

Supplementary materials

Table S1 Effect of temperature on the densities (ρ), molar volumes (V_m), Isobaric expansion coefficient (α_p) pH, conductivity (σ) and viscosity(η) of the ILs containing 20% water at atmospheric pressure

*The ND means not measurable

IL	Temperature (K)	ρ (g/cm ³)	V_m (cm ³ ·mol ⁻¹)	α_p	pH	σ (ms·cm ⁻¹)	η (mpa·s)
[N ₄₄₄₄]Br	298.15	1.0483	57.7415	4.7068	6.66	5.23	58.90
	308.15	1.0432	58.0221	4.7290	6.65	7.08	41.92
	318.15	1.0386	58.2796	4.7515	6.62	8.69	32.11
	328.15	1.0322	58.6415	4.7742	6.50	10.31	24.97
	338.15	1.0265	58.9660	4.7971	6.40	11.71	20.82
[N ₄₄₄₄]Cl	298.15	0.9410	62.5307	5.2865	8.19	6.77	55.12
	308.15	0.9319	63.1440	5.3146	7.78	8.35	40.83
	318.15	0.9294	63.3132	5.3430	7.91	10.53	27.63
	328.15	0.9240	63.6832	5.3717	7.72	12.12	21.89
	338.15	0.9189	64.0360	5.4007	7.84	ND	18.25
[N ₄₄₄₄]CF ₃ COO	298.15	1.0280	59.8992	5.7859	10.97	4.15	38.33
	308.15	1.0190	60.4295	5.8196	10.77	5.22	29.20
	318.15	1.0131	60.7796	5.8537	10.79	6.63	23.16
	328.15	1.0051	61.2652	5.8881	11.03	7.86	17.45
	338.15	0.9987	61.6566	5.9230	11.13	8.50	14.69
[P ₄₄₄₄]Br	298.15	1.0353	59.5703	6.0967	2.52	7.92	46.23
	308.15	1.0256	60.1387	6.1103	2.42	10.15	29.61
	318.15	1.0179	60.6012	6.1525	2.09	12.02	26.10
	328.15	1.0110	61.0184	6.2149	1.92	12.88	22.74
	338.15	1.0046	61.4121	6.2565	1.71	ND	20.78
[P ₄₄₄₄]Cl	298.15	0.9475	62.8605	6.4350	6.32	7.44	43.08
	308.15	0.9388	63.4383	6.4767	6.21	9.37	30.49
	318.15	0.9373	63.5418	6.5189	6.17	11.59	24.63
	328.15	0.9289	64.1151	6.5617	6.08	12.60	19.59
	338.15	0.9248	64.4014	6.6050	5.94	ND	16.19
[P ₄₄₄₄]CF ₃ COO	298.15	1.0293	60.7481	6.9040	4.61	5.35	30.31
	308.15	1.0251	61.2432	6.9589	4.47	7.02	23.85
	318.15	1.0219	61.7074	7.0147	4.43	8.58	19.27
	328.15	1.0145	62.1128	7.0714	4.23	9.59	15.52
	338.15	1.0112	62.6953	7.1290	4.23	10.89	13.84
[P ₄₄₄₈]Cl	298.15	0.9369	65.3378	7.4691	1.71	4.49	66.32
	308.15	0.9261	66.0998	7.5172	1.69	5.37	47.59
	318.15	0.9208	66.4838	7.5659	1.64	6.59	35.11
	328.15	0.9164	66.7994	7.6153	1.59	7.80	26.44
	338.15	0.9113	67.1733	7.6654	1.57	8.82	21.34

Table S2 Effect of water content on the densities (ρ), molar volumes (V_m), pH , conductivity (σ) and viscosity(η) of the IL/ water systems at T = (298.15) K and at atmospheric pressure.

