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Review

Intelligent food packaging: The next generation

Mike Vanderroost[a,*], Peter Ragaert[a,b,c], Frank Devlieghere[a,c] and Bruno De Meulenaer[b,c]

[a]Laboratory of Food Microbiology and Food Preservation, Department of Food Safety and Food Quality, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Gent, Belgium (Tel.: +32 92649905; e-mail: Mike.Vanderroost@UGent.be)

[b]Research Group Food Chemistry and Human Nutrition, Department of Food Safety and Food Quality, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Gent, Belgium

[c]Pack4Food npo, Department of Food Safety and Food Quality, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Gent, Belgium

Since the beginning of the current millennium, food packaging innovation activities have gradually expanded toward the development of intelligent packaging. This evolution reflects the emerging need for new and efficient ways to economize on business processes, solve safety and quality issues through the supply chain, and reduce product losses. The general purpose of this paper is to provide an overview of ongoing scientific research, recent technological breakthroughs, and emerging technologies that offer the perspective of developing a next generation of intelligent food packaging systems to sense, detect, or record changes in the product, the package or its environment.

* Corresponding author.

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Introduction

Generally spoken, innovations in food packaging aim at improving, combining, or extending the four basic functions of traditional food packaging (Yam, Takhistov, & Miltz, 2005):

- *Protection*. Food packaging keeps food products in a limited volume, prevents it to leak or break-up and protects it against possible contaminations and changes.
- *Communication*. Food packaging communicates important information about the contained food product and its nutritional content, together with guidelines about preparation.
- *Convenience*. Food packaging allows for consumers to enjoy food the way they want, at their convenience. Food packages can be designed toward individual lifestyles through for example portability and multiple single portions.
- *Containment*. Containment is the most basic function of a package and is important for easy transportation or handling.

As society is becoming increasingly complex, users (food producers, food processors, logistic operators, retailers and consumers) continuously demand innovative and creative food packaging to guarantee food safety, quality, and traceability. This requires appropriate technologies that can be integrated in food packaging. For food packaging innovations to be commercially viable and successfully adopted by the target group, they must meet the ever increasing regulatory requirements and have a final beneficial outcome that outweighs the possible extra expenses of adding the new technology. In addition, food packaging innovations should also aim at decreasing the environmental pressure by taking into account a broad range of sustainability issues (waste prevention, efficient use of resources, process optimization, recycle, reuse …). Food packaging innovations should therefore not only be discussed on the basis of their scientific or technological contributions to the four basic functions of traditional food packaging, but also on their general contributions towards a more sustainable world in which the harmful impact of packaging waste and food loss on our environment is reduced.

Since the beginning of the current millennium, food packaging innovation activities have gradually expanded

toward the development of intelligent packaging. According to the legal definition of the EU (EC, 2009), intelligent packaging contains a component that enables the monitoring of the condition of packaged food or the environment surrounding the food during transport and storage. Intelligent packaging is thus a system that provides the user with reliable and correct information on the conditions of the food, the environment and/or the packaging integrity. Intelligent packaging is an extension of the communication function of traditional food packaging, and communicates information to the consumer based on its ability to sense, detect, or record changes in the product or its environment.

It can be derived from Fig. 1 that the number of publications on intelligent packaging has increased more rapidly since 2009 compared to the period before. This trend possibly reflects to a certain extent the emerging needs resulting from the financial crisis in 2007, which has forced companies to search for new and efficient ways to economize on business processes and to reduce losses. The development of new intelligent packaging providing continuous information on the food condition or packaging integrity is not only beneficial for the customer, but also enables the detection of calamities and possible abuse through the entire supply chain, from farm to fork. This undoubtedly results in a safer and more efficient supply chain, reducing food loss and waste and preventing unnecessary transport and logistics from an early stage. Intelligent packaging can also contribute to improving 'Hazard Analysis and Critical Control Points' (HACCP) and 'Quality Analysis and Critical Control Points' (QACCP) systems[1] (Heising, Dekker, Bartels, & Van Boekel, 2014) which are developed to

1. timely detect unsafe foods;
2. identify health hazards and establish strategies and procedures to prevent, reduce, or eliminate their occurrence;
3. identify processes that strongly affect the quality attributes and efficiently improve the final food quality.

