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Natural Indicators in Intelligent Packaging: A Colour Signal for Food Freshness

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Abstract: -

The increasing emphasis on food safety, quality preservation and environmental sustainability has driven the development of intelligent food packaging systems capable of monitoring changes associated with product deterioration. Natural colorimetric indicators have emerged as promising tools for non-destructive freshness assessment because of their responsiveness to changes in the food environment. Natural colourants, including anthocyanins, alizarin, betacyanins, chlorophyll, curcumin and shikonin can respond to changes in pH, oxygen, temperature and relative humidity, enabling visible detection of quality changes. Their integration with biodegradable biopolymers, including cellulose, chitosan, starch and protein-based materials, provides opportunities for developing sustainable and functional packaging. Some pigments additionally exhibit antioxidant and antimicrobial activities, allowing freshness indication and active food protection to be combined. Although challenges related to pigment stability, response consistency and large-scale application remain, natural colorimetric indicators offer considerable potential for developing smart, sustainable and consumer-friendly food packaging systems.

Keywords: Intelligent packaging, Freshness indicators, Natural colourants, Biopolymer packaging, Food quality, Sustainable packaging.

Introduction:

Food packaging plays an important role in protecting food from contamination, physical damage and environmental conditions. However, increasing concerns about food safety, food waste and environmental sustainability have expanded

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the role of packaging beyond simple protection. Modern packaging systems are increasingly being designed to provide information about food quality and storage conditions.

This development is particularly important for perishable foods such as meat, poultry and aquatic products, where microbial and biochemical changes can occur during storage. Intelligent packaging provides an opportunity to communicate such changes through indicators and sensors. Among these, colorimetric freshness indicators are particularly attractive because they provide a simple and visible signal without requiring the package to be opened.

What is Intelligent Packaging?

Intelligent packaging refers to packaging systems that monitor, detect or communicate information about food quality or storage conditions. Unlike conventional packaging, which mainly provides a protective barrier, intelligent packaging can provide additional information to consumers, retailers and food handlers.

Intelligent packaging generally includes indicators, sensors and data carriers. Indicators respond to changes in food or its surrounding environment, sensors detect specific chemical or biological changes, and data carriers store or communicate product-related information.

Freshness Indicators: A Key Component of Intelligent Packaging

Freshness indicators are an important component of intelligent packaging that respond to chemical or biochemical changes associated with food deterioration. Microbial growth can produce volatile compounds and alter the pH of food or package headspace. These changes can be detected by responsive materials and converted into a visible colour change.

Colour-based freshness indicators are particularly useful because their response can be observed directly by consumers without opening the package. However, they are intended to support rather than replace refrigeration, expiry information and established food-safety practices.

Natural Colour Indicators for Food Freshness

Natural colourants such as anthocyanins, alizarin, betacyanins, chlorophyll, curcumin and shikonin have been investigated for colorimetric intelligent packaging. Their responses to environmental conditions such as pH, oxygen, temperature and relative humidity can produce visible changes associated with food quality. Some natural colourants also exhibit antioxidant and antimicrobial properties, providing additional functional benefits (Chiu *et al*., 2024).

Among these pigments, anthocyanins are particularly promising because of their strong pH-responsive colour behaviour. Their colour can change from red to purple, blue or other shades depending on the surrounding chemical environment. Curcumin is valued for its antioxidant properties and also exhibits antimicrobial activity (Pan *et al*., 2026).

Anthocyanin-based films have demonstrated colour responses associated with microbiological and physicochemical freshness parameters in aquatic products. Some systems have also shown antibacterial and antioxidant activities, providing additional potential for improving storage stability (Chen *et al*., 2026).

Biopolymer-Based Intelligent Packaging

Biopolymers provide suitable matrices for incorporating natural colour indicators in the form of films, coatings and gels. Natural materials such as cellulose, chitosan, starch, gelatin and zein offer biodegradability, film-forming ability and useful barrier properties. However, no single biopolymer possesses all the properties required for food packaging, making combinations and functional modifications important for improving strength, moisture resistance and overall performance (Chiu *et al*., 2024).

Cellulose is particularly attractive because it is renewable, biodegradable and widely available. It can function as a carrier for indicators and active compounds. Recent approaches such as ionic-liquid processing, solvent exchange and 3D printing have further expanded the potential of cellulose-based intelligent packaging (Liang *et al*., 2026).

Why do Natural Indicators Matter?

The importance of natural indicator-based packaging lies in its ability to combine freshness monitoring, food protection and sustainability. A visible colour response can provide an immediate indication of changing food quality without opening the package, helping consumers and food handlers make better storage and handling decisions.

The use of naturally derived pigments and biodegradable biopolymers can also reduce dependence on conventional plastic-based packaging. Such systems are therefore particularly relevant to sustainable food packaging, where both food quality and environmental impact need to be considered.

Limitations and Research Needs

Despite their potential, natural colorimetric indicators face several challenges. Pigment can be sensitive to light, oxygen, temperature and moisture, which may affect their stability and colour response. The response can also vary with pigment concentration, packaging material and food composition.

Therefore, indicator systems require proper validation against established

microbiological, chemical and physicochemical quality parameters. Further attention is also needed towards response reproducibility, storage stability, cost-effective production and large-scale application.

Conclusion

Natural colour indicator-biopolymer systems offer a promising platform for freshness monitoring by linking changes in food quality with visible colour responses. Their successful application depends on improving pigment stability, response reliability and compatibility with different food matrices. Continued validation under real storage conditions will be essential for translating these systems from laboratory research into practical intelligent packaging.

References

1. Chen, S., Wang, Y., & Fan, K. (2026). Recent Advances in Anthocyanin-Based Active and Intelligent Packaging Films for Preserving Aquatic Products: A Review. *Packaging Technology and Science*, *39*(7), 865-895. https://doi.org/10.1002/pts.70067
2. Chiu, I., & Yang, T. (2024). Biopolymer-based intelligent packaging integrated with natural colourimetric sensors for food safety and sustainability. *Analytical Science Advances*, *5*(5-6), e2300065. https://doi.org/10.1002/ansa.202300065
3. Liang, J., Han, J., Zhou, M., Fakayode, O. A., Li, H., Ren, M., & Zhou, C. (2026). Cellulose in smart food packaging: production, forms, and multifunctional applications. *Cellulose*, *33*(4), 1833-1875. https://doi.org/10.1007/s10570-026-06946-z
4. Pan, X., Xing, Y., Wang, J., Luo, Y., Ma, D., Wu, H., & Xia, B. (2026). Curcumin-, Anthocyanin-, and Carotenoid-Based Active and Intelligent Packaging Systems for Food Preservation and Freshness Monitoring. *Foods*, *15*(15), 2630. https://doi.org/10.3390/foods15152630