Active Packaging for Fresh-Cut Fruits and Vegetables

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Introduction

Fresh-cut fruits and vegetables are produce that are minimally processed and altered by peeling, slicing, or chopping with or without washing (FDA 2007). These products are processed from fresh fruits and vegetables which remain metabolically active even after harvesting and undergo ripening and senescence processes. Most fresh-cut fruits and vegetable are usually consumed fresh and a nonthermal preservation method is applied before consumption. Because of these minimal processing operations, the shelf lives of these commodities are very short, usually a few days (1–3 days) less than those for fresh whole products even when kept at the optimum storage conditions of refrigeration and humidity (Allende et al. 2006; Abadias et al. 2008; Galindo et al. 2004). Processing operations of fresh-cut products accelerate the physical, physiological, and microbial deteriorations and change their metabolic activities, which usually leads to a shorter shelf life, the loss of nutritional quality, and sometimes the formation of hazardous compounds (Artés et al. 2007; Galindo et al. 2007). The use of commercial sterilizers, ultraviolet radiation, heat shock, ozone, chemical treatments, and packaging could be used to extend the shelf life of fresh-cut produce, but these methods of preservation cause low consumer acceptability, low durability of preservation, elimination of produce freshness, and reduction of sensory and nutritional quality (Chonhenchob et al. 2007; Erturk and Picha 2008; González-Aguilar et al. 2008). Therefore, using an active packaging could be an effective means of preserving the quality of fresh-cut produce.

Active packaging performs traditional functions of packaging such as providing barriers to moisture vapor and gases, preventing product contamination from outside, and making food handling and identification easy (Ahvenainen 1996; Ozdemir and Floros 2004). Additionally, the active packaging has secondary functions such as antimicrobial, antioxidation, and product traceability; thus it helps in further improvement of produce properties.

There is an increased consumption of fresh-cut fruits and vegetables due to the increased demand for better quality, fresh-like, and convenient food products. These trends initiated a vast amount of research in the field of active and intelligent packaging to provide the market with packaging technologies designed to keep produce fresh, since it is impossible to attain the optimum quality characteristics with the passive...
plastic package for a highly deteriorative and metabolically active produce (Ozdemir and Floros 2004). The active packaging technologies that have been especially developed for fruits and vegetables are oxygen scavengers, carbon dioxide emitters, moisture absorbers, ethylene absorbers, antimicrobial agent releasers, time–temperature integrators (TTI), gas and volatile indicators, and radio frequency indicators (Han and Floros 2007).

**Physiological Changes of Fresh-Cut Fruits and Vegetables during Ripening and Minimal Processing**

Each fruit and vegetable has an optimum ripening stage at which it contains sugars, firmness, flavor, and color at the most preferred levels. It is important to keep fresh produce at this optimum stage at the point of purchase. During ripening, natural organic acids and starch are broken down and metabolically transformed into simpler compounds, which leads to an increase in the pH (Galindo et al. 2007). There is also an increase in the total soluble solids, dry matter, protein, nitrogen, and reducing sugars. Flavor and color are also changing during ripening due to the synthesis of aromatic volatile compounds and phenolics (Chaib et al. 2007; Coolong et al. 2008). Firmness decreases and fruit peel softens during ripening because of pectin breakdown, which leads to the loss of cell turgor (Ng et al. 1998). This develops typical fruit texture and sensory characteristics rendering the fruit good to eat. Overripening leads to excessive tissue softening, and pigments break down. Reducing sugars make the fruit a favorite environment for the growth of spoilage and pathogenic microorganisms (Poole and Gray 2002). Vegetables undergo increase in tissue firmness and colorization by pigment formation during the ripening process (Toivonen and Brummell 2008). Overripening of vegetables causes tissue toughness due to thickening of the cell wall and cell adhesion. Unpleasant flavor and yellowish color are developed, leading to consumer dissatisfaction (Toivonen and Brummell 2008).

