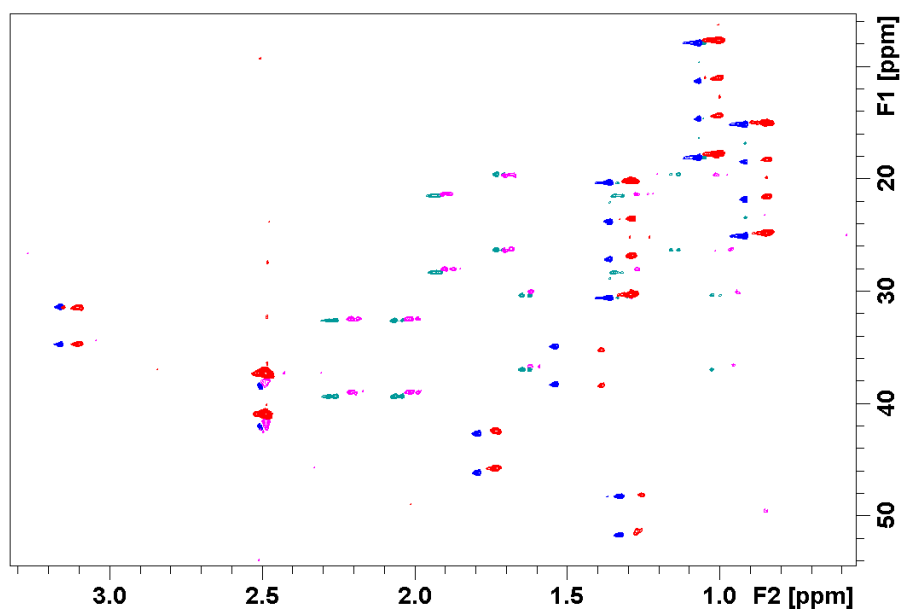


Fig. S6 Overlaid JSB-HSQC spectra of artemisinin in the isotropic phase (blue contours) and in anisotropic CNC-g-AA LCs (red contours).

Table S1 Comparison residual dipolar couplings of artemisinin extracted from JSB-HSQC spectra in the anisotropic. The assignment of artemisinin was taken from reference 3.

Atom number	Exp. RDC (Hz)	Comp. RDC (Hz)
C1, H1	-4.2	-3.97
C2, H2 _{a, b}	-1.8	-1.90
C3, H3 _{a, b}	-2.2	-2.45
C5, H5	-2.4	-2.35
C7, H7	-3.2	-3.40
C8, H8 _{a, b}	-1.4	-1.28
C9, H9 _{a, b}	-1.4	-1.93
C10, H10	-4.1	-4.00
C11, H11	-2.9	-2.85
C13, H13 _{a, b, c}	-0.4	-0.34
C14, H14 _{a, b, c}	-1.0	-0.97
C15, H15 _{a, b, c}	-1.3	-1.47

Calculated corresponding alignment tensor for artemisinin.

Alignment tensor information:

A'x=-1.014e-05

A'y=-7.596e-05

A'z= 8.609e-05

Saupe tensor

S'x=-1.520e-05

S'y=-1.139e-04

S'z= 1.291e-04

Alignment tensor eigenvectors

e[x]=(0.984, 0.014,-0.176)

e[y]=(0.004, 0.995, 0.099)

e[z]=(0.176,-0.099, 0.979)

Alignment tensor in laboratory coordinates:

[-7.147e-06,-1.927e-06,1.659e-05]

[-1.927e-06,-7.437e-05,-1.581e-05]

[1.659e-05,-1.581e-05,8.152e-05]

SVD condition number is 6.240e+00

Axial component Aa = 1.291e-04

Rhombic component Ar = 6.582e-05

Field=600.00 Teslas[0.07]

rhombicity R = 0.510

Asimmetry parameter etha =7.645e-01

GDO = 1.695e-04

ZY'Z'' Euler Angles (degrees)

Set 1

(-29.2,11.7,29.5)

Set 2

(150.8,-11.7,-150.5)