IL	w_{water}	ρ (g/cm ³)	V_m (cm ³ ·mol ⁻¹)	pH	σ (ms·cm ⁻¹)	η (mpa·s)
[N ₄₄₄₄]Br	10%	1.0504	105.4439	6.59	1.93	118.90
	20%	1.0483	66.2872	6.23	6.47	58.90
	30%	1.0437	48.3886	6.09	11.03	25.66
	40%	1.0368	38.2450	6.01	14.66	18.36
	50%	1.0324	31.5753	5.89	16.86	12.49
[N ₄₄₄₄]Cl	10%	0.9570	112.5789	7.52	2.43	106.90
	20%	0.9642	71.9081	7.40	7.31	55.17
	30%	0.9686	52.3921	7.33	13.09	25.30
	40%	0.9722	41.5489	7.24	17.09	18.05
	50%	0.9779	34.2618	7.04	ND	10.74
[N ₄₄₄₄]CF ₃ COO	10%	1.0320	109.6201	11.01	1.43	60.10
	20%	1.0290	68.1774	10.55	4.10	38.33
	30%	1.0281	49.5023	10.10	5.69	26.33
	40%	1.0249	39.0719	9.72	6.81	16.85
	50%	1.0212	32.2960	9.38	7.76	11.41
[P ₄₄₄₄]Br	10%	1.0469	107.7884	6.26	2.29	81.76
	20%	1.0424	67.3280	5.59	7.44	46.23
	30%	1.0392	49.2676	5.14	12.26	21.82
	40%	1.0335	39.1777	4.81	17.16	16.13
	50%	1.0285	32.4669	4.63	ND	12.00
[P ₄₄₄₄]Cl	10%	0.9552	115.8498	6.25	2.37	94.61
	20%	0.9651	72.9427	5.71	6.96	43.08
	30%	0.9734	53.0244	5.31	11.63	25.62
	40%	0.9797	41.5886	5.23	14.94	17.04
	50%	0.9817	34.2838	5.19	16.5	12.29
[P ₄₄₄₄]CF ₃ COO	10%	1.03025	115.6351	4.94	1.39	52.10
	20%	1.02505	70.9226	4.61	4.52	30.31
	30%	1.02185	51.1910	4.34	5.92	20.33
	40%	1.0145	40.4593	4.05	7.02	16.30
	50%	1.0112	33.1357	3.84	7.93	12.41
[P ₄₄₄₈]Cl	10%	0.94385	124.7643	1.96	1.83	124.50
	20%	0.95185	76.3259	1.71	5.66	66.32
	30%	0.95785	55.0911	1.62	8.25	38.33
	40%	0.9605	43.0576	1.63	9.99	29.97
	50%	0.9669	35.1671	1.69	11.63	17.88