Cutting processing of fruits and vegetables degrades appearance, textural quality, and freshness. These changes are specific for produce types and commodities, for examples, browning reactions in apples, chlorophyll degradation in leafy vegetables, and white blush in carrots (Toivonen and Brummell 2008). During the cutting operation many enzymes contact their potential substrates in the plant cell that were originally separated. The rate of these changes depends on the types and degree of processing (Iqbal et al. 2008; Park et al. 1998). A plant responds to these stress conditions by increasing respiration, which is in most cases 3–25 times higher than in the intact organ, and increasing ethylene production and transpiration (Ahvenainen 1996).

Conditions of storage (e.g., temperature), packaging (e.g., modified atmosphere packaging (MAP)), and handling play significant roles in keeping fruits at the optimum maturation stage. Packaging suppresses respiration and transpiration of the produce and, therefore, reduces the metabolic activity. It also prevents food contact with atmospheric oxygen, which accelerates deterioration reactions (Abbas and Ibrahim 1996). It was reported that MAP with low-density polyethylene maintained a high quality consumption period of fruits for 4 weeks at 10°C and 3 weeks at 15°C, while without MAP the shelf life was shortened to 1 week (Mohamed et al. 1996). Sozzi et al. (1999) reported that the storage of tomato at low levels of oxygen (3%) or elevated
carbon dioxide (20%) atmosphere significantly reduced ethylene production, maintained produce firmness and color, and delayed cell wall enzyme activity.

**Packaging Requirements of Fresh-Cut Fruits and Vegetables**

Every food product has a specific main deterioration factor that must be understood before active or intelligent packaging technologies are applied. Active and intelligent packaging for each particular product should be designed to overcome the main deterioration factor of the product. For example, for produce stored under conditions that promote mold growth, active packaging with oxygen scavengers or antimicrobials would be effective to prevent the deterioration of microbial quality (Jong and Jongbloed 2004). The parameters related to the deterioration process in food products include the intrinsic parameters (e.g., pH, nutrient content, oxidation reduction potential, cultivar, and maturation) and the extrinsic parameters (e.g., storage temperature, handling, pressure, and availability of oxygen) (Chakraverty 2001). Some of these factors can be controlled by active packaging technologies for quality preservation. To identify the deterioration reaction for each fruit and vegetable, it is important to conduct a case study to determine reactions related to the loss of produce quality or safety under the produce storage conditions; then a proper active package could be developed and applied.

One of the most important package-related parameters that could affect the postharvesting metabolism and postprocessing deterioration is storage gas composition. Every fruit and vegetable needs a different and sometimes very specific gas composition ratio to maximize its shelf life, although the gas concentrations depend on storage temperature and duration (Argenta et al. 2004). Packaging materials for minimally processed produce should have higher permeabilities to gases and ethylene, or contain gas absorbers to cope with high respiration and ethylene production. Modified atmosphere packaging with gas flush of 2–5% carbon dioxide and 2–5% oxygen was traditionally used for keeping fresh fruits and vegetables, but higher gas concentrations could be required for fresh-cut produce (Mohamed et al. 1996). Chonchenchob et al. (2007) found that the atmosphere of 6% oxygen and 14% carbon dioxide that was achieved at equilibrium in the headspace of packed fresh-cut pineapple increased shelf life 7 days at 10°C. Ayhan et al. (2008) found that storing minimally processed carrots in a high oxygen (80% oxygen and 10% carbon dioxide) atmosphere retained better quality properties of the carrots compared to the low (~5%) oxygen atmosphere. However, most plastic films do not have enough permeability to achieve the in-bag high gas concentration; therefore, nonaerobic respiration could be initiated (Ahvenainen 1996). Avella et al. (2007) developed a novel nanocomposite that is able to preserve apple cuts for up to 10 days at 4°C, through suppressing oxidation and microbial growth. Kim et al. (2005) found that adjusting the initial oxygen in the headspace of fresh-cut romaine lettuce is the most practical way to maintain the quality and shelf life of the produce for packages with suboptimal oxygen transmission rates.

