Protective Coatings for Shelf Life Extension of Fruits and Vegetables

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Abstract
Shelf life of fresh fruits and vegetable depends on two variables namely respiration rate of commodity and permeability of the packaging films. The modified atmosphere packaging using specially designed films acts as protective surface by controlling respiration of goods and permeation simultaneously. Although there are number of packaging films available now days, most of packages are designed from four basic sustainable polymers viz., polyethylene, polyethylene terephthalate, polypropylene and polyvinyl chloride for packaging of fresh produce. Edible coating is an alternative beneficial, low cost tool for shelf life extension of postharvest fruit and vegetable. Edible polymeric packaging materials can be made from polysaccharides, proteins and lipids. The objective of this review is to provide a comprehensive description of protective coatings used for preserving fruits and vegetables.

Keywords: Edible coatings, Plastic films, Biopolymers, Shelf life, Fruits and vegetables.

1. Introduction
The majority of fresh fruits and vegetables are harvested seasonally in large throughout the world and are mostly stored in suitable environments until marketed and consumed. Fresh fruits and vegetables are living organisms and continuing respiration even after harvesting. During storage and transport period, fruits and vegetable may undergo deterioration as their character such as nutrition, flavor, color and texture (Gatto et al., 2011; Terry and Joyce, 2004). Hence, during storage and transportation, fresh fruits and vegetables require careful storage to prevent deterioration as they are very susceptible (Kader, 1989). To extend the shelf life of postharvest fruit and vegetable, some effective measures including low temperature storage, modified atmosphere packaging, irradiation and coating, have been applied (Xanthopoulos et al., 2012; Castagna et al., 2013; Sanudo et al., 2009).

In case of fruit and vegetable storage, packaging plays vital role in preserving their quality characteristics such as color, texture, structure, flavor, etc from physical, chemical, or biological damage. An equally important function of good packaging is to deliver fresh fruits and vegetable at consumer’s door safely without losing ingredients (Coles, 2003). The packaging material should have following properties: It should be environment friendly, it should satisfy consumer desires and it should obey food safety principles (Marsh and Bugusu, 2007). Stability of a packaged commodity greatly depends on the characteristics of the packaging material and proper conditions of harvesting, storage and distribution.

Modified atmosphere packaging (MAP) is the technique in which sealed fresh fruits and vegetables alter the storage atmosphere (CO$_2$ and O$_2$ levels) through respiration and gas permeation through the packaging material. In general, the respiration rate of fruits and vegetables has inverse relation with their postharvest shelf-life. It is desirable that the natural interaction that occurs between the respiration of the fresh commodity and the packaging generates an atmosphere with low levels of O$_2$ and / or a high concentration of CO$_2$. The fruits and vegetables packed in suitable films having selective permeabilities creates atmosphere which has low concentration of O$_2$ and/or high concentration of CO$_2$. This environment further creates the barrier to the respiration and thus stops decaying and increases storability and/or shelf life (Beaudry, 2000; Iqbal et al., 2009; Kader et al., 1989). Atmospheres low in O$_2$ (1-5%) and high in CO$_2$ (5-10%) have been used to extend the shelf-life of fresh fruits and vegetables by reducing respiration, product transpiration and ethylene production. In addition to atmosphere modification, MAP vastly improves moisture retention, which can have a greater influence...
on preserving quality than $O_2$ and $CO_2$ levels. Furthermore, fruit coating isolates the product from the external environment and reduces exposure to pathogens and contaminants (Goulas, 2008; Mahajan et al., 2007). Polyethylene is the most commonly used polymer film for packaging with its advantages of being inert, permeable to gases and impermeable to water vapor (Rooney, 1995).

There are two types of modified atmospheric packaging: a) passive MAP and b) active MAP. In passive MAP, modified atmospheres can be obtained passively between plant material and sealed package as a result of vegetable respiration, which consumes $CO_2$ and releases $O_2$ in sealed package. In some cases, air inside the MAP is replaced with a single gas or mixture of gases, either naturally or artificially. In modified atmosphere packaging, gas introduction or modification in the concentration is carried out during packaging. No further control is exerted over the initial composition, and the gas composition is likely to change with time due to: a) the diffusion of gases into and out of the product, b) the permeation of gases into and out of the pack, and c) the effects of product and microbial metabolism (Kader et al., 1989). The deficiencies in passive MAP such as when a film is a good barrier to moisture, but not to oxygen, the film can still be used along with an oxygen scavenger to exclude oxygen from the pack. Such type of MAP is called as active MAP. An intentionally or actively obtained modified atmosphere occurs when the desired gas mixture is introduced into the container before sealing. In this way, atmospheric balance inside the package is reached faster or almost immediately.