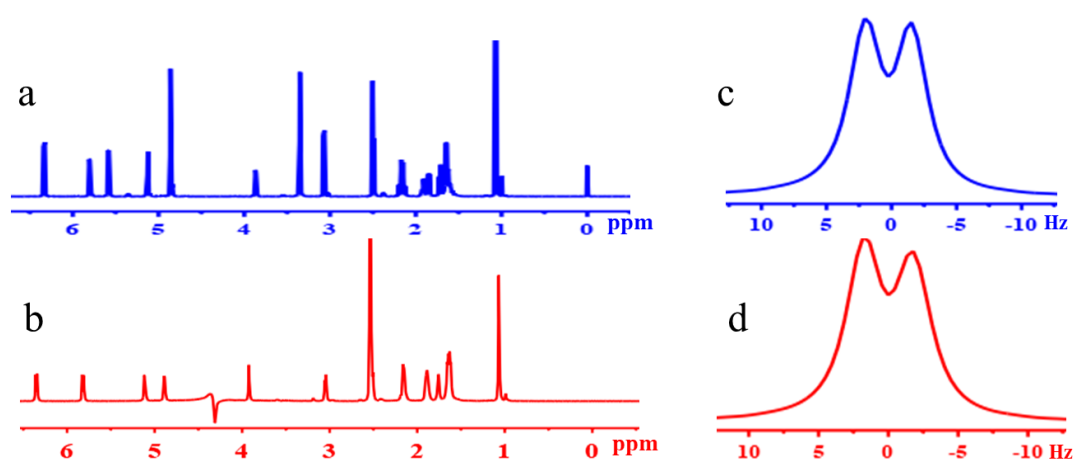


Fig. S7 (a) and (b) 1D ^1H NMR spectra of gibberellin in isotropic $[\text{D}_6]$ -DMSO (blue), and in anisotropic CNC-g-AA LCs using a NOESYPR1D pulse sequence for water suppression (red). (c) and (d) 1D ^2H spectra of CNC-g-AA LCs (81.3 mg mL^{-1} ; 3.46 Hz) spectral changes before (blue) and after testing (red) in $[\text{D}_6]$ -DMSO collected.

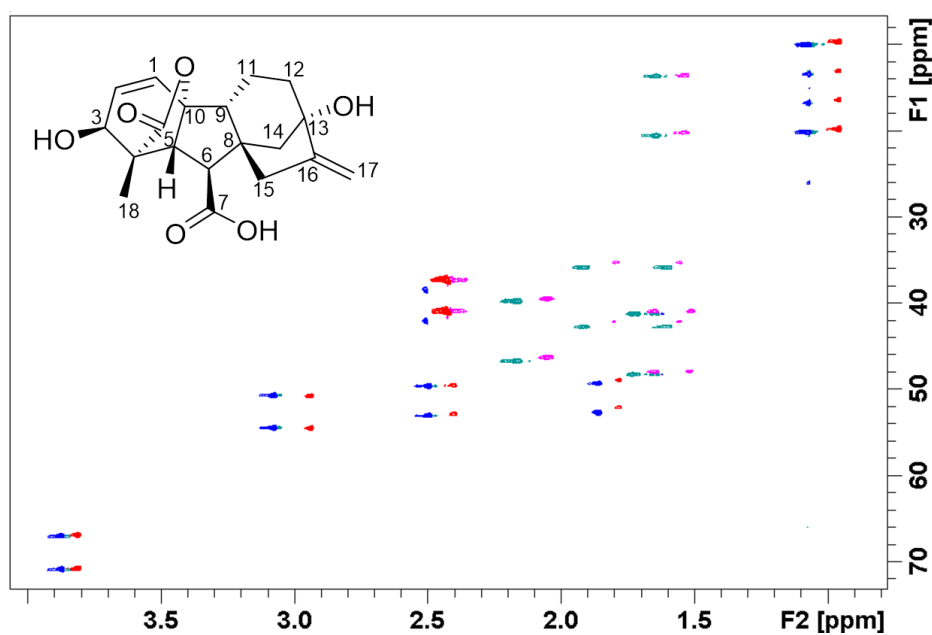


Fig. S8 Overlaid JSB-HSQC spectra of gibberellin in the isotropic phase (blue contours) and in anisotropic CNC-g-AA LCs (red contours).

Table S2 $^1J_{\text{CH}}$ spin coupling constants, total spin coupling constants $^1T_{\text{CH}}$ and RDC values for gibberellin. The assignment of a gibberellin was taken from reference 4.

