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Innovative food packaging and handling

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Abstract

Packaging is an inevitable part of food production, storage, marketing and distribution system. Traditional food packages act as passive barriers that delay the adverse effects of the environment on the food product. In the past few decades, the concept of intelligent and active packaging has been evolved that work in synergy to create what is called a "smart" packaging. Active packaging takes some action on food environment, while intelligent packaging senses and shares the information regarding some food quality. Sustainability, processing and nutritional preferences, demographic shifts, safety and shelf-stability are the key driving forces for changing food packaging system. The current trend of consumers seeking for environmental-friendly packaging forces towards biodegradable packaging. The objective of this review is to present an overview of recent innovations in food packaging.

Keywords: Food packaging, active packaging, intelligent packaging, biodegradable packaging

1. Introduction

Food packaging is multi-disciplinary art, science and management of food logistics in global food supply system. Food packaging is a dynamic system of the food product, visual and structural designs, transportation and distribution (Teck Kim *et al.*, 2014) [26]. Sustainability, processing and nutritional preferences, demographic shifts, safety and shelf-stability are the key driving forces for changing traditional packaging to active packaging and intelligent packaging. The magnitude and dimension of this industry influencing pharmaceuticals, drugs, electronics, hardware, food, personal care, transportation, export & import is astronomical. Direct and Indirect impact of packaging are apportionment, wider reach of produce, traceability, tamper indication, marketing and brand establishment, transport efficiency and revenue and employment generation.

Food product development and (re) formulation, production, packaging and its distribution to consumers with food quality and safety, and information communications from the marketing perspective are main objective of packaging development. The definition of packaging broadly implies a coordinated system of preparing goods for transport, distribution, storage, retailing and end-use, a means of ensuring safe delivery to the ultimate consumer in sound condition at optimum cost (Lockhart, 1997) [14] and a techno-commercial function aimed at optimizing the costs of delivery while maximizing sales (Paine, 2012; Coles & Kirwan, 2011) [20, 4]. It is an inevitable unit operation of food industry and just like compartmentalisation; packaging has primary, secondary and tertiary levels. Primary packaging is for retail use by consumer directly, secondary packaging is for distribution and intended to protect the content from mechanical damage and tertiary packaging is unitizing many secondary packages for shipping purposes. These levels are interrelated and affect each other. In fact, packaging is an integrated system, comprising of package system (primary, secondary or tertiary), packaging operation and packaging equipment.

Packaging industries had seen transition from rigid, inert and passive state to flexible, interactive and active state. Traditional food packages are passive barriers designed to delay the adverse effects of the environment on the food product. The concept of Intelligent and active packaging work in synergy to create what is called a "smart" packaging. An intelligent packaging monitors the condition of the packaged food product and does not act directly on food. An active packaging has some characteristics that act on the environment surrounding the food to increase the shelf-life. Therefore, active packaging takes some action on food environment, while intelligent packaging senses and shares the information regarding some food quality. The active component can be directly incorporated in the polymer-based package matrix or sachets and pads can be inserted in the package. The intelligent component can be instead integrated in the primary or secondary packaging. Advance technologies, like modified atmosphere packaging, active packaging, intelligent packaging, and biodegradable packaging, however, are needed to allow packages to take care of the food and environment as well (Brody *et al*., 2001; Lopez-Rubio *et al*., 2004) [2, 15]. The objective of this review is to present an overview of recent innovations in food packaging with clear definitions and classifications of each kind of active and intelligent.

2. Active Packaging (AP)

The popularity of Active Packaging (AP) has signified a major paradigm shift in packaging during the past 2 decades. The protection function of packaging has been shifted from passive to active. Previously, primary packaging materials were considered as “passive,” meaning that they functioned only as an inert barrier to protect the product against oxygen and moisture. Recently, a host of new packaging materials have been developed to provide “active” protection for the product (Sen *et al*., 2012; 2014) [22, 23]. AP has been defined as a system in which the product, the package, and the environment interact in a positive way to extend shelf life or to achieve some characteristics that cannot be obtained otherwise (Miltz *et al*., 1995) [17]. It has also been defined as a packaging system that actively changes the condition of the package to extend shelf life or improve food safety or sensory properties, while maintaining the quality of the food (Tian *et al*., 2010) [27].

Food packaging materials have traditionally been chosen to avoid unwanted interactions with the food. During the past two decades a wide variety of packaging materials have been devised or developed to interact with the food. These packaging materials, which are designed to perform some desired role other than to provide an inert barrier to outside influences, are termed 'active packaging'. The benefits of active packaging are based on both chemical and physical effects.