2. Advantages of Modified Atmosphere Packaging

The advantages of MAP were elaborated by (Mangaraj et al., 2009) is presented below: a) Synthetic chemicals are not used hence it is eco-friendly technology, b) increased shelf-life by 50 to 400% allowing lesser frequency of retail display shelves, c) improved presentation of the product, d) no toxic residue is left, e) hygienic stackable pack sealed and free from product drip and odor, f) reduction in production and storage costs due to better utilization of space and equipment, g) it decreases the economical loses, and h) it prevent water loss and cross-contamination.

Recent advances in the polymer science make available number of polymeric films with a wide range of gas-diffusion characteristics which have stimulated renewed interest in MAP of fresh agricultural produce. The increased availability of various absorbers/scavengers of $O_2$, $CO_2$ (Kirklanda et al., 2008), water vapour and $C_2H_4$ (Gorris and Tauscher, 1999) also provides additional tools for manipulating the micro-environment within MAP. Coating films (plastic/edible coatings) are widely used in packaging, and continue to grow in use such as modified atmosphere packaging (MAP). In these packages, plastic films may be used alone or in several layer combinations to serve the basic packaging functions of containment, protection, communication and utility in the delivery of quality products to the consumer (Hernandez et al., 2000).

In contrast, edible coatings can be applied as an alternative to modified atmosphere packaging (MAP) to improve the shelf-life of fruits and vegetables. Edible films and coatings may help to reduce the deleterious effects concomitant with minimal processing, not solely retarding food deterioration and enhancing its quality. Actually, the application of edible coatings to deliver active substances is one of the major advances reached so far to enhance the shelf-life of fruits and vegetables. Many materials such as polysaccharides, proteins, essential oils, may economically serve as edible coatings (Vanzela et al., 2013; Lima et al., 2010; Santos et al., 2012).

This review intended to highlights some of recent findings regarding the use of protective coating to maintain or enhance shelf life of fresh fruits and vegetables.

3. Flexible Films Used in Fruits and Vegetable Packaging

The numbers of flexible films available for packaging have proliferated in recent years. Table 1 represents wide range characteristics of these films such as gas permeability and water vapour transmission rate (Kader et al., 1989). Flexible plastic packaging materials comprise nearly 90% of the materials used in MAP. Sometimes the films are used alone, and often they are used in combinations that provide the benefits of multiple materials.

The most commonly used protective films may be classified as: a) plastic/polymer films, b) biopolymers c) edible coatings.

3.1 Polyethylene

The polyethylene is generally categorized in to high, medium and low density (Specific gravity = 0.941-0.965, 0.926-0.940 and 0.910-0.925, respectively), which can also be used to describe their water barrier properties.

3.2 Low-Density Polyethylene (LDPE)
Table 1: Properties of plastic films used as coating for MAP of fruits and vegetables

<table>
<thead>
<tr>
<th>Type of flexible film</th>
<th>Permeabilities (cm³ µm/m² h atm)</th>
<th>Moisture vapour transmission rate (g µm/m²·day) at 37.8 °C and 90 % RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene films</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>6666-8750</td>
<td>41662-54687</td>
</tr>
<tr>
<td>LLDPE</td>
<td>2916-8333</td>
<td>15105-4316</td>
</tr>
<tr>
<td>HDPE</td>
<td>166-3041</td>
<td>9979-18215</td>
</tr>
<tr>
<td>Polypropylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP</td>
<td>2083-3916</td>
<td>11706-22008</td>
</tr>
<tr>
<td>BOPP</td>
<td>1541-2416</td>
<td>8368-13119</td>
</tr>
<tr>
<td>Polyvinyl chloride (PVC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene terephthalate (PE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unoriented</td>
<td>154-10000</td>
<td>939-61000</td>
</tr>
<tr>
<td>Oriented</td>
<td>50-100</td>
<td>390-510</td>
</tr>
<tr>
<td>Polyvinylidene chloride (PVDC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General purpose</td>
<td>13-18</td>
<td>62-86</td>
</tr>
<tr>
<td>High Barrier</td>
<td>1.3</td>
<td>4.95</td>
</tr>
<tr>
<td>Ethylene-vinyl alcohol (EVOH)</td>
<td>0.325</td>
<td>10.10</td>
</tr>
<tr>
<td>32 mol % Ethylene</td>
<td>1.25</td>
<td>37.50</td>
</tr>
<tr>
<td>44 mol % Ethylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyamide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nylon-6</td>
<td>20-42.50</td>
<td>84-179</td>
</tr>
<tr>
<td>Nylon-11</td>
<td>521</td>
<td>2084</td>
</tr>
</tbody>
</table>

