Sensors for monitoring food quality and safety

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Population growth and environmental concerns urge the necessity of agile assessment of food quality and safety, particularly in the increasingly complex food supply chain. According to the World Health Organisation, there are nearly 600 million cases of foodborne diseases, among those, 420,000 deaths each year.[1] Aiming to minimise food waste and health risk for consumers, food products must be shipped and distributed under highly controlled conditions along the food supply chain. Hence, it is essential for food suppliers to identify the provenance and traceability of the food. There are commonly four classes of analytes for designing advanced food sensors: (i) biological and chemical contaminants, (ii) allergens, (iii) nutritional ingredients, and (iv) food additives which may be harmful at a higher dose. The identification of some analytes can be used to determine the freshness of a desirable food product.

Most commercial food sensors in the market assess the food quality indirectly by monitoring environmental indicators such as temperature, humidity and changes in gasses such as oxygen and carbon dioxide.[2] These sensors, that are mostly colourimetric, aim to model the freshness or safety of the packaged food by showing their thermal histories such as potential temperature shocks and variation, possible thawing cycles, or the extent of exposure to elevated temperatures. Thus, it is fair to say that the time-temperature sensors are passive indicators as they merely reflect the history of food packaging rather than measuring food's actual state.

Sensors can also be used to identify the ripeness and freshness of packaged food by detecting the change in pH, or the presence of certain chemicals (e.g., ethylene) and metabolites that are produced in the process of ripening. For instance, SensorQ™, which is a pH-based sensor composed of a polymer matrix decorated with a green dye bromocresol sensitive to pH and is mostly used for identifying the freshness of meat. RipeSense™, developed in New Zealand by Jenkins Group in partnership with Plant and Food Research Institute, is a colourimetric sensor correlating the ripeness of fruit to the release of aromas in the packaging. Recently, several cost-effective colourimetric, flexible and scalable gas sensors were developed for detection of meat spoilage under various storage conditions and fruit ripeness (e.g., kiwis and avocados), respectively.[3,4] These sensors can be powerful decision-making tools that can be used for reducing the food waste as they monitor food quality in the whole supply chain.

Advances in sensing mechanisms and materials provide the opportunity to design more selective sensors which can directly measure the chemicals, toxins, or undesirable pathogens in the food package. These sensors, that are mostly electrochemical, directly measure the released chemicals rather than the environmental condition. However, most manufactured electrochemical sensors are voltametric or impedimetric, which demands an external energy source. Hence, there is great interest to manufacture cost-effective chemiresistive sensors which can not only measure the chemical component released in the food package, quantitively, but also do not need any external electrical source such as batteries. An example of such sensors is a recently developed hydrogen peroxide paperbased sensor.[5] Hydrogen peroxide is a common side-product of most enzymatic reactions which often occur during the process of food spoilage and perishing. Coupling such sensors with near field communication (NFC) tags assists the food supplier to collect the data.[6] Also, the whole system is printable and can be easily manufactured in large scale.

Future direction

Although great progress has been reported in the field of food sensors, the current technology has several challenges including its relatively high cost of manufacturing, using non-compostable materials and being limited to a specific operating temperature (i.e., unable to sense accurately at all storage temperatures such as room, refrigeration, and sub-zero). To date, most sensors that have reached the market are limited to colourimetric sensors because of their ease of fabrication and compatibility with packaging materials.

Also, most manufactured sensors cannot detect multiple components simultaneously. What has been reported in the literature as the selectivity of these sensors was merely sensitivity of these systems against individual chemicals (e.g., gases)[4,7] which may not reflect the true selectivity in which the sensor should be exposed to a mixture of gases.

The increasing global problem of waste generated from food and food packaging has also fuelled the further development of sensors for food applications. Future food sensors should be fabricated from environmentally friendly, compostable, ingestible, bioresorbable or even metabolisable materials preferably sourced from natural resources. Silk is one such example, offering natural abundance, biocompatibility, and suitable mechanical, electrical and adhesive properties. Also, flexible electronics and new active materials can be employed in future electrochemical food sensors to enable their incorporation in flexible food packaging.