Atom number	1J (Hz)	1T (Hz)	Exp. RDC (Hz)	Comp. RDC (Hz)
C1, H1	167.0	166.7	-0.2	-0.27
C2, H2	163.8	158.8	-2.5	-2.60
C3, H3	145.5	147.5	1.0	0.88
C5, H5	142.0	139.6	-1.2	-1.37
C6, H6	129.4	122.5	-3.5	-3.08
C9, H9	126.6	119.9	-3.4	-3.62
C11, H11 _{a, b}	129.1	125.2	-2.0	-2.10
C12, H12 _{a, b}	130.2	128.6	-0.8	-1.01
C14, H14 _{a, b}	132.4	132.1	-0.2	-0.25
C15, H15 _{a, b}	131.4	128.4	-1.5	-1.51
C17, H17 _{a, b}	157.0	160.3	1.7	1.52
C18, H18 _{a, b, c}	127.9	127.6	-0.2	-0.15

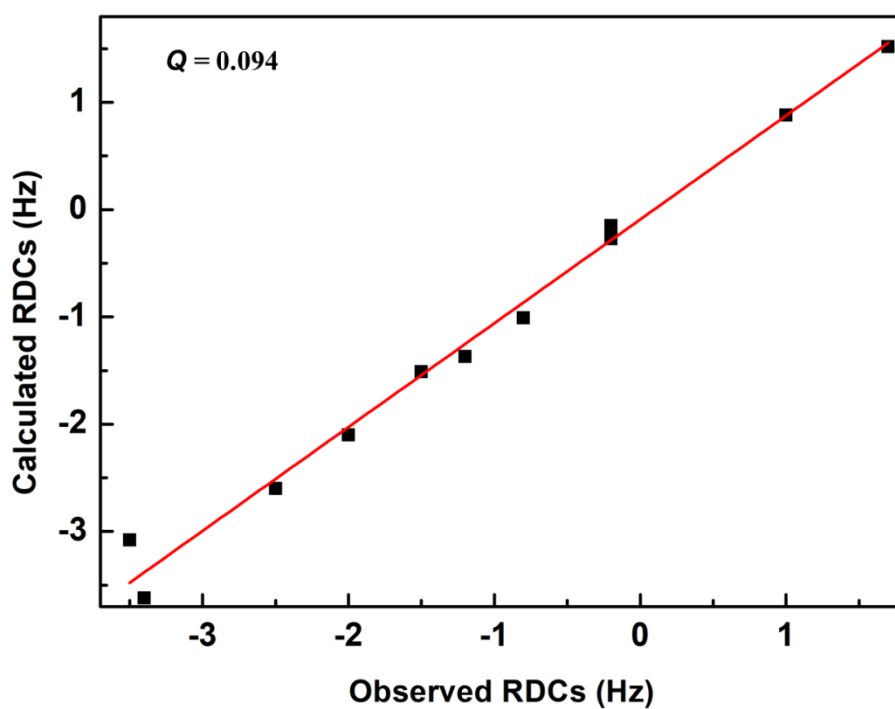


Fig. S9 Correlation between experimental $^1D_{\text{CH}}$ and the back-calculated ones for gibberellin aligned in CNC-g-AA LCs.

Calculated Corresponding alignment tensor for Gibberellin.

Alignment tensor information:

A'x=-2.031e-05

A'y=-4.901e-05

A'z= 6.932e-05

Saupe tensor

S'x=-3.046e-05

S'y=-7.352e-05

S'z= 1.040e-04

Alignment tensor eigenvectors

e[x]=(-0.092, 0.994,-0.060)

e[y]=(0.295, 0.085, 0.952)

e[z]=(0.951, 0.070,-0.301)

Alignment tensor in laboratory coordinates:

[5.827e-05,5.256e-06,-3.371e-05]

[5.256e-06,-2.007e-05,-4.204e-06]

[-3.371e-05,-4.204e-06,-3.819e-05]

SVD condition number is 4.425e+00

Axial component Aa = 1.040e-04

Rhombic component Ar = 2.870e-05

Field=600.00 Teslas[0.07]

rhombicity R = 0.276

Asimmetry parameter etha =4.141e-01

GDO = 1.251e-04

ZY'Z'' Euler Angles (degrees)

Set 1

(4.2,107.5,86.4)

Set 2

(-175.8,-107.5,-93.6)