Active packaging elements can be divided into three categories: Absorber, releasing system and other system. For any fresh fruits, absorbing system is used as active packaging components to remove undesired gases and substances (oxygen, carbon dioxide, moisture, ethylene, and taints) in order to extend the shelf life.

3. Intelligent Packaging (IP)

Intelligent packaging is 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 to extend shelf life, enhance safety, improve quality, provide information, and warn about possible problems (Yam *et al*., 2005) [30]. Comparing AP with IP, the later one is a provider of enhanced communication, whereas, AP is a provider of enhanced protection. Thus, in the total packaging system, IP is the component responsible for sensing the environment and processing information and AP is the component responsible for taking some action (for example, release of an antimicrobial) to protect the food product. It may be noted that the terms IP and AP are not mutually exclusive; some packaging systems may be classified either as IP or AP or both, but this situation does not detract the usefulness of these terms. In appropriate situations, functions of IP, AP and the traditional packaging work synergistically to provide a desirable solution (Yam *et al*., 2005) [30].

Intelligent package devices are small, labels or tags that are attached onto primary packaging (for example, pouches, trays, and bottles), or more often onto secondary packaging (for example, shipping containers), to facilitate communication throughout the supply chain so that appropriate actions may be taken to achieve desired benefits in food quality and safety enhancement. There are 2 basic types of smart package devices: data carriers (such as barcode labels and radio frequency identification [RFID] tags) that are used to store and transmit data, and package indicators (such as time-temperature indicators, gas indicators, biosensors) that are used to monitor the external environment and, whenever appropriate, issue warnings.

3.1 Barcodes

Barcodes are the least expensive and most popular form of data carriers. The UPC (Universal Product Code) barcode is a linear symbology consisting of a pattern of bars and spaces to represent 12 digits of data to store limited information such as manufacturer identification number and item number. To address the growing demand for encoding more data in a smaller space, a new family of barcode symbologies called the Reduced Space Symbology (RSS) is recently being introduced. The RSS-14 Stacked Omni-directional barcode encodes the full 14-digit Global Trade Item Number (GTIN), and it may be used for loose produce items such as apples or oranges. The RSS Expanded Barcode (also available in stacked format) encodes up to 74 alphanumeric characters, and it may be used for variable measure products.

3.2 Radio frequency identification tags

The RFID tag is an advanced form of data carrier for automatic product identification and traceability. In a typical RFID system, a reader focus radio waves to capture data from an RFID tag, and the data is then passed onto a host computer (which may be connected to a local network or to the Internet) for analysis and decision making (Want, 2004) [28]. Inside the RFID tag is a minuscule microchip connected to a tiny antenna. RFID tags may be classified into 2 types: passive tags that have no battery and are powered by the energy supplied by the reader, and active tags that have their own battery for powering the microchip’s circuitry and broadcasting signals to the reader. The more expensive active tags have a reading range of 30 m or more, while the less expensive passive tags have a reading range of up to 4.5m.

3.3 Time-temperature indicators

Temperature is usually the most important environmental factor influencing the kinetics of physical and chemical deteriorations, as well as microbial growth in food products. Time-temperature indicators (TTIs) are typically small self-adhesive labels attached onto shipping containers or individual consumer packages. These labels provide visual indications of temperature history during distribution and storage, which is particularly useful for warning of temperature abuse for chilled or frozen food products. They are also used as “freshness indicators” for estimating the remaining shelf life of perishable products. There are 3 basic types of commercially available TTIs: critical temperature indicators, partial history indicators, and full history indicators (Singh *et al*., 2007) [24].

3.4 Gas indicators

The gas composition in the package headspace often changes as a result of the activity of the food product, the nature of the package, or the environmental conditions. Gas indicators in the form of a package label or printed on packaging films can monitor changes in the gas composition, thereby providing a means of monitoring the quality and safety of food products. Oxygen and carbon dioxide gas indicators are widely used in food packaging.

3.5 Biosensors

A biosensor is a compact analytical device that detects, records, and transmits information related to biochemical reactions. This smart device consists of 2 primary components: a bio receptor that recognizes a target analyte and a transducer that converts biochemical signals into a quantifiable electrical response. The bio receptor is an organic or biological material such as an enzyme, antigen, microbe, hormone, or nucleic acid. The transducer can assume many forms (such as electrochemical, optical, acoustic) depending on the parameters being measured. These can be used for rapid, accurate, on-line sensing for in situ analysis of pollutants, detection and identification of pathogens, and monitoring of post-processing food quality parameters.

