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How ‘smart’ hydrogel packaging tells you if your food is still fresh

By fixing a natural pigment onto a metal-organic framework, Kyushu University researchers developed a self-healing hydrogel that reliably signals spoilage through color change while extending food shelf life

Fukuoka, Japan—The cuts of meat in a supermarket case can look perfectly fresh even as bacteria are already multiplying inside the package. Is there a way to know before you open it?

Researchers at Kyushu University think the packaging itself should do the telling. In a study published in *Chemical Engineering Journal*, they developed a soft, flexible film embedded with a natural plant pigment that shifts color as food spoils, giving consumers a visible signal without opening the package. The material can also repair its own cuts, keeping bacteria out through shipping and handling.

Freshness has a chemical signature. Meat, for example, starts mildly acidic. As bacteria multiply, they break down proteins and release alkaline compounds, so the meat’s pH climbs steadily before any visible spoilage appears.

Anthocyanins—the pigments behind the color of purple sweet potatoes and red cabbage—track that shift directly. As pH rises, they turn from purple-red to yellow-green. This change is visible to the naked eye, and their natural origin also makes them safe for food contact. However, light and heat can easily disrupt their color response, causing false readings and making them unreliable as a long-term indicator.

The team sourced their anthocyanins from purple sweet potato, an affordable and widely available crop, then ground and freeze-dried them into a powder. For stabilization, they turned to UiO66-NH_2, a metal-organic framework (MOF) known for its thermal and chemical stability.

“MOFs have attracted enormous attention because of their unique porous structures and versatile functions, and I became curious whether they could be used for something closer to everyday life, like food preservation,” recalls Xirui Yan, corresponding author of the study and a JSPS researcher at Kyushu University’s Faculty of Agriculture. “At the HOPE Meetings with Nobel Laureates, I attended Professor Susumu Kitagawa's lecture on the sustainable use of functional porous materials. His perspective inspired me to think more broadly about how MOFs could create value in food systems.”

In their design, anthocyanin molecules adsorb onto the MOF's surface through multiple chemical interactions, anchoring it in place. Fixed and less mobile, the molecules are shielded from the oxygen, light, and heat that drive degradation while remaining sensitive to pH. In food tests using pork, the protected pigment proved consistently responsive: as the meat spoiled and alkaline gases accumulated, the material shifted continuously from purple-red to yellow-green, giving a readable signal at every stage.

The team then incorporated the anthocyanin-loaded MOF into a hydrogel, producing a soft, shapeable film that is largely plant-derived and biodegradable. Beyond freshness monitoring, the material also extended the shelf life of pork by about 12 hours compared to untreated samples.

“Another interesting thing about this material is that it doesn’t just protect food—it heals itself,” notes Fumihiko Tanaka, Professor at Kyushu University’s Faculty of Agriculture. When cut and pressed back together, the damage becomes nearly invisible within minutes, and tensile strength recovers to 99% within two hours. “In conventional packaging, any crack is permanent and becomes an entry point for bacteria. This material bonds back together on its own. The wound heals, and so does its ability to protect what’s inside, which makes it more durable and reliable in practical use.”

The team is now exploring a companion smartphone app, giving manufacturers, logistics companies, and shoppers a reliable, objective way to assess food quality in real time.

“This doesn’t have to stop at food packaging,” adds Fumina Tanaka, Associate Professor at the same faculty. “Smart materials built from natural ingredients and nanotechnology may have uses we haven’t imagined yet. If anyone sees a place where this could work, we'd love to hear about it.”

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For more information about this research, see “Self-Healing Cellulose-based Hydrogel Smart Packaging Embedded with Anthocyanin-Immobilized Metal-Organic Frameworks for Food Preservation and Freshness Monitoring,” Fanze Meng, Xirui Yan, Shinobu Yasuo, Tiantian Ma, Jiao Zeng, Donghui Luo, Tran Thi Van, Reshaka Kavindi Malawara Arachchige, Laras Putri Wigati, Phuong Thi Hang Nguyen, Ata Aditya Wardana, Fumina Tanaka, Fumihiko Tanaka, *Chemical Engineering Journal,* https://doi.org/10.1016/j.cej.2026.176764

About Kyushu University
Founded in 1911, Kyushu University is one of Japan's leading research-oriented institutions of higher education, consistently ranking as one of the top ten Japanese universities in the Times Higher Education World University Rankings and the QS World Rankings. Located in Fukuoka, on the island of Kyushu—the most southwestern of Japan’s four main islands—Kyushu U sits in a coastal metropolis frequently ranked among the world’s most livable cities and historically known as Japan’s gateway to Asia. Its multiple campuses are home to around 19,000 students and 8,000 faculty and staff. Through its VISION 2030, Kyushu U will “drive social change with integrative knowledge.” By fusing the spectrum of knowledge, from the humanities and arts to engineering and medical sciences, Kyushu U will strengthen its research in the key areas of decarbonization, medicine and health, and environment and food, to tackle society’s most pressing issues.

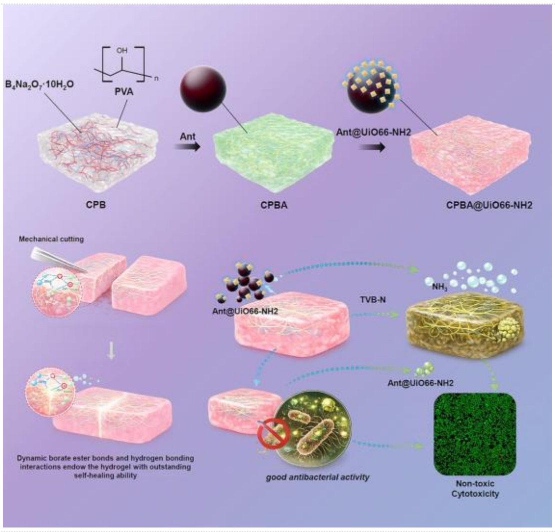

FIG.1 Conceptual illustration of a self-healing smart hydrogel
By fixing a natural pigment onto a metal-organic framework, Kyushu University researchers developed a self-healing hydrogel that reliably signals spoilage through color change while extending food shelf life.

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