



Dual-modal signal collaborative probe: Real-time visual monitoring of the spoilage process of fresh meat

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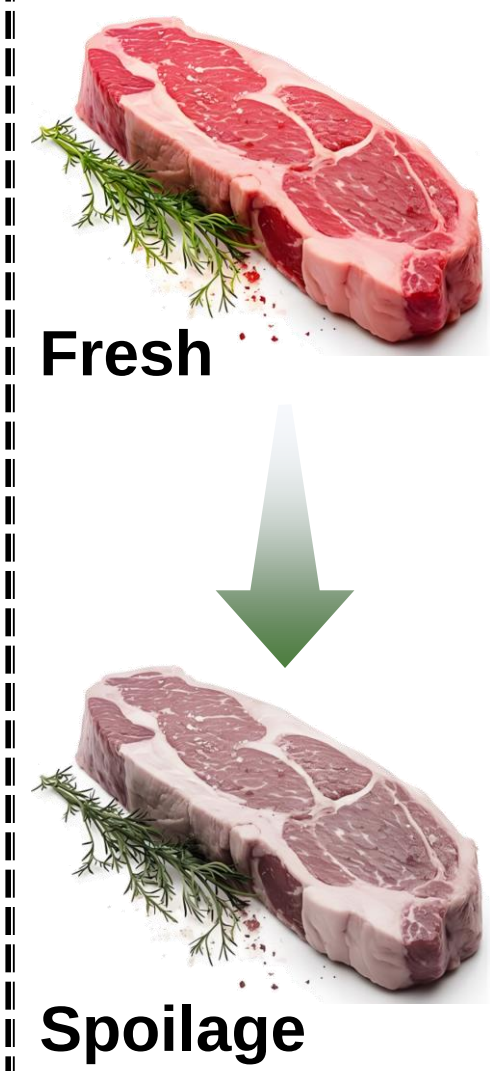
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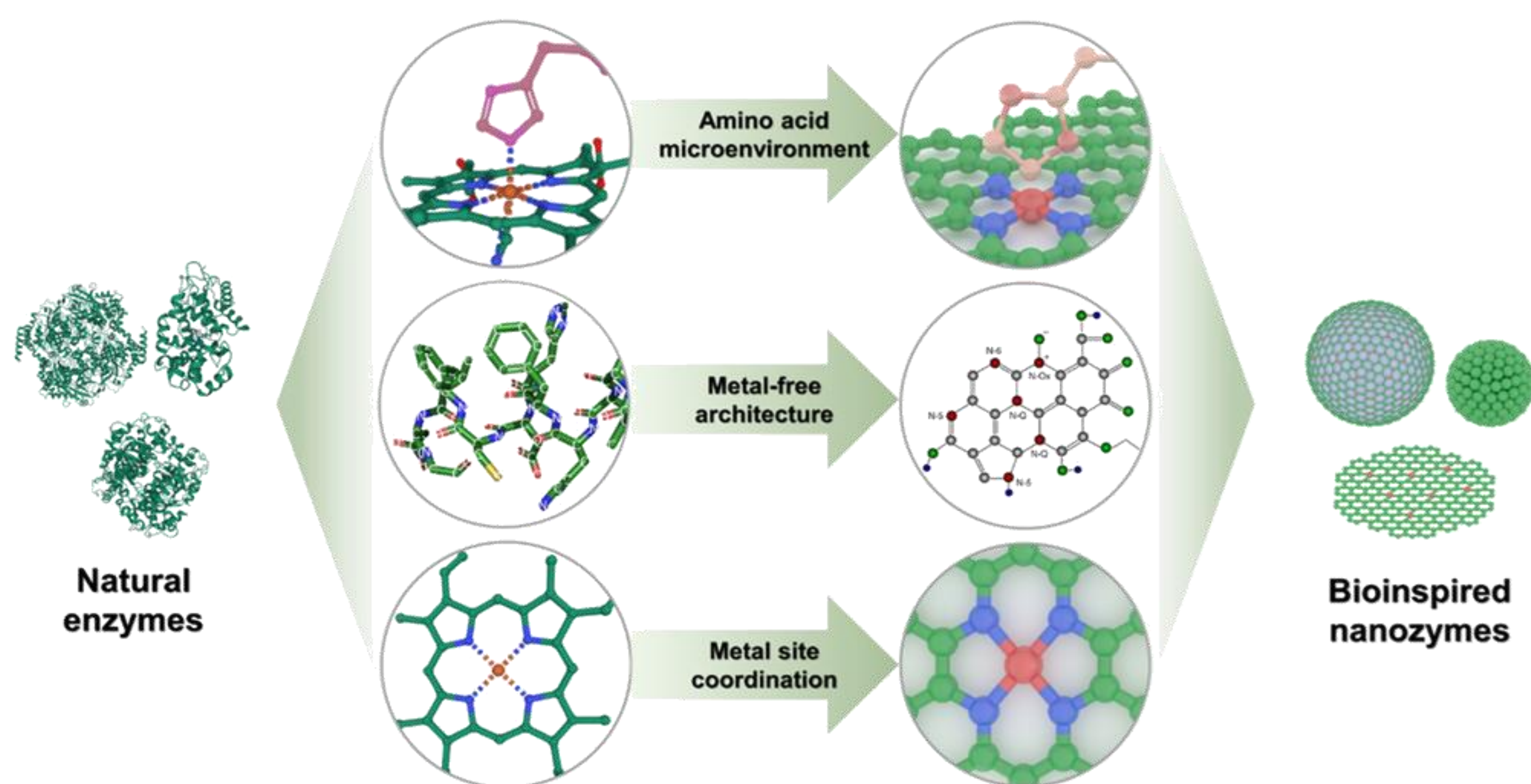
ABSTRACT