4. Modified Atmosphere Packaging (MAP)

Modified Atmosphere Packaging (MAP), usually used for fresh produces, is a package in which the atmosphere inside the package is modified or altered to provide an optimum atmosphere for increasing shelf life. Modification of the atmosphere may be achieved either actively or passively. Active modification involves displacing the air with a controlled, desired mixture of gases, and is generally referred to as gas flushing. Passive modification occurs as a consequence of the respiration/metabolism of the enclosed commodity which changes the gaseous concentrations inside the package (Sen & Das, 2016) [21].

The normal composition of air by volume is 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.03% carbon dioxide, and traces of other nine gases. The three main gases used in active MAP are O_2, CO_2 and N_2, either singly or in combination. The choices of suitable packaging materials for the MAP of respiring produce such as fruits and vegetables are complex due to the dynamic nature of the product. The main characteristics to be considered when selecting packaging materials for MAP are the package permeability to gases and the respiration characteristics of the commodity.

5. Aseptic packaging

Aseptic packaging is filling of sterile containers with a commercially sterile product and sealing under aseptic conditions. Depending upon the severity of sterilisation, aseptic packaged foods are of two types: Complete aseptic packaged foods viz., long-life milk or coffee milk and Commercialised aseptic packaged foods viz., processed meat produces. Not all foods are suitable for this type of packaging. Acidic liquids, having a natural pH of 4.6 or less, are favoured because they naturally retard bacterial growth. Thus, orange juice was among the first food products to be aseptically packaged (Hirsch, 1991) [8].

Products that are heat-treated in bulk prior to package under aseptic conditions generally have better sensory and nutritional quality than products that have undergone heat treatment after packaging (Lechevalier, 2016) [13]. Other advantages include no refrigeration required that saves energy both in transportation and in storage.

In general, aseptic food packaging systems are composed of food sterilizers, aseptic fill/packaging machines, packaging material washing sterilizers, and bioclean rooms. Various chemical and physical methods employed for the sterilization of packaging materials currently used in aseptic packaging system are shown in Figure 1. Hydrogen peroxide, with concentrations up to 30%, temperatures of up to 80 °C and contact times up to 15s, with or without wetting agent, has been found to be successful for inline aseptic packaging (Ansari & Datta, 2003) [1].

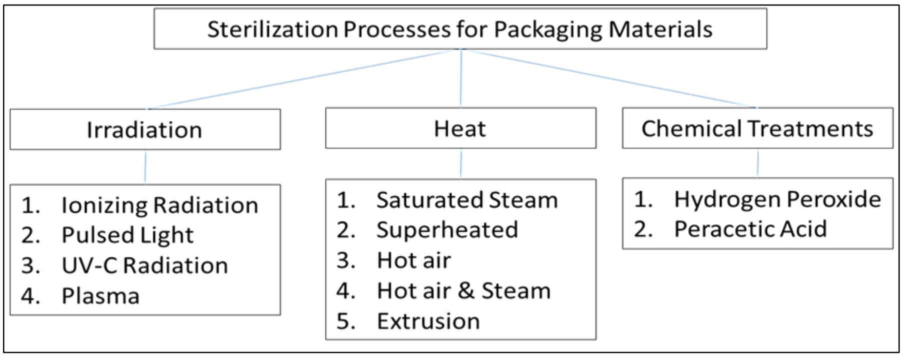

Fig 1: Methods for sterilizing aseptic packages

6. Packaging for non-thermal processes

Nonthermal processing methods such as ultra-high-pressure processing (HPP), pulsed electric field (PEF), Ionizing radiations (IR) and ultrasound processing etc. offer shelf-life extension with minimal impact on the nutritional and sensory characteristics of food.

Package for HPP should be design to survive high water mediated hydrostatic pressures, which typically range from 30-600 MPa, but could be as high as 800 MPa (Baek *et al*., 2018). HPP has reported to lead to disruption of flexible laminations by virtue of fluctuations during pressurisation and depressurisation operations of HPP (Morris *et al*., 2007) [18].