*The ND means not measurable

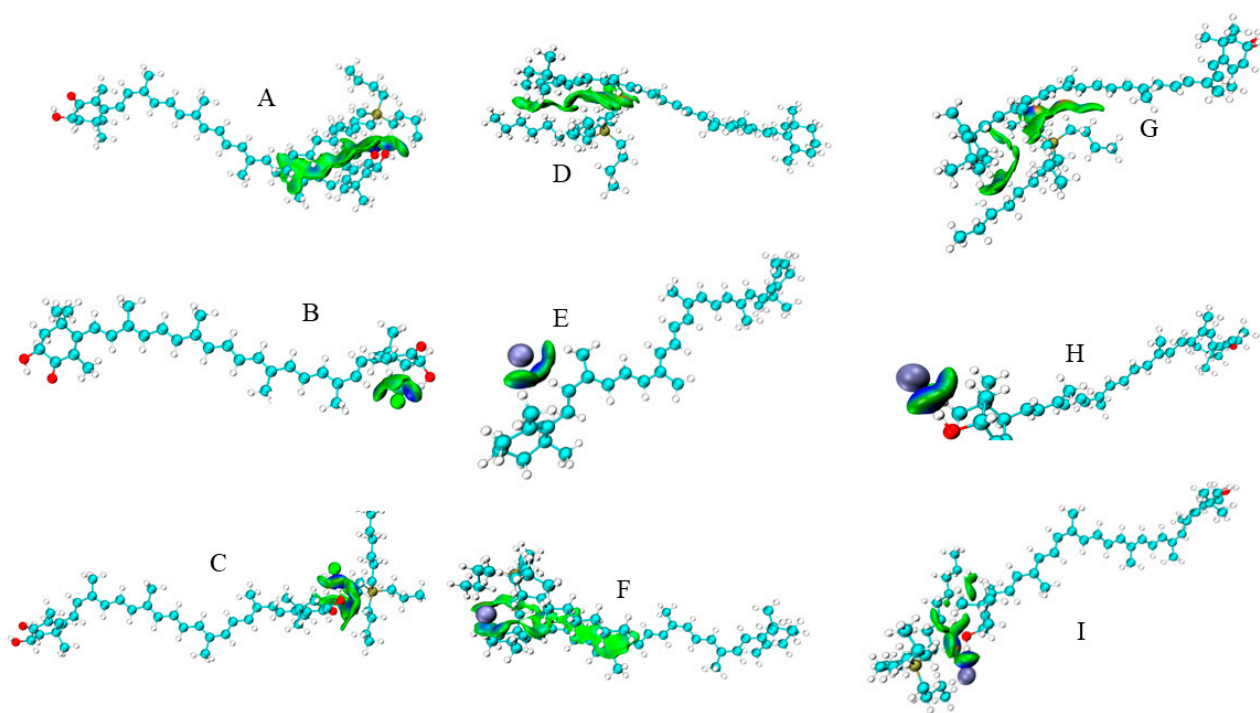


Figure S1 The scatter diagrams of $[\text{P}_{4448}]^+$ -astaxanthin (A), Cl^- -astaxanthin (B), $[\text{P}_{4448}]\text{Cl}^-$ astaxanthin (C), $[\text{P}_{4448}]^+$ - β -carotene (D), Cl^- - β -carotene (E), $[\text{P}_{4448}]\text{Cl}^-$ - β -carotene (F), $[\text{P}_{4448}]^+$ -lutein (G), Cl^- -lutein (H), and $[\text{P}_{4448}]\text{Cl}^-$ -lutein (I)