Edible coatings preserve the quality of fresh-cut fruit though limiting gas and water vapor exchanges between fruit and the surrounding atmosphere, and act they effectively in preserving appearance, texture, flavor, and nutritional value (Daniel and Zhao 2007; Olivas et al. 2003; Vargas et al. 2008; Shon and Haque 2007; Dang et al. 2008). They
also inhibit the surface spoilage of fruits by blocking aerobic microorganisms from the access of oxygen (Park et al. 1998). Edible coatings used on fruits consist of proteins such as calcium caseinate and whey protein isolate, polysaccharides such as starch, carboxy methyl cellulose, cellulose, and alginate, and lipids such as short chain fatty acids, paraffin, and natural waxes (Conforti and Totty 2007; Olivas et al. 2007). Polysaccharide coatings were the most investigated because they are less expensive and less allergenic, and they can carry a larger variety of functional ingredients. They could be made to create various physical properties of produce comparable to those coated with the expensive protein films (Hernández-Muñoz et al. 2006). Mehyar and Han (2004) developed coating materials made of pea starch that had lower oxygen permeability and comparable water vapor permeability to the well-known protein films.

**Active Packaging for Fresh-Cut Fruits and Vegetables**

Active packaging plays an additional role in maintaining the quality and safety of fresh-cut produce compared with traditional packaging systems. The active packaging systems are specifically designed to control produce’s deterioration reactions by utilizing active ingredients that have been deliberately included in the packaging material or the headspace (Rooney 2005; Day 2008; Ozdemir and Floros 2004). Intelligent packaging can sense and inform the conditions of the food or the headspace by external devices connected to indicators that show food safety or quality (Rodrigues and Han 2003; Day 2008). As mentioned earlier, each type of food has a specific and unique deterioration mechanism(s) that must be suppressed by an active or intelligent packaging technology. Thus, it is necessary to maintain the product quality, freshness, and safety during the period for the commercialization and consumption of the packaged products. Table 14.1 contains selected commercial active and intelligent systems that are used or can potentially be used for fresh-cut fruits and vegetables.

**Active Packaging**

Currently, most active packaging technologies for fruits and vegetables depend on sachet technology, which contains the active ingredients inside small bags that are placed in the food package. These bags are usually permeable to gases but impermeable to the in-sachet contents. Sachets have low consumer acceptance due to possible accidental ingestion of their contents (Ozdemir and Floros 2004). The high moisture content and a high transpiration rate of fresh-cut produce may lead to the dissolution of the hydrophilic sachet contents, which are usually toxic. Therefore, active film/container applications are more appropriate for fresh-cut produce (Day 2008). This active plastic converting technology has a number of advantages over the sachets, which includes the reduction in package size, effective delivery of the active ingredients due to more contact with food, good processing characteristics of packaging operations, ease of use in foods, low cost, and convenience (López-Rubio et al. 2004; Han and Floros 2007).

Although the application of active polymeric films and coatings is very convenient, their commercial uses in the food industry should be accompanied by the
Table 14.1. Selected commercial active and intelligent systems that are used or can potentially be used for fresh-cut fruits and vegetables