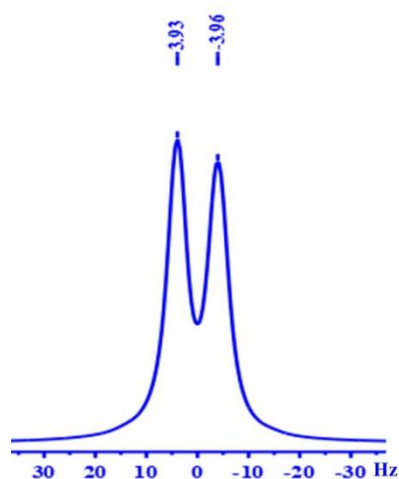


Fig. S10 1D ^2H NMR spectrum of the anisotropic sample containing 5.0 mg oridonin in 116 mg mL^{-1} CNC-g-AA LCs phase resolved in DMSO showing quadrupolar couplings of 7.89 Hz with the line width of 3.27 Hz.

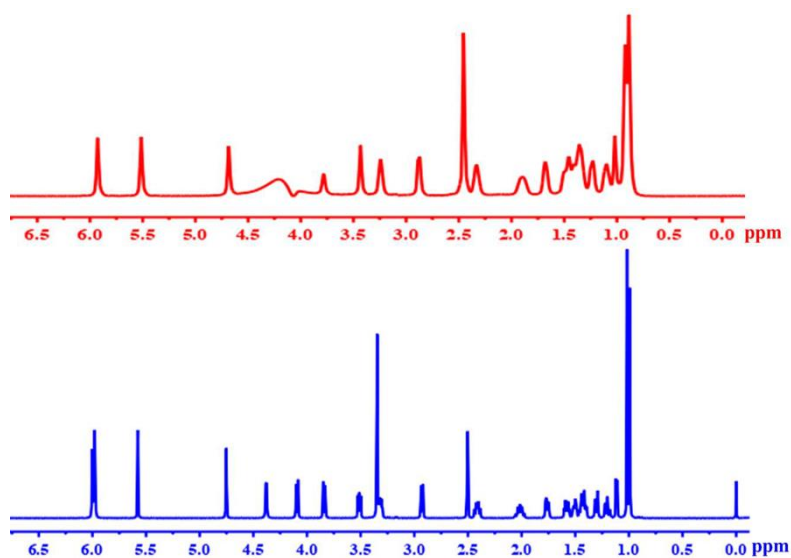


Fig. S11 (a) and (b) 1D ^1H NMR spectra of oridonin in isotropic $[\text{D}_6]\text{-DMSO}$ (blue) and in anisotropic CNC-g-AA LCs using a NOESYPR1D pulse sequence for water suppression (red).

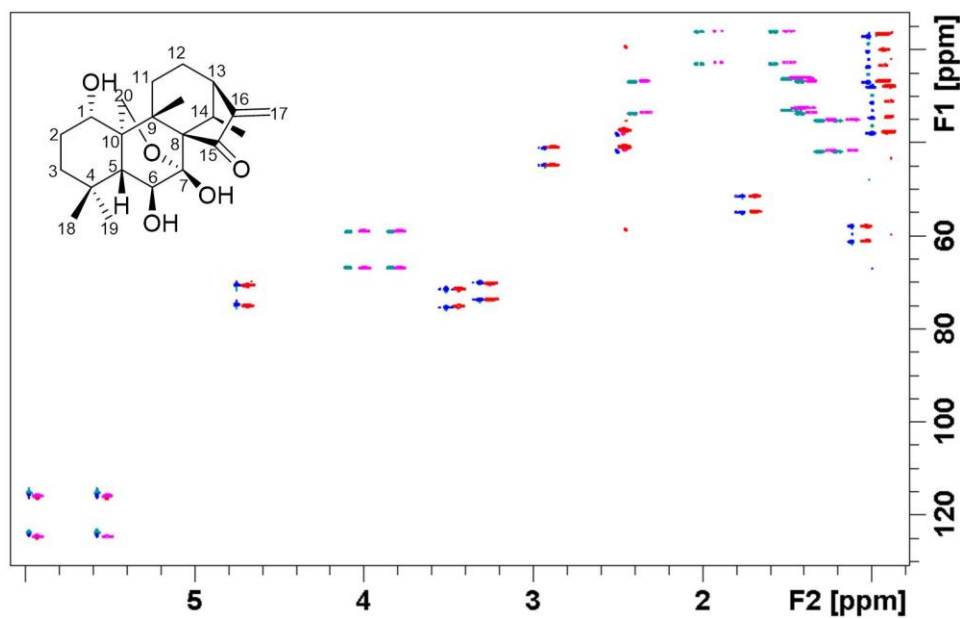


Fig. S12 Overlaid JSB-HSQC spectra of oridonin in the isotropic phase (blue contours) and in anisotropic CNC-g-AA LCs (red contours).