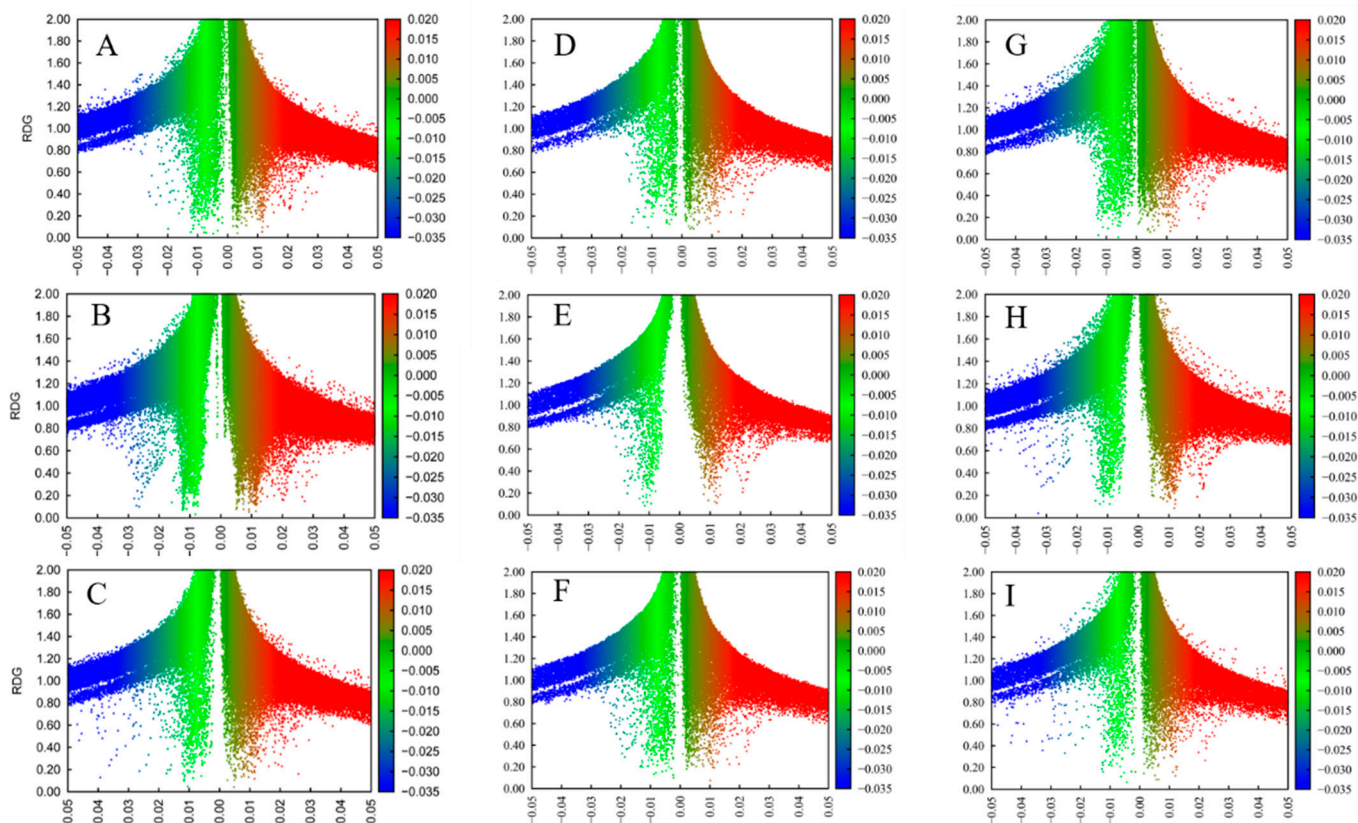


Figure S2 Plots of reduced density gradient (RDG) versus electron density multiplied by the sign of λ_2 : [P₄₄₄₈]⁺-astaxanthin (A), Cl-astaxanthin (B), [P₄₄₄₈]Cl-astaxanthin (C), [P₄₄₄₈]⁺- β -carotene (D), Cl- β -carotene (E), [P₄₄₄₈]Cl- β -carotene (F), [P₄₄₄₈]⁺-lutein (G), Cl-lutein (H), and [P₄₄₄₈]Cl-lutein (I).

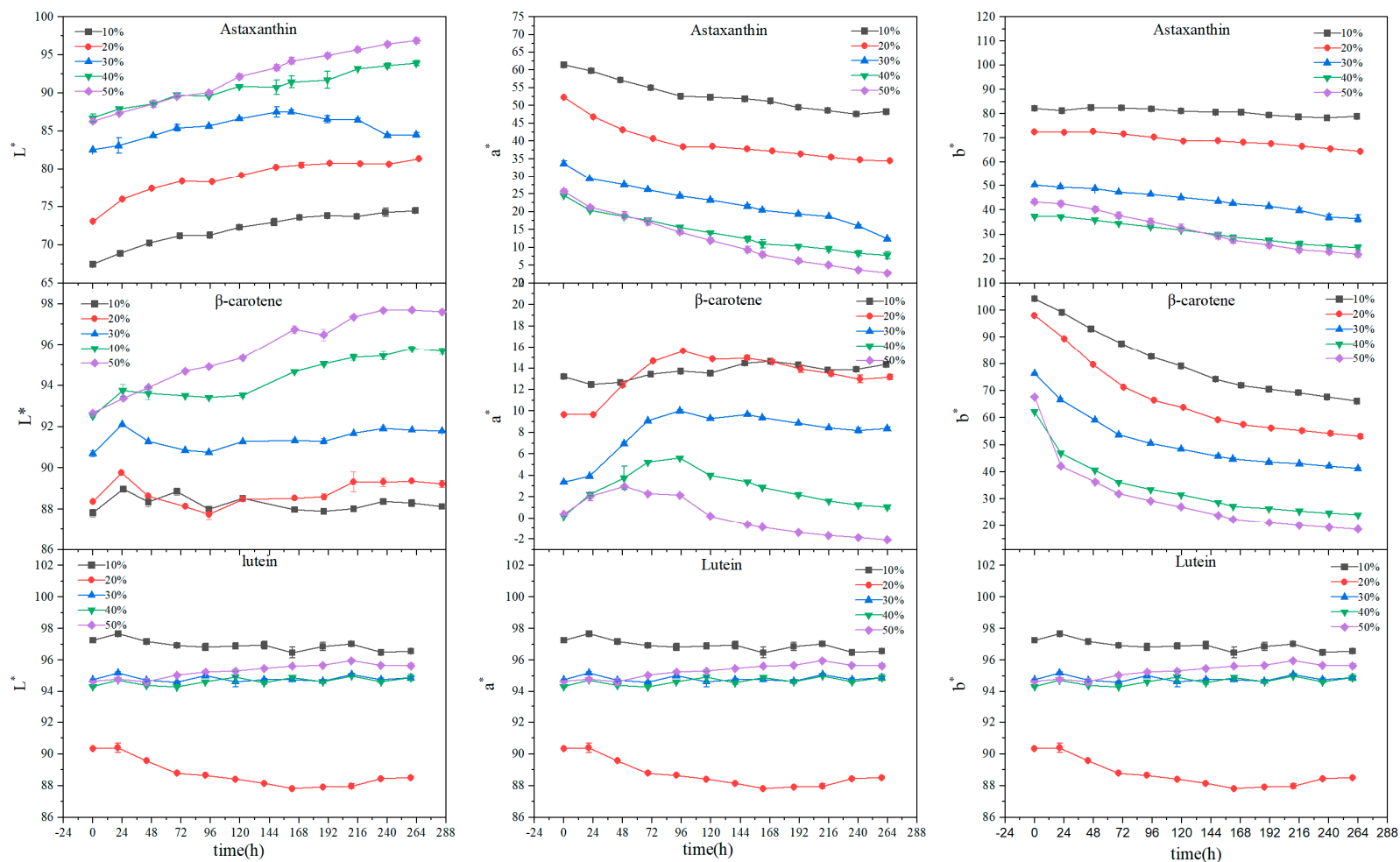


Figure S3 Color parameters (L^* , a^* and b^*) of $[P_{4448}]Cl$ aqueous solution containing astaxanthin (top), β -carotene (middle) and lutein (bottom) as a function of water content in storage at 25°C in the dark