<table>
<thead>
<tr>
<th>Packaging System</th>
<th>Commercial Name</th>
<th>Mechanism of Action</th>
<th>Manufacturer</th>
<th>Packaging Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen scavenger</td>
<td>Ageless</td>
<td>Iron based</td>
<td>Mitsubishi Gas Chemical Co. Ltd.</td>
<td>Sachets and Labels</td>
</tr>
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<td></td>
<td>Freshilizer</td>
<td>Iron based</td>
<td>Toppan Printing Co. Ltd.</td>
<td>Sachets</td>
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<td></td>
<td>Oxyguard</td>
<td>Iron based</td>
<td>Toyo Seikan Kaisha Ltd.</td>
<td>Plastic trays</td>
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<td></td>
<td>Zero2</td>
<td>Dye/organic compounds</td>
<td>Food Science Australia</td>
<td>Plastic films and containers</td>
</tr>
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<td>Ethylene scavenger</td>
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<td>Potassium Permanganate</td>
<td>Air Repair Products, Inc.</td>
<td>Sachets/blanks</td>
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<td>Neupalon</td>
<td>Activated carbon</td>
<td>Sekisui Jushi Ltd.</td>
<td>Sachet</td>
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<td></td>
<td>Evert-Fresh</td>
<td>Activated zeolites</td>
<td>Evert-Fresh Corporation</td>
<td>Plastic film</td>
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<td></td>
<td>Bio-fresh</td>
<td>Activated clays/zeolites</td>
<td>Grafit Plastics</td>
<td>Plastic film</td>
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<tr>
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<td>Not known</td>
<td>Toppan Printing Co.,</td>
<td>Absorber sheet</td>
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<tr>
<td></td>
<td>Thermarite</td>
<td>Not known</td>
<td>Thermarite Pty Ltd.</td>
<td>Absorber sheet</td>
</tr>
<tr>
<td>Time–temperature integrators</td>
<td>CheckPoint</td>
<td>Enzymatic activity</td>
<td>VITS A.B.</td>
<td>Adhesive label</td>
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<td>eO</td>
<td>Microbial growth</td>
<td>CRYOLOG</td>
<td>Adhesive label</td>
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<td>Diffusion of polar compounds</td>
<td>Avery Dennison Corp.</td>
<td>Adhesive label</td>
</tr>
<tr>
<td>Gas and volatiles indicators</td>
<td>It's Fresh</td>
<td>Chemical reaction</td>
<td>It's Fresh Inc.</td>
<td>Indicator tag</td>
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<tr>
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<td>Freshness Guard</td>
<td>Enzymatic detection</td>
<td>UPM Raflatac</td>
<td>Test strips or biochemical biosensors</td>
</tr>
<tr>
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<td>Toxin Guard</td>
<td>Immunochemical reaction</td>
<td>Toxin Alert Inc.</td>
<td>Indicator tag</td>
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</table>

*Table contents were collected from Day (2008), López-Rubio et al. (2008), and Smolander (2008).*
following precautions and considerations (López-Rubio et al. 2004; Han and Floros 2007).

1. The active ingredient may change polymer properties such as barrier properties (gas and water vapor permeabilities) and physical properties (tensile strength and elongation).

2. The active ingredient could be harmful to human health either by contacting the food or by leaving residues.

3. Desorption kinetics of active ingredients are variable and depend on plastic permeability, type of active ingredient, and type of food and storage conditions.

4. The active substances should be authorized by regulatory agencies before commercial use.

5. The active packaging should not create any significant confusion in consumers using the new package or any capital requirement of new installation in the supply chain.

Oxygen Scavengers
High levels of oxygen in the package headspace accelerate quality and safety deterioration of high respiring produce and lead to an increase in ethylene production. Excessive oxygen causes the oxidation of ingredients such as vitamins, pigments (formed by enzymatic and nonenzymatic browning), flavor compounds, and lipids, and facilitates the growth of aerobic microorganisms in the cut tissue (Sanjeev and Ramesh 2006). Examples of minimally processed fruits are potatoes, apples, banana, and peaches, where their processing increases the oxidation–reduction potential and accelerates the formation of the reactive oxygen species such as peroxide ions and superoxide anions that promote color oxidation (Sanjeev and Ramesh 2006). Controlling the oxygen concentration provides benefits in protecting the produce against the quality deterioration associated with oxygen, such as off-flavor formation, color change, nutritional value reduction, and safety losses (Sanjeev and Ramesh 2006). Furthermore, low available oxygen helps in reducing the respiration and ethylene production and keeps the produce fresh longer (Gorny et al. 2002; Oms-Oliu et al. 2008b). Oxygen scavengers are active additives used in the packaging system to absorb residual oxygen that remains after the package is sealed and that originated from the product respiration and the package permeability.

The concentration of oxygen inside package depends on the equilibrium between the product respiration and the gas permeation though the package (Lammertyn et al. 2001). Flushing inside the package with low oxygen concentration is not enough to eliminate the oxygen inside the package (López-Rubio et al. 2008; Sanjeev and Ramesh 2006). Aerobic microorganisms such as Pseudomonas spp., Aspergillus, and Penicillium spp. and facultative microorganisms such as Enterobacteriaceae can grow in an atmosphere of 1–2% oxygen even in elevated levels of carbon dioxide (Bennik et al. 1998). Therefore, the use of an oxygen scavenger was recommended to be used in combination with MAP and vacuum packaging for fresh fruits and vegetable as an additional hurdle (Sanjeev and Ramesh 2006).