◆ **Volatile amines (VAs)** are critical for meat freshness, yet nondestructive, real-time VAs detection remains challenging. We developed a colorimetric-fluorescent dual-signal biosensor using single-atom iron nanozyme (SAFe-N-C) and carbon quantum dots (CDs): SAFe-N-C catalyzes red TMB to ox TMB , quenching CDs fluorescence via inner filtering effect (IFE). VAs reduce ox TMB , recovering CD fluorescence. With low ammonia LOD (**0.0838 ppm**, **0.5-50 ppm** range), it enables nondestructive, real-time VAs monitoring in livestock/poultry meat, advancing portable freshness assessment.

INTRODUCTION

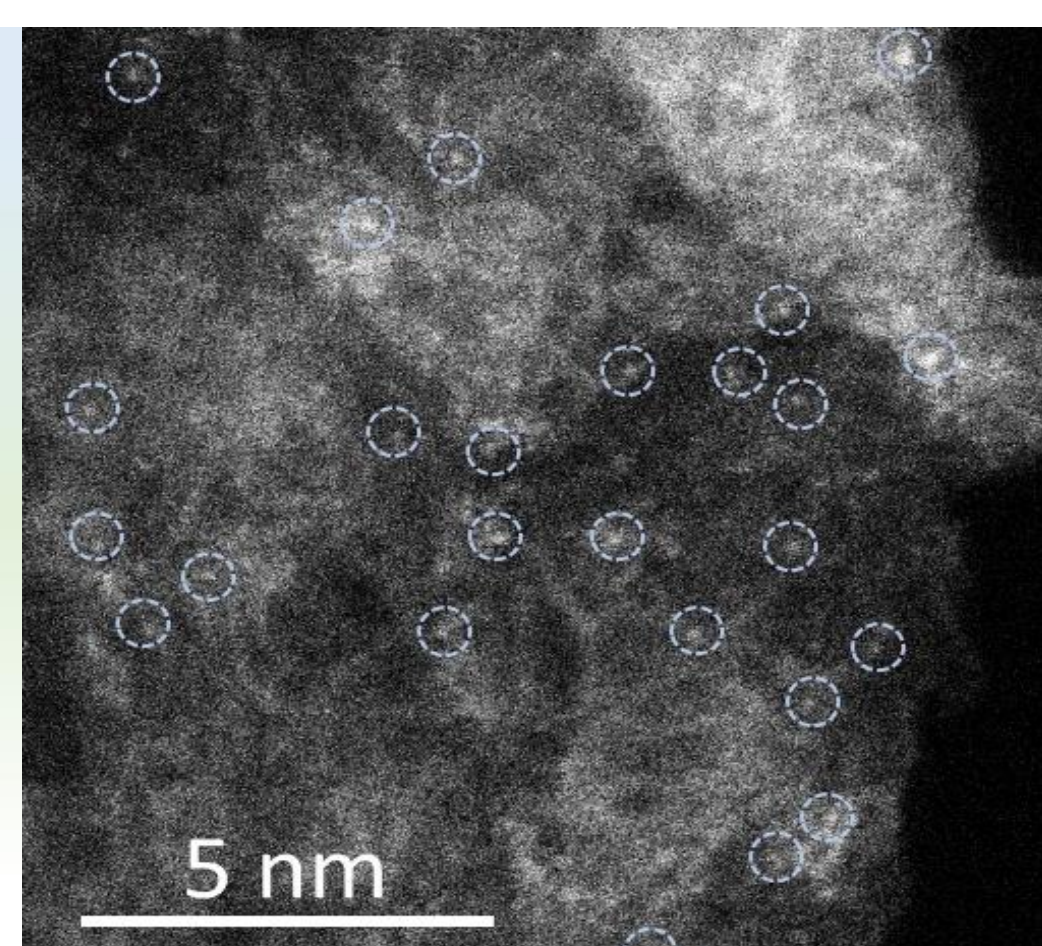
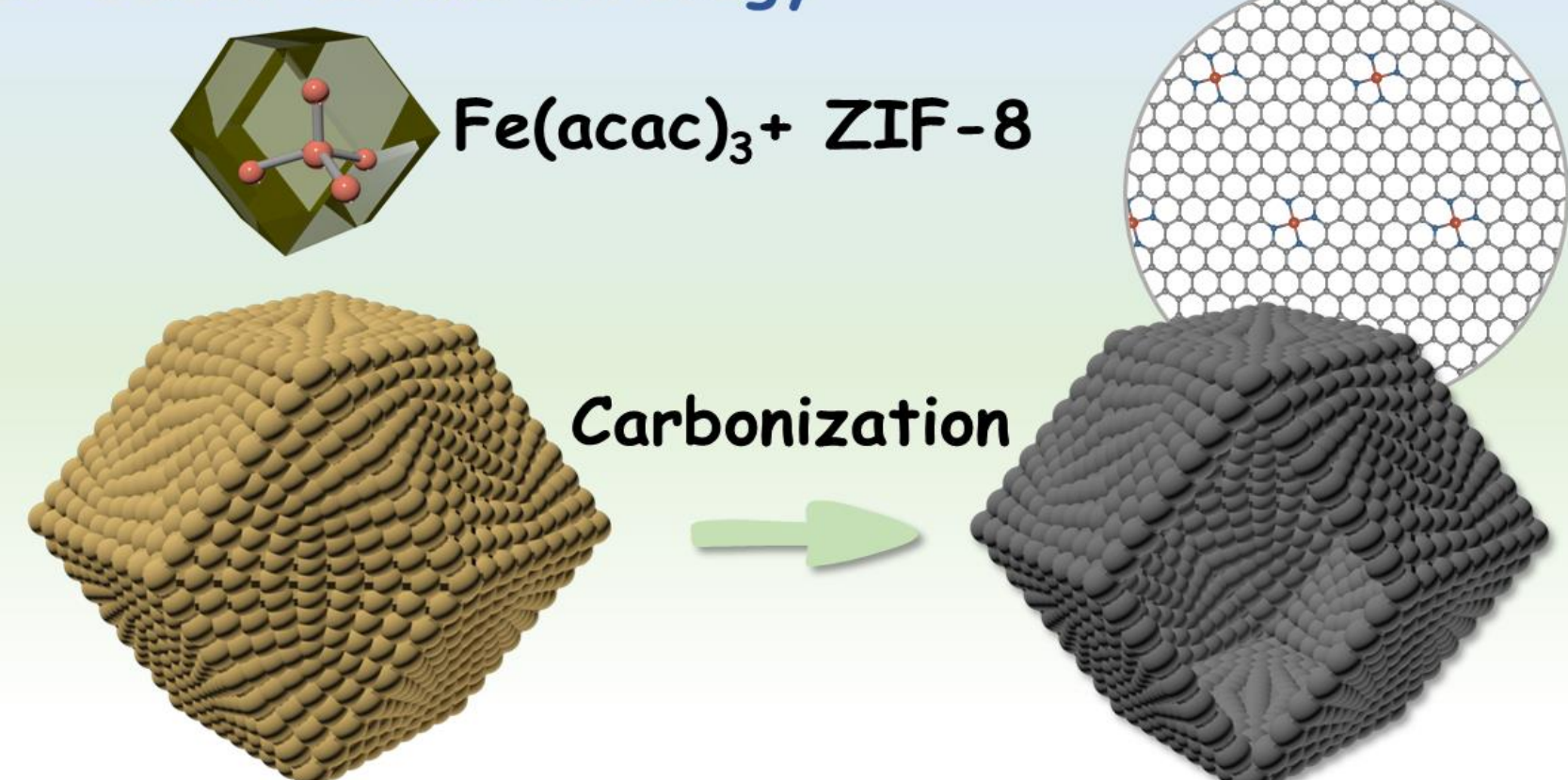
- ◆ Microbial contamination during food processing, storage, and transportation leads to **volatile amines (VAs)**, causing spoilage, affecting flavor, and posing health risks like headaches and nausea.
- ◆ Traditional VAs detection methods, such as gas chromatography and mass spectrometry, are expensive and require expertise, highlighting the need for real-time, cost-effective monitoring.
- ◆ Single-atom nanozymes (SAzymes) with carbon quantum dots (CDs) form a **dual-signal biosensor**, enabling rapid, efficient VA detection and improving food safety.