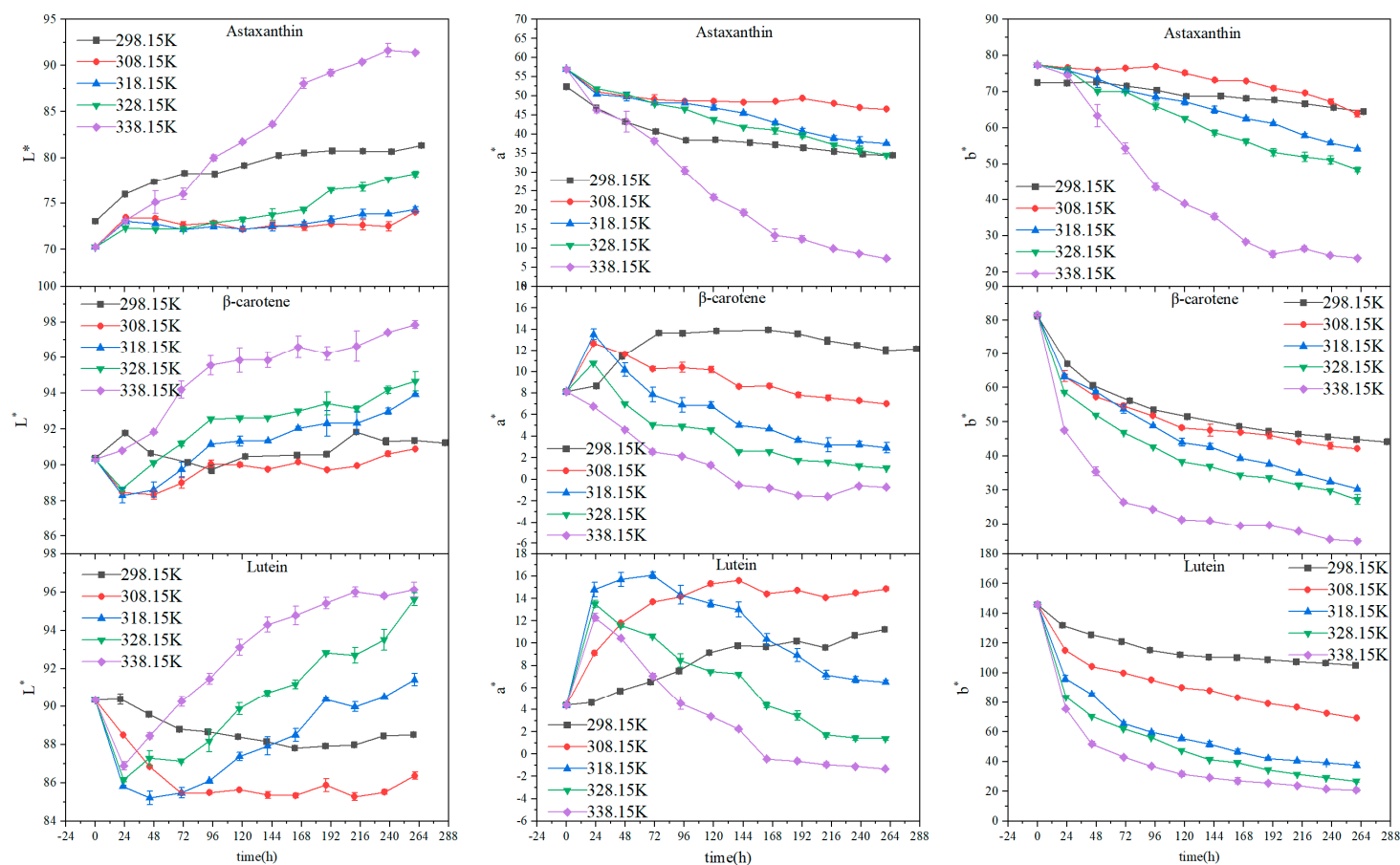


Figure S4 color parameters (L^* , a^* and b^*) of $[P_{4448}]Cl$ aqueous solution containing astaxanthin (top), β -carotene (middle) and lutein (bottom) as a function of temperature in storage at 20% water in the dark.