LDPE film is heat sealable, chemically inert, odour free and shrinks when heated. It is less expensive than most films and is therefore widely used, including applications in shrink- or stretch-wrapping. LDPE is a good barrier to water vapour, but a poor barrier to oxygen, carbon dioxide and many odour and flavor compounds. The LDPE have a high ratio of CO₂: O₂ permeability which is important in allowing decrease of O₂ concentration without an associated excessive buildup of CO₂ inside the package.

### 3.3 Linear Low-Density Polyethylene (LLDPE)
LLDPE is a co-polymer of ethylene with small quantities of higher olefins and has branches at regular intervals on the main chain. It is stronger than LDPE and a better heat-sealable component. LLDPE is also a soft, flexible material, with a hazy appearance. At equal density and thickness, LLDPE has higher impact strength, tensile strength, puncture resistance and elongation than LDPE. Like LDPE; LLDPE has good water vapour barrier properties, but is a poor barrier to oxygen, carbon dioxide and many odour and flavor compounds (Abdel-Bary, 2003; Maier, 1998). Polyethylene terephthalate (PET) also has a high melting point, making it suitable for application where thermal resistance is required. The permeability of cast PP to water vapour and gases is relatively low, comparable with high-density polyethylene (Abdel-Bary, 2003; Maier, 1998). It is heat-sealable, but at a very high temperature, 170°C. It is usually coated with PE or PVDC/PVC copolymer to facilitate heat-sealing.

### 3.5 High-Density Polyethylene (HDPE)
HDPE is stronger, thicker, less flexible and more brittle than low-density polyethylene and has lower permeability to gases and moisture. High density polyethylene (HDPE) is a linear polymer with little branching. It is considerably more crystalline than LDPE, hence more rigid and less transparent. Its melting range is higher (128-138°C). HDPE has a higher tensile strength and stiffness than LDPE. Its permeability to gases is lower and it can withstand higher temperatures. The water vapour barrier of HDPE is better, as is their gas barrier. However, permeability to oxygen and carbon dioxide is still much too high for HDPE to be suitable as a barrier for these permeants (Marsh, 2007).

### 3.6 Polypropylene (PP)
Polypropylene is a polymer of the olefin propylene. PP has the lowest density of the commodity plastics (0.89-0.91 g/cm³). It is harder and more transparent than polyethylene. PP has good resistance to chemicals and is effective at baring water vapour. Its high melting point makes it suitable for application where thermal resistance is required. The permeability of cast PP to water vapour and gases is relatively low, comparable with high-density polyethylene (Abdel-Bary, 2003; Maier, 1998). It is heat-sealable, but at a very high temperature, 170°C. It is usually coated with PE or PVDC/PVC copolymer to facilitate heat-sealing.

### 3.7 Polystyrene
Polystyrene is another thermoplastic film with high transmission rate and relatively high CO₂: O₂ permeability ratio. It has a high tensile strength but a less resistant barrier to moisture vapour and gases transmission (Abdel-Bary, 2003; Kader et al., 1989; Newton, 1997). It is a widely used polymer of styrene (vinyl benzene). Polystyrene is a brittle clear sparkling...
film which has high gas permeability. It may be oriented to improve the barrier properties.

3.8 Polyester

Polyester (PET) film used in food packaging is polyethylene terephthalate, which is usually produced by a condensation reaction between terephthalic acid and ethylene glycol and extruded. There is little use of the non oriented form of PET but it widely used in the bi-axially oriented form. Oriented PET has good tensile strength and can be used in relatively thin gauges. It is often used coated with PE or PVC copolymer to increase its barrier properties and facilitate heat-sealing. It is stable over a wide temperature range and can be used for ‘boil in the bag’ applications.

3.9 Polyvinyl Chloride (PVC)

A numerous varieties of PVC are also available as flexible films for coating. PVC films typically have moderate levels of water vapour transmission rate and they can be soft, clear, non-foggy and durable. Polyvinyl chloride films are formed by combining PVC resin, produced by addition polymerization of vinyl chloride, with plasticizers and other additives to produce a flexible film. Permeability is relatively high (Ahvenainen, 2003; Massey et al., 2003). Both oriented and un-oriented films are available. It can withstand relatively high temperatures such as those encountered during hot filling and retorting. The oriented PVC has improved strength and barrier properties and is highly heat-shrinkable.

