Standardized Colorimetric Scale for Ammonia-Responsive Agarose–Anthocyanin Hydrogel Patches as a Universal Multi-Food Spoilage Detector

Kim, Dohui (School: Korean Minjok Leadership Academy)

Foodborne illness affects approximately 10% of the global population each year, highlighting the need for accessible, real-time tools for monitoring food spoilage at the consumer level. Among volatile spoilage markers, ammonia is a widely produced byproduct of microbial protein metabolism, making it a reliable cross-category indicator for protein-rich foods such as meat, fish, eggs, and dairy. Though instrumental methods such as gas chromatography and electronic nose systems provide high sensitivity, they require expensive equipment and trained staff, limiting practicality for everyday use. In contrast, colorimetric sensors enable passive, instrument-free, and visually intuitive detection, but many existing designs remain limited to specific food types and lack a standardized readout scale. This study developed an agarose-anthocyanin hydrogel patch as an ammonia-responsive colorimetric sensor for universal spoilage detection across multiple protein-rich food categories. Anthocyanin showed the clearest concentration-dependent response to ammonia, while agarose produced the most uniform and stable hydrogel films. The optimized sensor responded rapidly to low ammonia concentrations, showing a visible color change within seconds at 0.008–0.010% ammonia. Color responses were quantified using A600/A520 ratios, and sensor performance was validated under sealed packaging at 25°C and 4°C using eggs, beef, cheese, and fish. These results establish agarose-anthocyanin hydrogels as a low-cost, broadly applicable spoilage detection platform for household and supply-chain food safety monitoring.

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