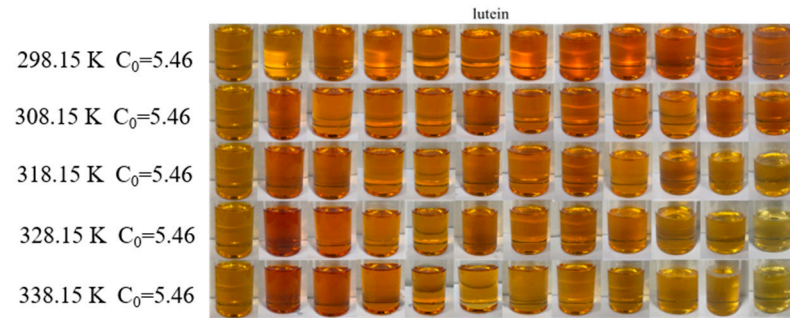
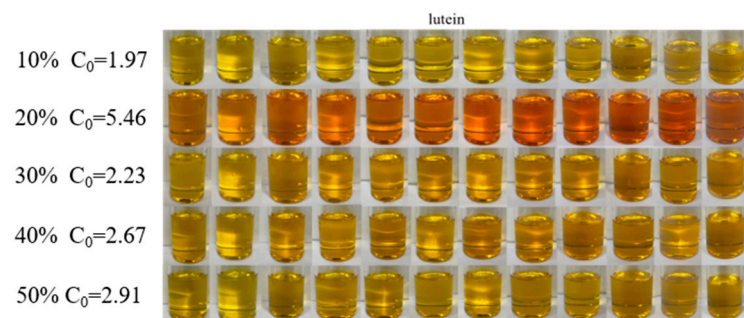
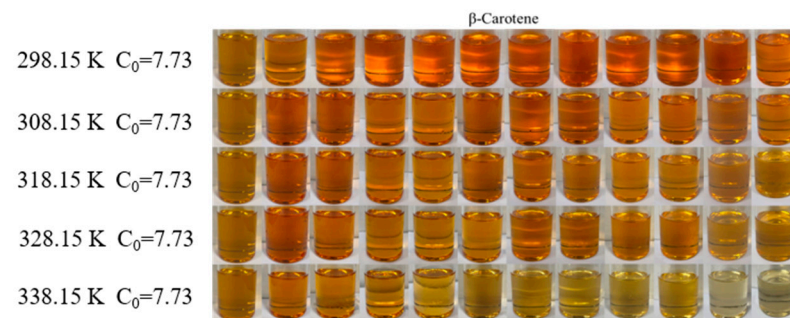
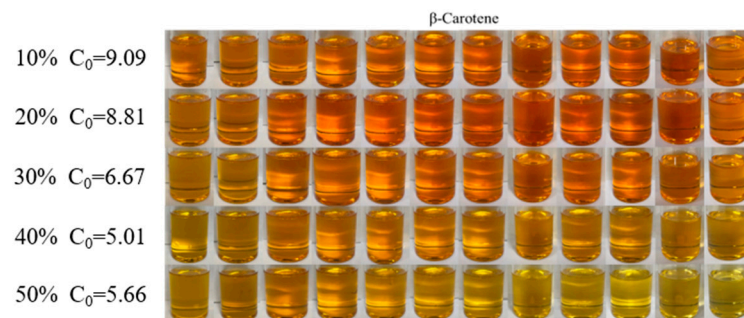
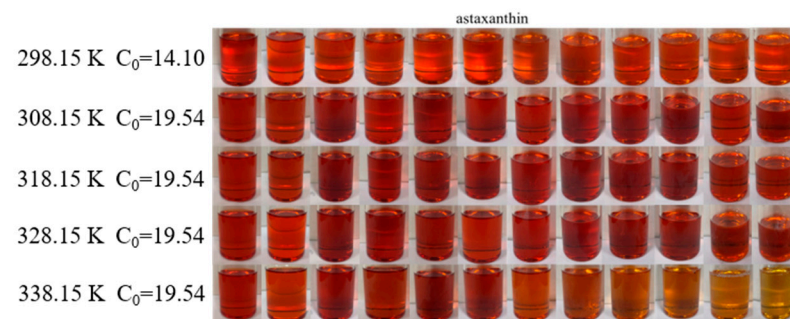
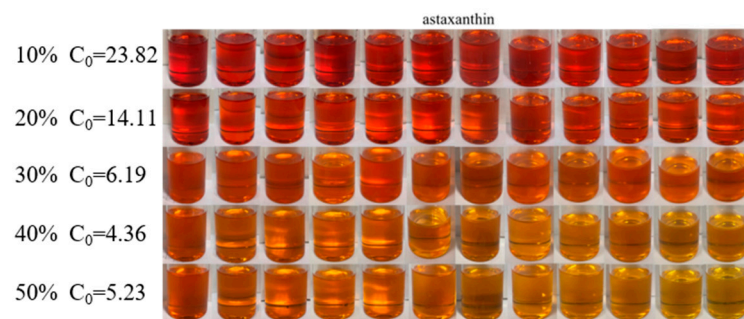