METHODS

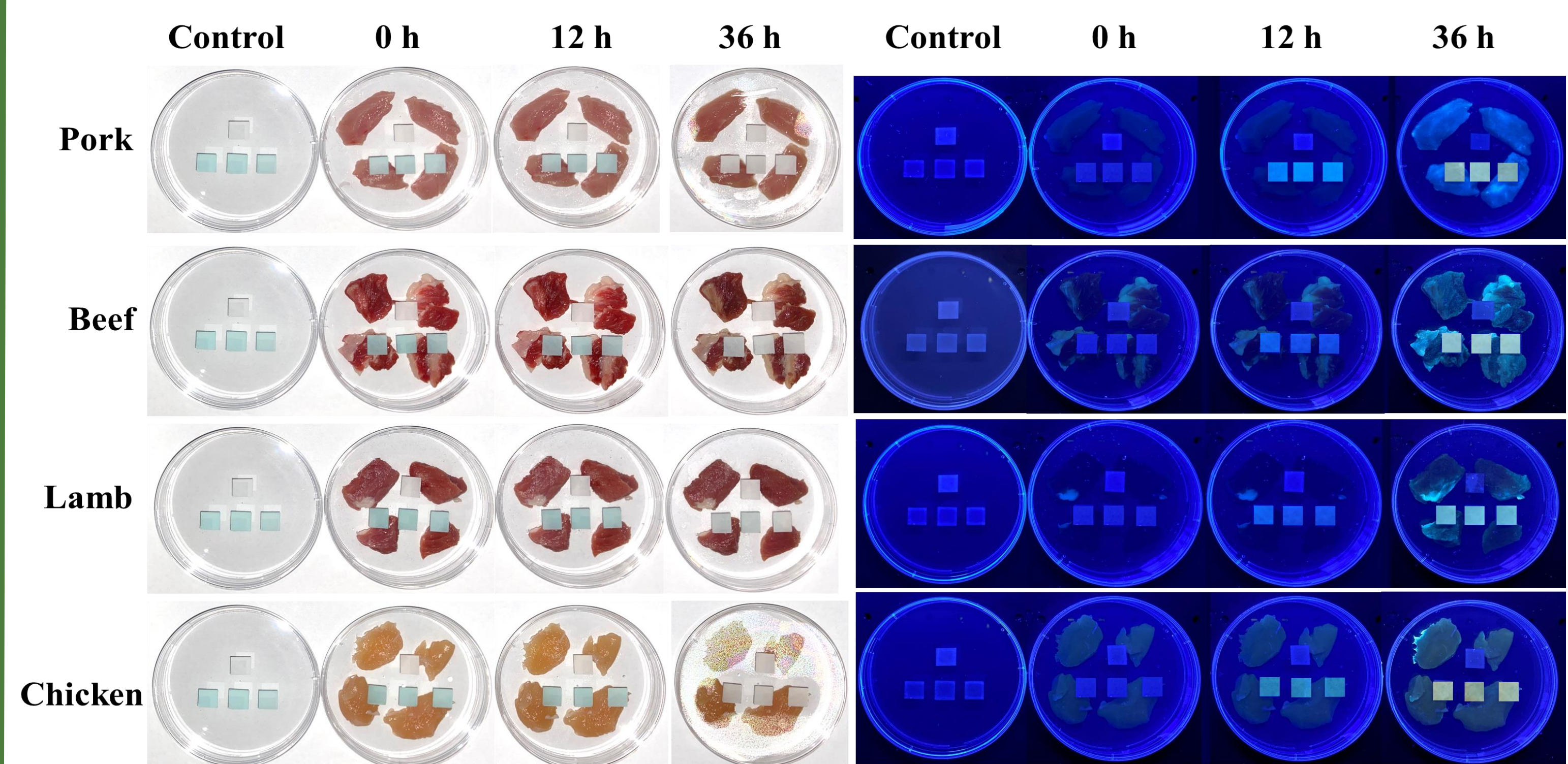
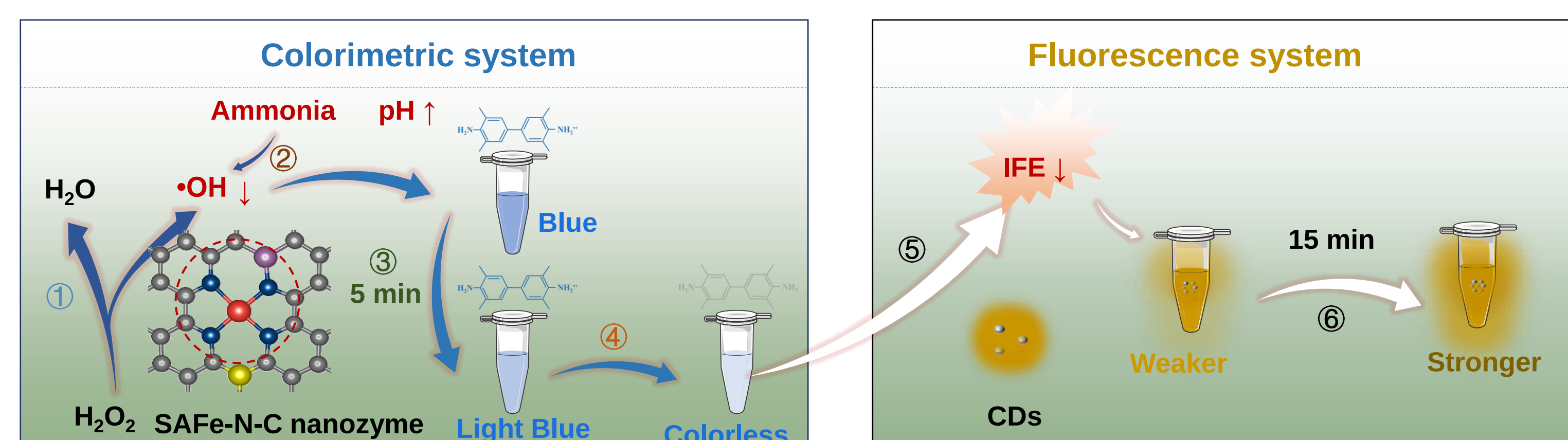
- ◆ **Synthesis of SAFe-N-C nanozyme:** SAFe-N-C nanozyme was synthesized by mixing $\text{Zn(NO}_3)_2 \cdot 6\text{H}_2\text{O}$, iron acetylacetonate, and 2-methylimidazole in methanol, heating at 120°C for 4 hours, centrifuging, washing, and calcining at 950°C for 3 hours under nitrogen flow.
- ◆ **Preparation of the CDs:** 1.0 mg/mL in ethanol, stored dark.
- ◆ **Calculation of POD-like catalytic activity:** enzyme parameters were calculated using the Michaelis-Menten equation.
- ◆ **Preparation of dual-signal biosensor:** Whatman No. 1 filter paper soaked in SAFe-N-C and CDs, dried to form dual-signal biosensor.
- ◆ **Monitoring the freshness of meat samples:** Livestock and poultry meat samples were monitored with a colorimetric-fluorescent biosensor at 25°C . Changes in color and fluorescence were recorded using a smartphone and spectrometer. Freshness was verified by TVB-N according to national standards.