Packaging materials with very low values of oxygen permeability should be selected for PEF-treated foods (pumpable liquid and semi-liquid foods) which are prone to oxidation (Kumar & Han, 2012) [12]. The packaging materials for irradiation should be chemically stable under the radiation dose without depolymerization, cross-linking or significant changes in elastic modulus of the packaging materials. Packaging materials approved for use during irradiation are listed in 21 CFR 179.45 (Han, 2007) [7]. Packaging material used for Pulsed Light (PL) treatment should be transparent for light transmission (Han, 2007) [7]. Examples of suitable materials for PL treatments are polyethylene (PE), polypropylene (PP), polyolefin (PO) and polyvinyl chloride (PVC) (Keklik *et al*., 2010) [10].

7. Food Shelf life and Package selection

Wholesome nature of food is compromised by physical and chemical changes in the food itself, or from the activity of micro-organisms growing in or on the product. Shelf-life prediction has traditionally evolved from empirical procedures of quality evaluations of packaged food to various mathematical models to predict the shelf life of packed foods. Longer shelf life generally represents higher packaging cost.

The challenge in package design is to find a good balance between the product and the packaging (Grönman *et al*., 2013) [6]. Package design should concur with Product design for the benefits of economic, environmental and societal characteristics of the product–package combination optimisation e.g., microwave meals of CuliDish. However, if the package designs for a new product does not begin until the last stages of the product development, the scope for feasible innovations are limited. The selection of the packaging material must take into following considerations:- The composition of the food product and its physical state; Stability of the food; Physical stress exerted by the product; Light; Cost.

8. Environmental considerations

In recent days, use of synthetic polymer has to be restricted because they are not totally recyclable and/or biodegradable and packages developed from homo polymer can be recycled a limited number of times, and show degraded properties after further persuasion and pose serious ecological problems (Singh, 2000) [25]. Concerned to synthetic multilayer plastic packaging, recycling these materials is impracticable and most of the times economically not convenient. Incineration of any plastic put carbon foot prints in atmosphere. As a consequence, several thousands of tons of plastic packages are landfilled, increasing the problem of municipal waste disposal (Kirwan & Strawbridge, 2003) [11]. The growing environmental awareness imposes to packaging films and process possessing both user-friendly and eco-friendly attributes. As a consequence, biodegradability is not only a functional requirement but an important environmental attribute. Different sources of biodegradable polymers used for development of films are summarized in Figure 2.

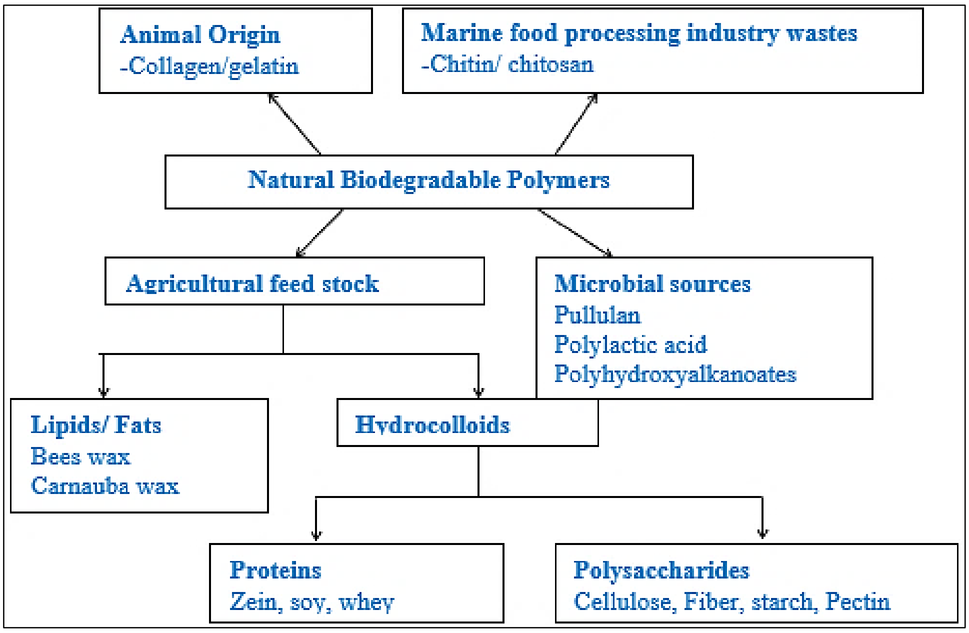

Fig 2: Animal and plant sources for natural biodegradable polymers

9. Plasticizer and cross-linking agent to modify film properties

A plasticizer is a substance that is incorporated into biopolymer to increase its flexibility, workability, and dispensability. Addition of plasticizer produces a film which is less likely to break and is more flexible. Thus, its use in starch film is an invariable part to avoid stiffness. The content of plasticizer necessarily varies from 10-60% (dry basis) according to the nature and type of film and its application (Yang & Paulson, 2000) [31]. Among various available plasticizers, glycerol is the most widely used. The effectiveness of glycerol in biodegradable blend films is most likely due to its small size which allows it to be more readily inserted between the polymer chains (Wittaya, 2012) [29].