Table S3 $^1J_{CH}$ spin coupling constants, total spin coupling constants $^1T_{CH}$ and RDC values for oridonin. The assignment of a oridonin was taken from reference 5.

Atom number	1J (Hz)	1T (Hz)	Exp. RDC (Hz)	Comp.RDC (Hz)
C1, H1	139.2	129.6	-4.8	-4.86
C2, H2 _{a,b}	126.6	121.8	-2.4	-2.62
C3, H3 _{a,b}	126.1	123.7	-1.2	-0.83
C5, H5	124.4	118.9	-2.8	-2.54
C6, H6	145.6	137.4	-4.1	-4.31
C9, H9	130.6	126.6	-2.0	-2.13
C11, H11 _{a,b}	130.0	127.2	-1.4	-1.39
C12, H12 _{a,b}	129.4	127.5	-1.0	-0.88
C13, H13	141.1	146.3	2.5	2.35
C14, H14	156.9	163.9	3.5	3.33
C17, H17 _{a,b}	160.7	163.8	1.6	1.62
C18, H18 _{a,b,c}	124.3	126.8	1.3	1.26
C19, H19 _{a,b,c}	125.4	123.5	-1.0	-1.11
C20, H20 _{a,b}	146.5	149.5	1.5	1.51

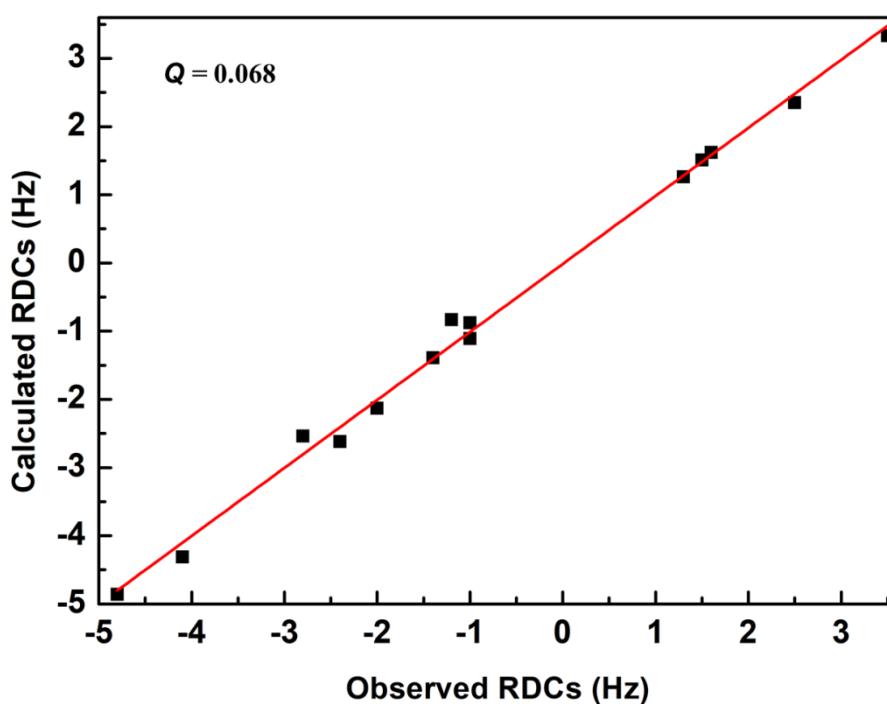


Fig. S13 Correlation between the experimental and calculated $^1D_{CH}$ values of oridonin.

Calculated Corresponding alignment tensor for oridonin.