Host-Guest define strategy



RESULTS

- ◆ **Dual-signal biosensor:** A colorimetric-fluorescent biosensor was developed by coupling SAFe-N-C with CDs. VAs (e.g., ammonia) increased system pH, reducing $\bullet\text{OH}$ generation and ox TMB formation, thereby alleviating IFE to restore CDs's fluorescence (475 nm). The system showed rapid response (6 min colorimetric, 15 min fluorescent) and low LODs (0.984 ppm and 0.0838 ppm, respectively) for ammonia detection.
- ◆ **Meat freshness monitoring:** Paper-based sensors demonstrated real-time freshness tracking for pork/beef/lamb/chicken at 25°C , correlating color/fluorescence changes with TVB-N ($R^2 > 0.91$). The portable device maintained stability for 3 years, outperforming natural HRP in reusability (>4 cycles), offering a cost-effective solution for meat supply chains.



CONCLUSION

- ◆ A dual-signal biosensor for food freshness detection was developed using SAFe-N-C nanozyme and CDs.
- ◆ The colorimetric response (652 nm) and fluorescence quenching (475 nm) enable rapid detection of volatile gases like ammonia, trimethylamine, and cadaverine.
- ◆ The sensor offers high accuracy, anti-interference, and quick results via a portable phone-based program, ideal for monitoring meat freshness.

ACKNOWLEDGEMENT

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GROUPS

