

Supplementary information

pH-responsive color indicator film based on sodium carboxymethylcellulose and natural acid buffering matrix for real-time beef sub-freshness monitoring

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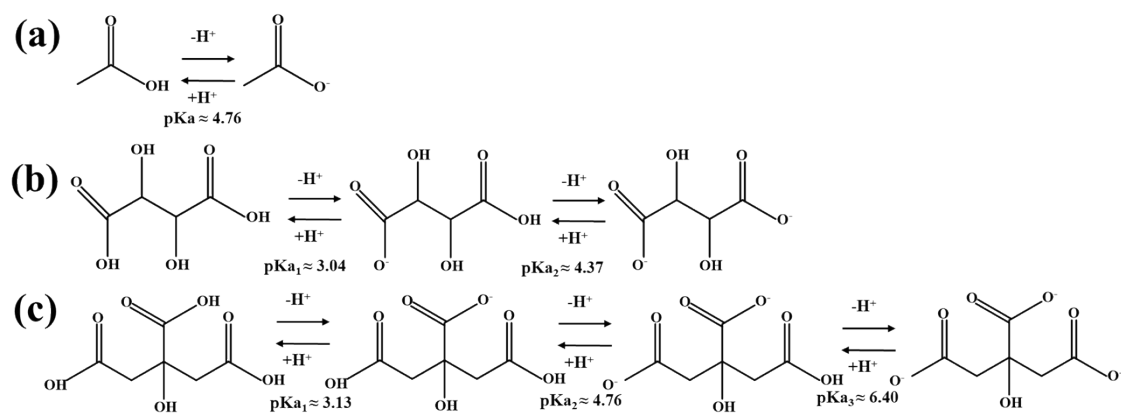


Fig. S1. The dissociation constants of HAc (a), TA(b), and CA(c) at each stage.

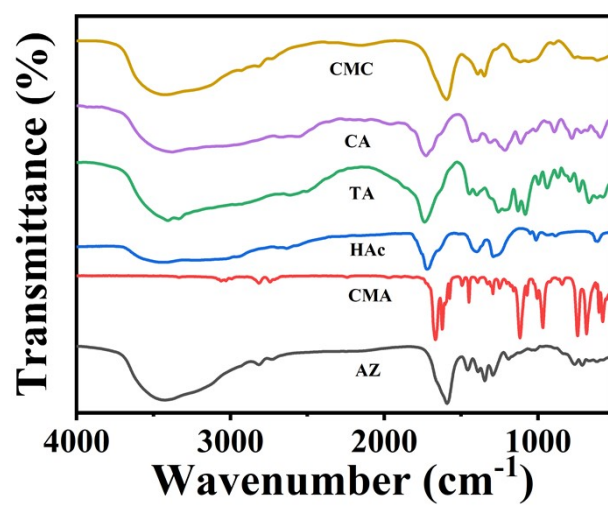


Fig. S2. FT-IR spectra of compounds in the pH indicator film.

Table. S1. Thickness and mechanical property of the pH indicator film

Film	Crystallinity (%)	Thickness (mm)	TS (MPa)	EB (%)
CMC-Na	4.88	0.145 ± 0.010	6.92	8.42
CMC-Na/Ca ²⁺	0.78	0.154 ± 0.015	16.49	61.57
CMC-Na/Ca ²⁺ /CMA	2.54	0.145 ± 0.016	7.99	34.94
CMC-Na/Ca ²⁺ /CMA/AZ	0.21	0.156 ± 0.007	12.58	22.13
CMC-Na/Ca ²⁺ /CMA/AZ/HAc	0.11	0.148 ± 0.012	13.61	21.72
CMC-Na/Ca ²⁺ /CMA/AZ/TA	0.10	0.163 ± 0.008	20.56	50.37
CMC-Na/Ca ²⁺ /CMA/AZ/CA	0.37	0.154 ± 0.014	15.81	57.12

Table. S2. Color response time of different pH indicator film to ammonium hydroxide

Ammonium hydroxide concentration	Color response time	Limit of detection (LOD)	References
0, 10, 20, 50, 100, 200, 500, 1000 ppm	1 min	≤ 20 ppm	1
0.1 mg/mL	19 min	0.1 and 0.01 mg/mL	2
0.01 mg/mL	24 min		
0.2 % (v/v), at different volumes	2 min	0.43 μ M	3
—	30 min	0.26 μ M	4
0.8 mM	1 min	0.8 mM	5
—	1-2s	1 μ g/mL	6
25, 50, 100, 150, 200, and 250 ppm	60 min	25 ppm	7
5–2000 ppm	—	22.4 ppm	8
0–100 μ M	—	3.32 μ M	9
1–20 mg/L $\text{NH}_3\text{-N}$	30 min	20 ppm	10
—	10 min	4 mg/L $\text{NH}_4^+\text{-N}$	11
—	21 min	0.11 ppm	12

The concentration of gaseous ammonia in the sealed system was calculated following the **Equation 6³**:

$$c = \frac{\rho_0 \times V_0 \times W}{M \times V} \quad (6)$$

where c is the concentration of gaseous ammonia in the sealed system (mol/L), ρ_0 is the density of the ammonium hydroxide (g/mL), V_0 is the volume of the aqueous ammonia (mL), W is the mass fraction of ammonia in the aqueous ammonia, M is the molar mass of ammonia (g/mol), V is the volume of the sealed system (L).

The LOD was calculated following the **Equation 7**:

$$LOD = \frac{3\sigma}{S} \quad (7)$$

where σ is the standard deviation of the blank measurement; S is the slope of the fitted curve.

References

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