Natural Food Colorant Based pH-Sensitive Smart Way for Food Quality and Safety Monitoring

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Food packaging is one of the most significant aspects of a product from the consumer's point of view, and it is extremely vital in modern commercial commerce because it aids transportation, allows for secure storage, avoids damage and loss, cuts down on monetary losses, aids in product promotion, and indirectly keeps consumers safe (Bahrami et al., 2020). Petroleum-based food packaging is usually inert. It protects food against microbial/physicochemical deterioration, ambient conditions, and external stimuli, extending its shelf life. However, the extensive usage of petroleum-based plastic packaging is a global environmental issue due to its manufacture and disposal. The design and manufacture of biodegradable packaging materials from natural and biological resources has grown in popularity.While one of the roles of food packaging is to protect food quality and safety, current packaging must additionally inform the customer about food quality and appropriateness for consumption. Several smart packaging solutions based on colorimetric indications are capable of providing customers with real-time quality monitoring for packaged goods via quality sensor/indicators, particularly pH-sensing indicators, which are currently extensively developed.

An overview of smart packaging

As a novel technology in food packaging, smart/active and intelligent packaging has been developed in response to customers' expanding worries regarding the quality and safety of food items. In order to protect food products, control the environment, detect changes in the headspace and track product history smart packaging systems are typically designed based on the beneficial interaction between food and the packaging environment (Biji et al., 2015). In contrast, intelligent food packaging refers to a packaging system that possesses the capability to continuously monitor the quality of food and promptly communicate this information to consumers through the emission of signals, such as colorimetric, optical, chemical, or electric responses. These signals are triggered by variations in both the packaging environment and the food quality, enabling real-time assessment (Rai et al., 2019). Furthermore, intelligent packaging systems can aid in the development of Hazard Analysis and Critical Control Points (HACCP) and Quality Analysis and Critical Control Points (QACCP) systems, which are designed to identify possible risks and prepare countermeasures or prevention plans for them. Consumers and businesses can now track product information through key stages in the food supply chain thanks to smart packaging technology. Different types of indicators and sensors, such as freshness sensors and time-temperature integrators, have been created for smart packaging systems to monitor the integrity of goods. These intelligent packaging systems measure pH variations, gases (CO2, O2, H2S, ethylene, NH3, etc.) and volatile compounds, pathogens or their metabolites and toxins, time-temperature changes, and humidity to keep an eye on the product's freshness, microbial development, and any chemical changes in the product (Xiao-wei et al., 1018).

Among the various freshness indicators and sensors used in food packaging systems, smart packaging based on natural colours and biodegradable films has recently emerged as an appealing alternative for use in food packaging due to their low or non-toxicity, eco-friendliness, ease of preparation, biodegradability, low cost, availability, renewable, and pollution-free properties. These natural colourants incorporated in the biopolymeric film matrix change colour in response to shifts in the food's physiological circumstances as it spoils, giving the buyer an indication of the product's freshness and safety (Sonar et al., 2019).

Natural food colourant properties with packaging film and pH response

In general, there are four main factors to take into account when choosing a chemo-responsive colourant: The detection of results would be repeatable and reliable if

(i) Strong reaction between the colourant and the desired analyte

(ii) Colour difference following the reaction and a very strong colour interaction to an intense chromophore

(iii) Primarily a group of different pH-responsive colourants that are cross-responsive in an indicator/sensor array

(iv) Detection of findings would be reproducible and reliable

The most common indication for determining the stability of colours, especially natural colourants, is pH. The kind of pigment determines how well-behaved and responsive natural colourants are to pH fluctuations and other conditions. In fact, the main sensing components of a smart system like colorimetric sensors are chemo-responsive colourants. Depending on the surroundings, these substances can change colour. Due to their low price, abundance, simplicity of production, availability, and stable halochromic capability, natural colourants are now the focus of extensive research into pH indicators in the form of optical sensors i.e. colorimetric (Martins et al., 2016).