3.10 Bio-Polymers

Biobased flexible films or biopolymers are materials derived from renewable sources i.e. replenishable agricultural feed stocks, animal sources, marine food processing industry wastes, or microbial sources. Some biopolymers are made of from cellulose and starches (Miles and Bistons, 1965). These materials can be used for food applications. Bio degradable polymers can be classified into three main categories based on their origin and production.

3.10.1 Biomass Based Polymers

Polymers directly extracted/removed from biomass. Examples are polysaccharides such as starch and cellulose, chitosan/chitin and proteins like casein and gluten. Chitin is a biopolymer with a chemical structure similar to cellulose (Tharantharan, 2003). Chitosan is a linear polysaccharide originating from deacetylated derivative of chitin. It was non-toxic, biodegradable, bio-functional, and biocompatible. Chitosan has strong antimicrobial and antifungal activities that could effectively control fruit decay (Aider, 2010). It could easily form coating on fruit and vegetable, and the respiration rate of fruit and vegetable was reduced by adjusting the permeability of carbon dioxide and oxygen (Elsabee and Abdou, 2013).

3.10.2 Chemically Synthesized from Biomass

Polymers produced by classical chemical synthesis using renewable bio-based monomers. A good example is polylactic acid, a bio-polyester polymerised from lactic acid monomers.

3.10.3 Derived from Microorganisms

Polymers produced by microorganisms or genetically modified bacteria. To date, this group of bio-based polymers consists mainly of the polyhydroxyalkanoates, but developments with bacterial cellulose are in progress (Cutter and Sumner, 2002).

3.11 Cellulose Films

Cellulose-based plastics (e.g. cellulose acetate, cellulose butyrate, cellulose propionate, copolymers, etc) are most often used as sheet rather than film. Their high price and water sensitivity limit their usefulness. Higher quantities of softener and longer residence times in the acid–salt bath produce more flexible and more permeable films. Plain cellulose is a glossy transparent film which is odourless, tasteless and biodegradable within approximately 100 days. It is tough and puncture resistant, although it tears easily. It has low-slip and dead-folding properties and is unaffected by static buildup, which make it suitable for twist-wrapping. However, it is not heat sealable, and the dimensions and permeability of the film vary with changes in humidity.

3.12 Edible Coatings

An edible coating or film could be defined as primary packaging made from edible components. The films may be a complete food coating and can be disposed as a continuous layer between food components (Guilbert, 1986). Edible polymeric packaging materials can be made from polysaccharides, proteins and lipids. Edible packaging are generally used to minimize respiration in fruits and vegetables, limit the movement of moisture and other gases, provide antimicrobial or antioxidant capabilities to the product, and extend the shelf life of the product (Pascale and Lin, 2013; Marsh and Bugusu, 2007).

The edible films can also be classified in to three type based on their origin (Donhowe and Fennema, 1993): a) hydrocolloids (such as proteins, polysaccharides, and alginate), b) lipids (such as fatty acids, acylglycerol, waxes) and c) composites. Hydrocolloid films possess good gas barrier properties especially barrier to oxygen, carbon dioxide.
These are also having barrier to lipids but not to water vapor. Most hydrocolloid films also possess superb mechanical properties, which are quite useful for fragile food products.

4. Factors to be Considered While Selecting of Flexible Coatings for MAP

The selection a polymeric film for MAP depends on following factors (Ben-Yehoshua, 1985; Blakistone, 1997; Kader et al., 1989; Lange, 2000; Lee et al., 2008): a) the respiration rate of the produce to be packed, b) storage temperature to be used, c) optimum O₂ and CO₂ concentrations for the produce.

Gas diffusion across a film is determined by film structure, film permeability to specific gas, thickness, strength, area, concentration gradient across the film, temperature and temperature stability, relative humidity, and pressure difference across the film. For temperature and temperature stability, relative strength, area, concentration gradient across the film, structure, film permeability to specific gas, thickness, most fruits and vegetables (expect CO₂, Blakistone, 1997; Kader et al., 2008) depends on following factors (Ben-Yehoshua, 1985; Ben-Yehoshua S (1985). Individual seal-packaging of fragile food products. Journal of Bioresource Engineering and Technology | Year-2014 | Volume 1 | Pages 01-06

Selecting of Flexible Coatings for MAP

Factors to be Considered While Selecting of Flexible Coatings for MAP

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Reference


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