Cross-linking is a key technique for modifying the properties of starches and can be achieved by adding intra-and inter-molecular bonds at random locations (Wittaya, 2012) [29]. Inter chain cross-linking tends to limit the contact of the free OH-groups with surrounding water (El-Tahlawy *et al*., 2007) [5]. Starch cross-linking is normally performed by treating starches with reagents (e.g. Glutaraldehyde) capable of forming either ether or ester linkages between hydroxyl (-OH) groups. Manoj and Rizvi (2010) [16] explained that the increase of mechanical property by cross-linking is due to reinforcing the structure of starch and limiting its water absorption, thereby restricting the mobility of the starch chain in the amorphous region.

10. Incorporation of natural antimicrobials in biodegradable films

Development of biopolymer films includes incorporation of antimicrobials as these films are usually susceptible to be infected with air-borne microbes, particularly in humid condition. So, irrespective of nature of uses, inclusion of antimicrobial preservative(s) in the film may become essential for its stability (Chowdhury & Das, 2010) [3].

Weak organic acids and their salts such as, propionic acid, potassium sorbate and benzoic acid, and some essential oils (cinnamon, oregano, clove etc.) which are commonly used as antimicrobial preservatives in food systems, may be incorporated into biodegradable films to inhibit the outgrowth of both bacterial and fungal cells. Being GRAS certified, they do not affect the food quality, or the eco system when discarded after use. Furthermore, it is also claimed that these impart some additional cross-linking effect that gives more structural stability to the system (Ojagh *et al*., 2010) [19]. However, enough experimental verification to the above fact is not available in literature. Also, more research is needed to evaluate the effect of anti-microbials on various film properties.

The food industry has seen great advances in the packaging sector since its inception in the 18th century with most innovations occurring during the past century. These advances have led to improved food quality and safety. However, excessive use of petroleum based synthetic packaging materials leads to ecological imbalance, global warming and continuous depletion of limited petroleum resources. Although films made from natural biopolymer usher promising solution, to arrive at commercial utilization, lot of research is needed in this field.

11. Interactions between packaging material and foods

Food and packaging interactions can be defined as interplay between food, packaging, and the environment, which produces an effect on the food and/or package (Hotchkiss, 1997) [9]. Interactions could be both desirable and undesirable. It is desirable in case of Active packaging and undesirable in case of flavour loss, oxygen-ingress or loss of carbonation. Factors such as the processing, hot filling, pH, and poor processing of polymers increase the migration risk of packaging constituents into the food stuffs. Liquid products have more serious problems than solid or semisolid foods. Package interactions are of three types: migration, sorption/scalping and permeation (Figure 3).

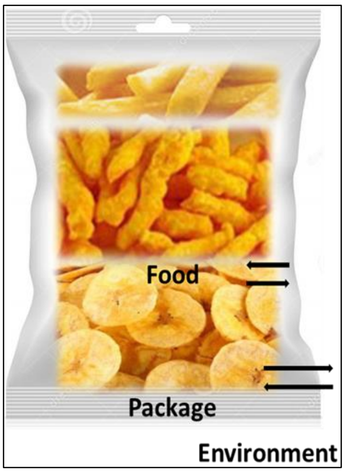

Fig 3: Dynamic interactions of Food, Package and Environment

The mass transport of package components to the product is known as migration. Migration depends on nature and composition of plastic and food, ratio of surface/product, type of contact, time, temperature, amount and the characteristics of the migrant. The mass transport of product components to the package is scalping. Scalping is dependent partly on the nature of the polymer (especially polypropylene) and partly on the size, polarity and solubility properties of the aroma compound.

12. Summary and Conclusion

Food packaging technology is an equilibrium between food wastage during distribution, shelf-life extension, consumer interaction and environmental wastage in terms of energy inputs on production and recycling. Selecting most appropriate packaging for a product requires a knowledge and understanding of the food chemistry and microbiology of the product, the environmental conditions that it will encounter from production to consumption and how this affects interactions between the packaging and the food and cost, sustainability and regulatory factors. The path ahead for package demands microwavability, dispensability, freshness guard, recyclability and reduced cost are the trend setting features of future market.

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