The instability of carotenoids in acidic settings is commonly ascribed to several factors, including the protonation of carotenoids, duration of exposure to acidic conditions, acid concentration, cis-trans isomerization and supplementary degradation mechanisms which is demonstrated that the degradation of carotenoids occurred at acidic conditions (pH = 3–3.5) by sulfuric acid. Ion pairs that can dissociate the carotenoid carbocation are thought to be responsible for the clear colour of carotenoids at low pH levels. On the other hand, the trans- to cis-isomer transition of carotenoids can result in turbidity of colour since the isomers are highly unstable and induce colour deterioration (Boon et al., 2010).

It is necessary to immobilise these pigments by integrating them into a base material such as polymer/biopolymer matrices in order to fully utilise the potential of these pH sensitive natural colourants for halochromic packaging. A crucial component of the design of colorimetric sensors and smart packaging systems is the selection of chemo-responsive colourants. Because of their inexpensive cost, simple preparation, wide availability, and dependable halochromic, weak acids and weak bases are typically used as pH sensors or indicators. They are effective and affordable alternatives. According to Park et al. (2015), pH indicators typically consist of two parts: a solid base and a colourant that reacts to pH variations. These sensors/indicators can be affixed to the inside or outside of a box or integrated in packaging materials (Balbinot-Alfaro et al., 2019). Several studies have investigated the color changes of natural pigments as pH indicators, including anthocyanins, carotenoids, betanins, anthraquinone, curcumin and chlorophylls in pH-responsive packaging/films (Alizadeh-Sani et al., 2020).

Applications of natural colorant-pH responsive films in food products

The application of natural colorant-responsive films in real food models especially protein foods and fruits and vegetables. Natural colorant-responsive films are most frequently used in the creation of intelligent packaging and other food quality indicators, such as time-temperature, gases and volatile compounds, freshness, integrity, chemical array, toxin and microbial sensors as well as development of colorimetric sensors. Using smart packaging to replicate a pH indicator in pasteurised milk at ambient temperature. Colorimetric pH indicator film based on agar/potato starch/anthocyanins extracted from sweet red potatoes. The films were applied to pork, and the film color altered from red to green according to the pH changes and consequent deterioration of the samples (Choi et al., 2017). The creation of optical indicators/sensors and colorimeters, the design of freshness and integrity indicators, and the detection of poisons, pollutants, residual medications, and microbes may all be done using pH-sensitive films based on natural food colourants.

To improve the stability of natural pigments, packaging techniques like MAP (Modified Atmosphere Packaging) and CAP (Controlled Atmosphere Packaging) or nanotechnology (nanoencapsulation) may be used. The investigation of the films response to various factors, such as gases and volatile vapours, temperatures; evaluating the pigment stability in the packaging/film; developing films with improved physical and mechanical characteristics, moisture resistance, UV-vis light barrier, the analysis of colour changes via simulator solutions and then, applications in various foods; and correlating the pH values to food degradation and sensory evaluation are additional future developments.

Conclusion

Traditional packaging, as previously said, is often made from petroleum resources and is intended to shield food from elements and contaminants including moisture, gases, bacteria, and off flavours and tastes. However, they are unable to advise the buyer about the product's purity and safety. Currently, there is a high demand for and widespread interest in the usage of smart packaging (active and intelligent systems) based on biopolymers and fitted with colorimetric indications/sensors, notably natural colourants (in this case, pH indicators). Smart packaging and films based on natural colourants do more than only keep food secure from danger; they also improve the quality and safety of packaged goods, keep them fresh for longer, and keep consumers up to date on the state of their purchases. Food waste, foodborne illness, spoilage, and deterioration may all be reduced with the use of smart packaging based on chemo-responsive natural colourants, and this method may even prove more effective when combined with nanomaterials. However, smart packaging that displays a pH shift in packaged food may be used as a visual pH detection label, and monitoring the freshness, safety, and quality of packaged foods in real-time through the colour changes of the packaging/film is a quick and easy process.

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