Figure S5 Pictures of $[P_{4448}]Cl$ aqueous solution containing astaxanthin (top), β -carotene (middle) and lutein (bottom) as a function of different storage conditions from 0 day to 12 day. $C_0(\mu g/ml)$ represents the initial concentration of carotenoids in the solution.

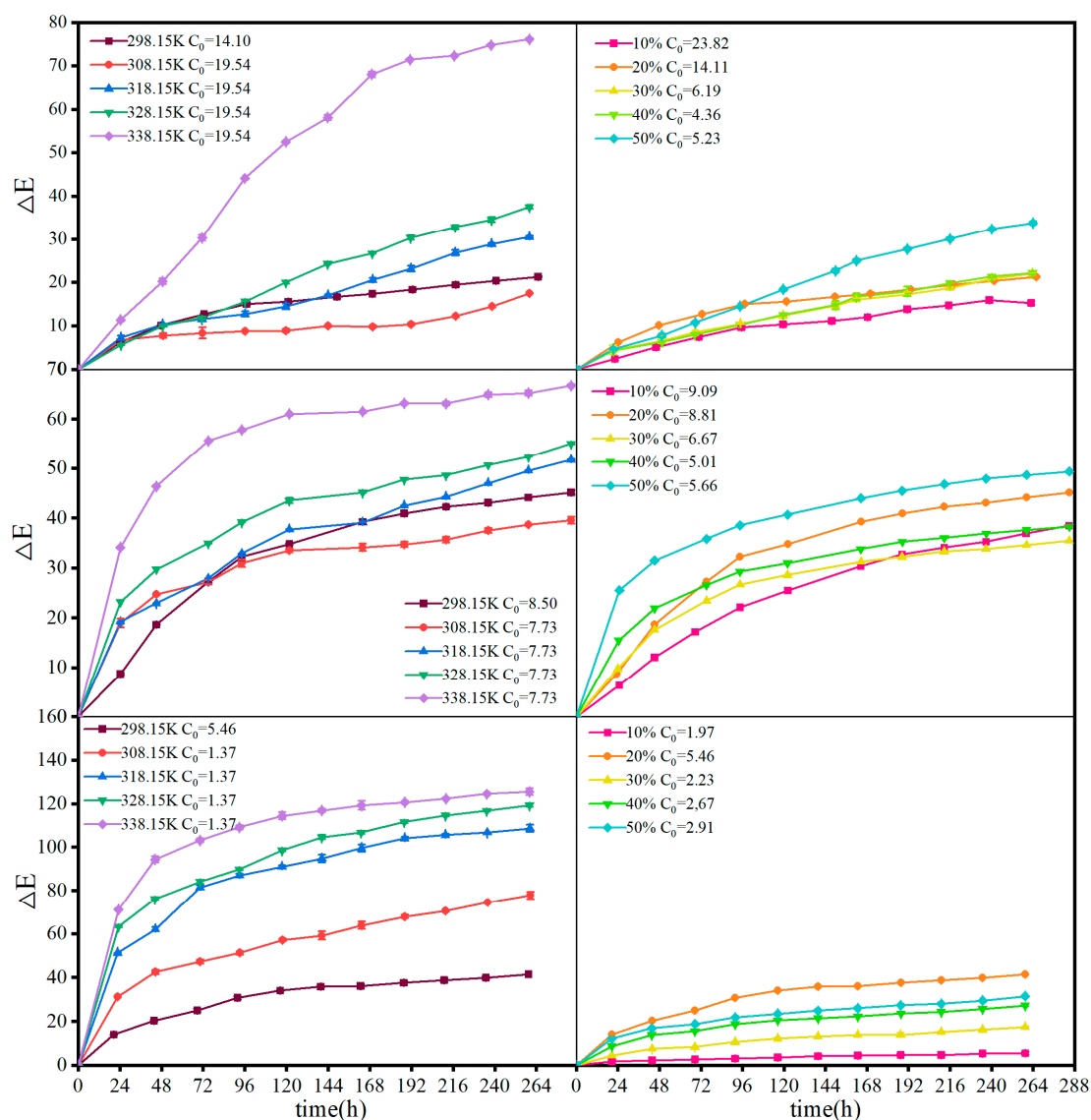


Figure S6 ΔE of [P₄₄₄₈]Cl aqueous solutions containing astaxanthin (top), β -carotene (middle), and lutein (bottom) in the storage for 12 days. $C_0(\mu\text{g/ml})$ represents the initial concentration of carotenoids in the solution.

