Intelligent Packaging for Perishable Products

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The preservation of perishable products to maintain their quality is of paramount importance for food safety and security, and is attracting more attention with the increasing concerns on food quality, healthcare and life. Advances in technology and materialsin recent years have led to the development and implementation of intelligent packaging for perishable products that can monitor or evencontrol their quality in supply chain. In this paper, the techniques used in intelligent packaging (i.e., indicators, sensors, and identification technology) and the major printing methods for fabricating electronics (i.e., inkjet printing, screen printing, and gravure printing) are reviewed with a focus on the packagingof perishable products. Althoughthehigh manufacturing costs pose a big challenge for their commercialization and large-scale deployment, it is expected that the technological progressesin printing electronicswill significantly reduce the manufacturing cost of intelligent packaging to a threshold of acceptance by markets and the broad applications of intelligent packaging can facilitate the traction and monitoring of perishable products for better control of the product quality and improved management of supply chain.

Keywords: Intelligent Packaging ; Smart Packaging ; Printed Electronics ; Perishable products ; Printing methods

1. Introduction

Perishable products such as seafood, fruits, and vegetables are important items used in the daily livesofmany people. One common characteristic of perishable products is that they have a short shelf life and are prone to decay. The consumption of such decayed perishable products may lead to illness or even death. In the United States, approximately9000 deaths occur each year owing to diseases caused by spoiled perishable products [1]. In Spain, 0.06% of people suffer fromfoodbornediseaseseveryyear. Besides the health hazards, substantialeconomic loss is another grave concern in the supply chain of perishable products.Because of the ineffective management of perishable products in the supply chain, especially during transportation, almost one-third of the products intended for human consumption arelost or wasted annually[2],[3]. The large volumes of food waste have also become a significant financial burdenforthe food industry in the supply chain [4],[5].

2. Technologies and Fabrication of Intelligent Packaging for Perishable Products

Packaging is essential for perishable products, as it protects them from contamination, damage, and decay along the supply chain[6]. There are two main techniques through which packaging can be improved: active packaging and intelligent packaging.Janjarasskul and Suppakul have reviewed both methods. They concluded that the two methods both helped in the monitoring and preserving of quality of perishable products[7]. Active packaging is an innovative packaging system that either releases substances into or absorbs substances from the perishable products or their surrounding environment to maintain their quality and to extend their shelf life. In the past, researchers primarily focused on active packaging, however, in recent years advances in information technology and demand on effective management along the supply chain have led to a shift in research focus to intelligent packaging[6],[8].There is a growing need for perishable product companies to enable the packaging of their products to include more information on the product status and the environment conditions inside or outside the package[8]. Hence, there is a strong need for the development of intelligent packaging for the perishable product industry to allow for the improved protection of product quality and reduced economic losses.

Intelligent packaging or smart packaging was defined as “a packaging system that is capable of carrying out intelligent functions (such as detecting, sensing, recording, tracing, communicating, and applying scientific logic) to facilitate decision making for the extension of shelf life, enhancement of safety, improved quality through the provision of information and to notify about possible problems”[9]. In Europe, the legal definition of “intelligent food contact materials and articles” is “materials and articles that monitor the condition of packaged food or the environment surrounding the food”[10]. The basic functions of an intelligent package include tracking the products, monitoring the surrounding environment, and

communicating with the backend system or consumers. Consequently, intelligent packaging can provide consumers or food supplierswiththe condition of a food product and its storage environment.Also,anearly warning signal is given when there is an abnormal occurrence[[11]].

The basic functions of traditional food packaging: protection, communication, convenience, and containment have been enriched by the new development of intelligent packaging[[9]]. Kerry et al. proposed that intelligent packaging systems must include three main technologies, i.e., (i) indicators, a more convenient way of informing consumers about the quality of the food; (ii) data carriers, for storage and distribution of data including tracking; and (iii) sensors, for the rapid and accurate quantification of the analyses[[4]]. There are some other intelligent tools that can be applied in addition to these main intelligent packaging techniques[[12]].Holograms can help prevent counterfeiting—and at a lower cost than radio-frequency identification (RFID)tags, which is very useful in the pharmaceutical industry. Thermo chromic inks can change color in different temperatures, and can be used for beverage packaging or for microwavable products, allowing consumers to know whether the hot or cold product is ready to be served.Ghaaniet al. reviewed the intelligent packaging technologies for food and showed the gap between its demand and itsapplication in the market due to higher costs. Hence, future research should also address this problem tomakeintelligent systems commercially viable for the packaging of everyday commodities. It will be attractive to have packaging costs that are less than 10% of the total cost of the products[[13]]. The development in printing electronics for large scale fabrication will be important and the sole approach to reduce the cost of intelligent packaging.