Currently, an integrated system covering the entire food supply chain and combining material and informational flows into one continuous food safety and quality management process is still nonexistent.

It is important to emphasize that intelligent packaging should not be confused with active packaging. Active packaging is an extension of the protection function of traditional food packaging and is designed such that it contains a component that enables the release or absorption of substances into or from the packaged food or the environment surrounding the food (EC, 2009). Active packaging is thus a system in which the product, the package, and the environment interact in a positive way to extend shelf life, improve the condition of

[1] A HACCP system helps food business operators look at how they handle food and introduces procedures to make sure the food produced is safe to eat.

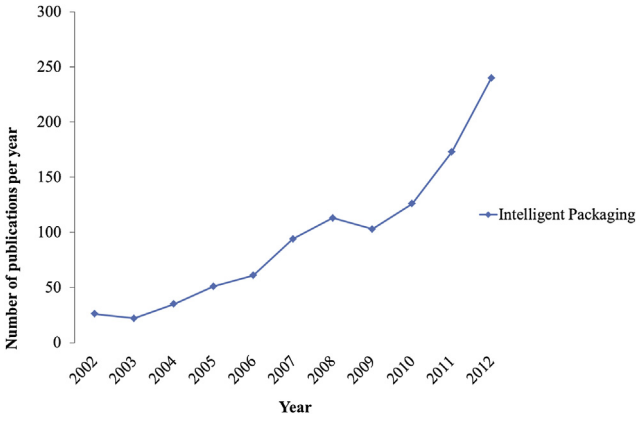

Fig. 1. The evolution (2002–2012) of the number of publications on intelligent packaging. Source: Google Scholar: http://scholar.google.com.

packaged food, or to achieve some characteristics that cannot be obtained otherwise (Miltz, Passy, & Mannheim, 1995). Intelligent packaging and active packaging are not mutually exclusive. Both packaging systems can work synergistically to realize so-called smart packaging. Smart packaging provides a total packaging solution that on the one hand monitors changes in the product or the environment (intelligent) and on the other hand acts upon these changes (active). Although the concepts of smart and intelligent packaging are often used interchangeably in literature, the authors of this paper would like to emphasize that they are not the same.

To date, three major technologies exist for realizing intelligent packaging: sensors (and by extension nose systems), indicators, and radio frequency identification (RFID) systems (Kerry, O'Grady, & Hogan, 2006). These technologies differ from each other not only in "hardware" (physical composition), but also in the amount and type of data that can be carried and how the data are captured and distributed (Heising *et al.*, 2014). In Fig. 2, it is shown that the number of publications on the application of each major intelligent packaging technology has increased each year in the period between 2002 and 2012, indicating that the

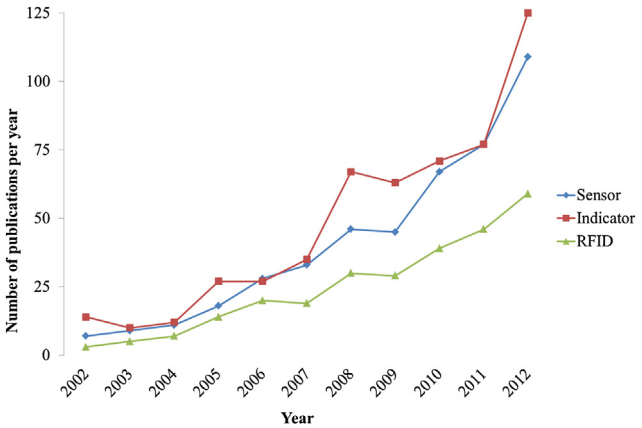

Fig. 2. The evolution (2002–2012) of the number of publications on the three major technologies applied in intelligent packaging: sensors, indicators and RFID. Source: Google Scholar: http://scholar.google.com.