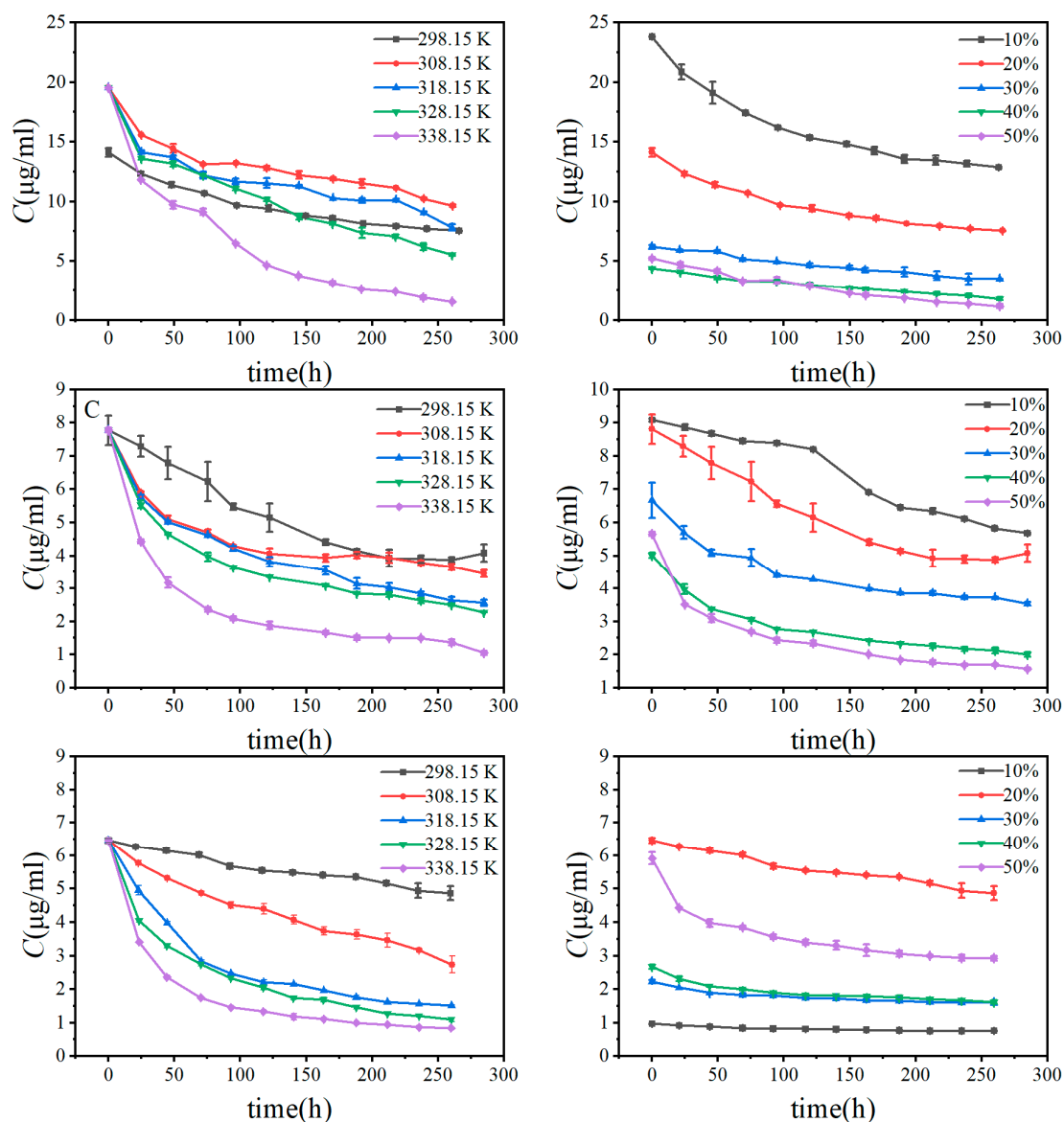


Figure S7 Concentration(C) of astaxanthin (top), β -carotene (middle), lutein (bottom) in [P₄₄₄₈]Cl aqueous solution in the storage for 12 days.