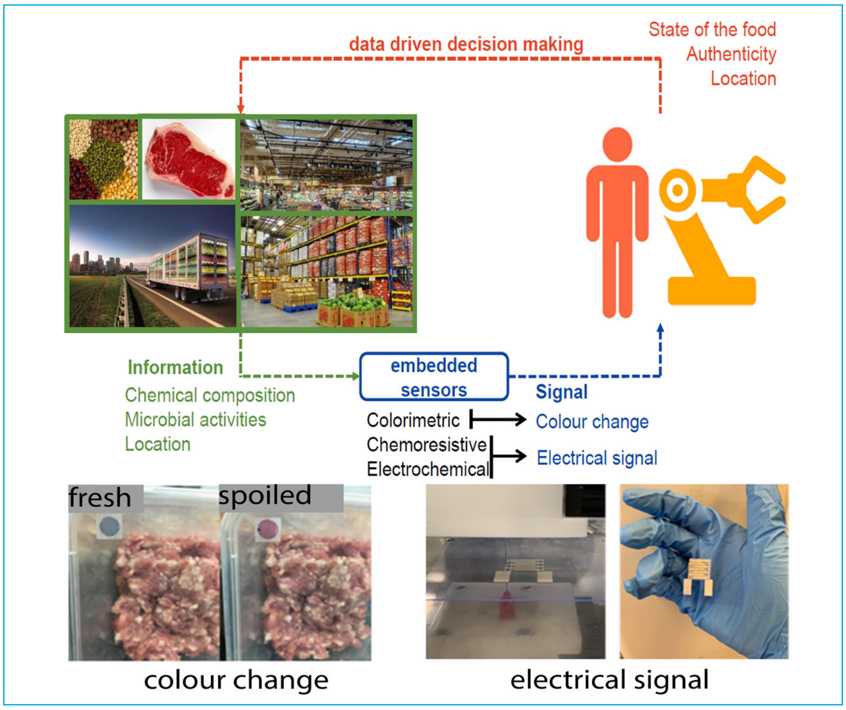

Figure 1: Sensors for monitoring food quality and safety

Cost is another pivotal factor for the success of food sensors in the market. Here, cost-effective fabrication technologies such as inkjet printing can be utilised for large scale production of sensors directly applied to the food packaging. Economically viable materials such as cellulose and its derivatives can also be used to reduce production costs.

References

1. World Health Organization (2015). WHO estimates of the global burden of foodborne diseases: foodborne disease burden epidemiology reference group 2007-2015
2. Oveissi *et al.* (2021). "Sensors for food quality and safety" In: Food Engineering innovations across the Food Supply Chain (Juliano P., Knoerzer K., Sellahewa J., Nguyen M., Buckow R., Eds), Amsterdam: Elsevier. In-press
3. Nguyen *et al.* (2020). "Naked-eye detection of ethylene using thiol functionalized polydiacetylene-based flexible sensor" ACS Sensors, 5(7) 1921:1928. https://doi.org/10.1021/acssensors.0c00117
4. Nguyen *et al.* (2019). "Polydiacetylene-based sensors to detect food spoilage at low temperatures"*Journal of Materials Chemistry C*, 7 1919:1926. https://doi.org/10.1039/C8TC05534C
5. Giaretta *et al.* (2021). "Paper-base, chemiresistive sensor for hydrogen peroxide detection", *Advanced Materials Technologies*, 2001148 https://doi.org/10.1002/admt.202001148
6. Barandun *et al.* (2019). "Cellulose fibers enable near zero-cost electrical sensing of water-soluble gases" ASC Sensors 4(6) 1622:1669. https://doi.org/10.1021/acssensors.9b00555
7. Nguyen et al. (2019). "Nanocellulose for sensing applications" *Advanced Materials Interfaces* 6(18) 1900424. https://doi.org/10.1002/admi.201900424

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