Alignment tensor information:

A'x=-3.357e-05

A'y=-6.330e-05

A'z= 9.686e-05

Saupe tensor

S'x=-5.035e-0

S'y=-9.494e-05

S'z= 1.453e-04

Alignment tensor eigenvectors

e[x]=(0.912,-0.251,-0.325)

e[y]=(0.383, 0.806, 0.452)

e[z]=(0.149,-0.536, 0.831)

Alignment tensor in laboratory coordinates:

[-3.505e-05,-1.957e-05,1.096e-05]

[-1.957e-05,-1.533e-05,-6.895e-05]

[1.096e-05,-6.895e-05,5.038e-05]

SVD condition number is 3.380e+00

Axial component Aa = 1.453e-04

Rhombic component Ar = 2.973e-05

Field=600.00 Teslas[0.07]

rhombicity R = 0.205

Asimmetry parameter etha =3.069e-01

GDO = 1.717e-04

ZY'Z'' Euler Angles (degrees)

Set 1

(-74.5,33.8,54.3)

Set 2

(105.5,-33.8,-125.7)

REFERENCES

1. X. M. Dong, T. Kimura, J. F. Revol and D. G. Gray, *Langmuir*, 1996, **12**, 2076-2082.
2. M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, G. A. Petersson, H. Nakatsuji, X. Li, M. Caricato, A. Marenich, J. Bloino, B. G. Janesko, R. Gomperts, B. Mennucci, H. P. Hratchian, J. V. Ortiz, A. F. Izmaylov, J. L. Sonnenberg, D. Williams - Young, F. Ding, F. Lipparini, F. Egidi, J. Goings, B. Peng, A. Petrone, T. Henderson, D. Ranasinghe, V. G. Zakrzewski, J. Gao, N. Rega, G. Zheng, W. Liang, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, K. Throssell, J. A. Montgomery Jr., J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, T. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, J. M. Millam, M. Klene, C. Adamo, R. Cammi, J. W. Ochterski, R. L. Martin, K. Morokuma, O. Farkas, J. B. Foresman, D. J. Fox, Gaussian 09, Revision E.01, Gaussian, Inc., Wallingford CT **2016**.
3. A. Navarro-Vázquez, R. R. Gil and K. Blinov, *J. Nat. Prod.*, 2018, **81**, 203-210.
4. L. N. Mander, *Chem. Rev.*, 1992, **92**, 573-612
5. M. Kong, M.T. Wang, *Chin. J. Magn. Reson.* 1993, **10**, 309-314.

The coordinate data file for the analytes

1. artemisinin

Symbolic Z-matrix:

Charge = 0 Multiplicity = 1

O	3.9123	14.984	-0.0191
O	2.0129	14.0686	0.2864
O	4.1391	17.6483	-1.3173
O	4.1202	16.81	-2.5201
O	5.7456	16.427	-0.2482
C	2.7783	14.4781	-0.4964
C	2.561	14.5022	-2.0492
C	3.9501	14.4299	-2.762
C	4.8006	15.5381	-2.3356
C	5.1408	15.2972	-0.7573
C	5.4715	17.7062	-0.84
C	6.5488	17.9711	-1.9474
C	7.1442	16.6462	-2.5138
C	6.1425	15.6826	-3.112
C	6.804	14.2372	-3.2838
C	5.8685	13.0809	-3.6784
C	4.6116	13.105	-2.8511
C	1.5687	13.4181	-2.3865
C	5.4999	18.7661	0.1464
C	7.9191	14.3335	-4.2957
H	2.2444	15.2755	-2.4336
H	3.9369	14.3576	-3.7363
H	5.8807	14.6034	-0.7159
H	7.3001	18.5348	-1.5897
H	6.152	18.4409	-2.629
H	7.6696	16.1355	-1.7883
H	7.8907	16.8172	-3.1648
H	5.9998	15.8657	-4.0577
H	7.2094	13.8927	-2.4578
H	6.2247	12.2498	-3.8178
H	5.5008	13.3435	-4.6457
H	4.8384	12.6497	-2.0352
H	3.9586	12.3678	-3.2813
H	1.8059	12.5292	-2.0148
H	0.705	13.6084	-1.8545
H	1.2861	13.2977	-3.2584
H	5.2561	19.6695	-0.2762
H	4.88	18.7107	0.8846
H	6.3712	19.0046	0.574

H	8.6004	14.9478	-4.066
H	8.3992	13.4687	-4.4898
H	7.5865	14.5913	-5.1854

2. Gibberelin

Symbolic Z-matrix:

Charge = 0 Multiplicity = 1

C	0	13.7555	11.2449	1.6813
C	0	14.0844	12.2729	2.465
C	0	13.4357	12.5111	3.8117
C	0	12.2534	11.5438	4.0841
C	0	12.6983	10.1465	3.6605
C	0	11.7192	8.9968	3.8875
C	0	11.923	8.2913	5.1977
C	0	11.9163	8.0444	2.6708
C	0	12.5869	8.927	1.5562
C	0	12.665	10.3213	2.1446
C	0	11.8875	8.8197	0.204
C	0	11.611	7.3629	-0.1798
C	0	11.2254	6.4933	1.0384
C	0	10.6367	7.3935	2.1381
C	0	12.7933	6.8019	2.9179
C	0	12.4705	5.9299	1.7306
C	0	13.1004	4.8248	1.341
C	0	11.715	11.7028	5.4932
C	0	11.1738	11.8211	3.024
O	0	14.3762	12.3054	4.8599
O	0	12.9385	8.2844	5.8497
O	0	10.8218	7.5955	5.5568
O	0	11.3864	11.0205	1.9469
O	0	10.362	5.4874	0.5486
O	0	10.258	12.5911	3.0933
H	0	14.2216	11.084	0.7096
H	0	14.856	12.9828	2.16
H	0	13.0415	13.5421	3.8519
H	0	13.6941	9.8886	4.0366
H	0	10.6829	9.3564	3.8586
H	0	13.6281	8.5909	1.442
H	0	12.489	9.3123	-0.5711
H	0	10.9487	9.3818	0.2554
H	0	12.4753	6.9056	-0.6764
H	0	10.7706	7.3159	-0.8835

H	0	9.8926	8.1054	1.7662
H	0	10.1645	6.7914	2.9279
H	0	12.4742	6.2845	3.8352
H	0	13.8595	7.0295	3.0341
H	0	12.7446	4.264	0.476
H	0	13.9778	4.4466	1.8659
H	0	12.4968	11.4667	6.22
H	0	11.3708	12.7315	5.6507
H	0	10.8566	11.0412	5.6598
H	0	15.1141	12.9174	4.7366
H	0	11.0411	7.1338	6.3865
H	0	10.2539	4.8309	1.252

3. oridonin

Symbolic Z-matrix:

Charge = 0 Multiplicity = 1

O	0.08841	-0.21245	2.17687
O	0.54941	-2.81482	-0.31368
O	-1.13865	-2.07335	1.77513
O	-1.63118	-1.82495	-1.60426
O	-3.40553	-0.74092	1.50733
O	1.55919	3.25613	0.34942
C	1.81966	2.04897	-0.36424
C	3.31819	1.80111	-0.44147
C	3.63424	0.53332	-1.21534
C	3.06028	-0.7239	-0.54438
C	1.52062	-0.52568	-0.37953
C	0.83111	-1.65023	0.42459
C	-0.39912	-1.07131	1.14794
C	-1.33837	-0.23537	0.26702
C	-0.48111	0.97031	-0.32454
C	0.99505	0.8463	0.17113
C	-1.17152	2.31696	-0.07205
C	-2.64657	2.30711	-0.49622
C	-3.34848	0.97902	-0.12827
C	-2.58695	0.30374	1.015
C	-2.01499	-0.87719	-0.93997
C	-3.22947	-0.06114	-1.21782
C	-4.01849	-0.28728	-2.26734
C	3.82424	-0.99994	0.76094
C	3.31312	-1.91548	-1.47994
C	0.96901	0.81666	1.70072
H	-2.82806	-1.36406	1.97269
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H	3.77503	2.67363	-0.91981
H	4.71766	0.41934	-1.33432
H	3.22156	0.61934	-2.22963
H	-0.64263	3.10314	-0.61204
H	-1.09515	2.58912	0.98336
H	-2.73721	2.47945	-1.5731
H	-3.16095	3.1383	-0.00446
H	-4.39146	1.15178	0.14597
H	-2.31423	0.99203	1.81937
H	-3.78486	-1.08423	-2.96739
H	-4.91062	0.30148	-2.45805
H	3.70983	-0.22167	1.5175
H	4.894	-1.07675	0.5415
H	3.52938	-1.94876	1.21604
H	2.92918	-2.84713	-1.06134
H	4.38804	-2.03338	-1.65496
H	2.83153	-1.7655	-2.45186
H	1.9629	0.64349	2.12287
H	0.60035	1.76494	2.09676
H	1.48716	-1.97646	1.23841
H	1.12194	-0.60272	-1.40052
H	1.46627	2.24381	-1.38426
H	-0.53909	-2.66359	2.24704
H	-0.17692	-2.60377	-0.92948
H	-0.4324	0.84501	-1.41423
H	2.16151	3.30054	1.09983