To be better informed about the level of research interest in intelligent packaging, we looked at research records covering the last five years (2014–2018), using techniques such as keyword searches to explore the web of science database. As the numbers of publications identified using different keywords varied significantly, we carried out a normalization process, and have presented the data in Table 1, with publication trends illustrated in Figure 1. Looking at the data, we can see that there has been far more recent interest in intelligent packaging than in active packaging, with the main techniques used in intelligent packaging—sensors and printing—capturing more interest.

Table 1.(**a**) Recent publications about intelligent packaging.(**b**) Recent publications about intelligent packaging after normalization.

Keywords	2014	2015	2016	2017	2018
(**a**)					
Active Packaging	2246	2636	2757	2628	2968
Intelligent Packaging	483	718	815	1098	1292
Indicator and Intelligent Packaging	14	23	31	29	40
Sensor and Intelligent Packaging	208	280	306	412	521
Radio-frequency identification (RFID)and Packaging	289	308	243	309	311
Printing and Intelligent Packaging	29	35	46	61	80
(**b**)					
Active Packaging	0	0.540166	0.707756	0.529086	1
Intelligent Packaging	0	0.290482	0.410383	0.760198	1
Indicator and Intelligent Packaging	0	0.346154	0.653846	0.576923	1

Sensor and Intelligent Packaging	0	0.230032	0.313099	0.651757	1
RFID and Packaging	0.676471	0.955882	0	0.970588	1
Printing and Intelligent Packaging	0	0.117647	0.333333	0.627451	1

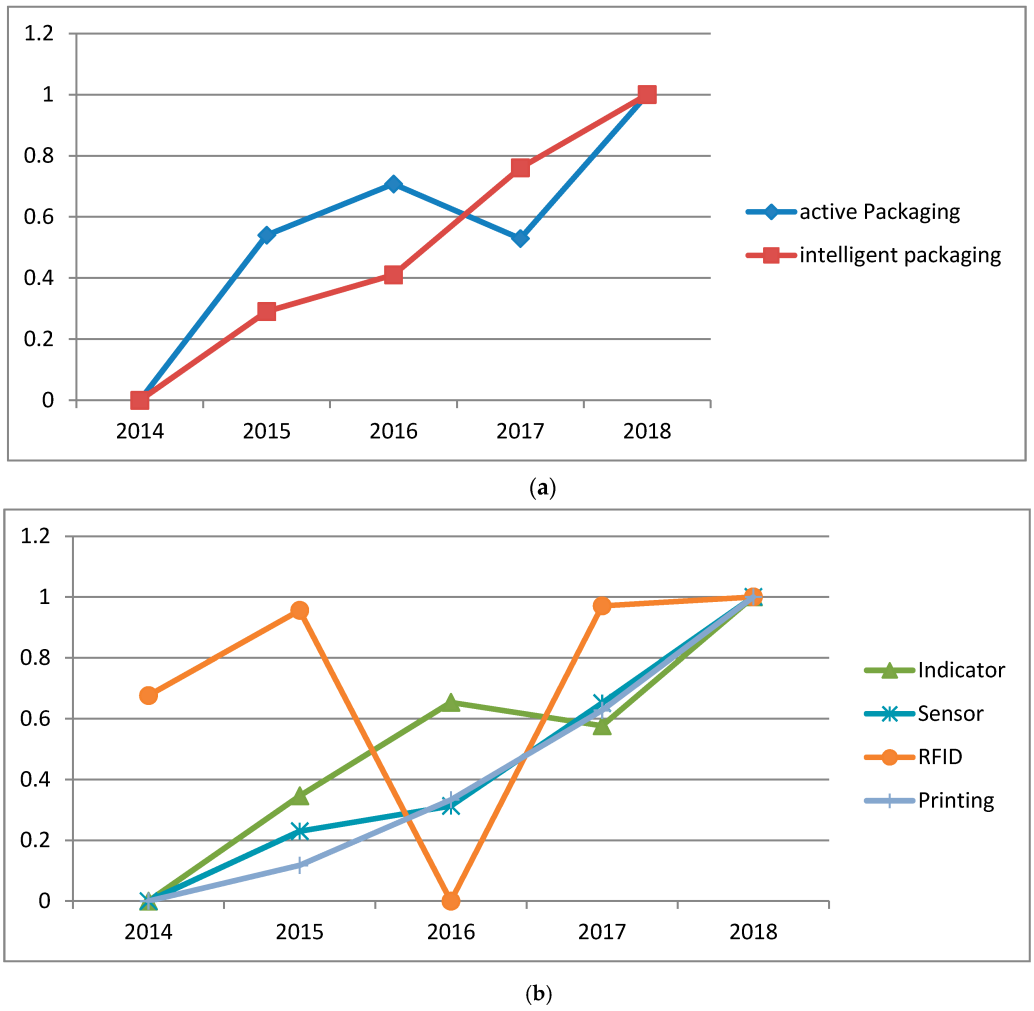

Figure 1.Publication trends: (**a**) active packaging and intelligent packaging (**b**) main techniques in intelligent packaging.

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