Figure 14.1 represents a multilayer oxygen scavenging system. The oxygen absorbing layer is permeable to oxygen enough to absorb in-package oxygen. The inner
layer is oxygen permeable but is impermeable to the oxygen absorbing substances to prevent any migration of these substances into food, while the outer barrier layer is oxygen impermeable to prevent permeation of the atmospheric oxygen to the oxygen absorbing layer (Ozdemir and Floros 2004). One practical problem of oxygen scavengers is that they can generate anaerobic conditions if the oxygen scavenging capacity is higher than packaging oxygen permeability for a particular respiration rate. Thus the selection of an appropriate oxygen scavenger requires case-by-case mathematical models of oxygen concentration during MAP storage (Charles et al. 2003).

Most commercially available oxygen absorbers have reaction mechanisms based on iron oxidation to iron oxide. This mechanism can reduce the oxygen concentration in the headspace to less than 100 ppm (Sanjeev and Ramesh 2006). Nonmetallic oxygen scavengers such as ascorbic acid, ascorbate salts, catechol, glutathione, enzymes (e.g., glucose oxidase and ethanol oxidase), and unsaturated fatty acids (e.g., oleic and linoleic acids) are used safely with packaging materials contacting with foods. These materials are usually nontoxic, but have less oxygen scavenging capacity than metallic scavengers (López-Rubio et al. 2008; Day 2008; Oms-Oliu et al. 2008a). Zero₂ is a commercial polymeric material that is inactive until activated by UV light. The extrusion process in the manufacturing of the package will not harm its activity. It can fabricate an oxygen scavenger layer in a multilayer structure that acts to remove the oxygen after postsealing UV activation (Day 2008). Oxyguard Tray® is another commercial example of a multilayer oxygen scavenger. This tray consists of a heat-sealable layer used for sealing the cover/lid followed by an inner oxygen absorbing layer, a barrier layer to prevent atmospheric oxygen from reaching the absorbing layer,
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and a strong outer layer used for package support and protection (López-Rubio et al. 2004). Edible coatings containing an oxygen scavenger have also been developed such as candelilla wax coating incorporating aloe vera and ellagic acid as antioxidants. This coating system prevents weight loss and changes in the pH, freshness, and color of fresh-cut fruits stored at 5°C for 6 days (Saucedo-Pompa et al. 2007).

It is important to notice that the barrier properties of the packaging materials to gases are highly affected by temperature and humidity. Changing the barrier properties of the packaging materials with temperature abuse (e.g., temperature oscillations occurring during transportation) is one of the important problems that degrade the product quality because the changes in the deterioration rate, in particular, the respiration, are faster than the changes in the film’s permeability. Packaging materials that are capable of changing their gas permeabilities with respect to the storage temperature were developed. Breath Way™ is a packaging system that alters gas permeability in response to temperature, and creates an optimum gas concentration inside the package (Poças et al. 2008). Gas permeable film or so-called breathable packaging is a commercial package that allows gas exchange between the internal and external atmospheres of the package. A three-layer breathable film that has high gas permeability was also developed to extend the shelf life of fresh vegetable salads (Ahvenainen 1996).

Humidity Absorbers

It is important to control the atmospheric relative humidity during the storage of fresh fruits and vegetables for maintaining high quality. Fruits and vegetables produce water by transpiration. The rate of transpiration is temperature dependent and also varies between day and night (Chakraverty 2001). The amount of moisture in a food package is a net result of product transpiration and the package permeability to water vapor. Minimal processing of fruits and vegetables may increase the relative humidity inside the package due to the increased water release of cut tissue. Excessive relative humidity inside the package promotes fungal and bacterial growth, while excessive water loss from packaged fruits and vegetables leads to shriveling and loss of quality and sensory properties (Rico et al. 2007).

Papers and desiccant pads are used to wrap one or more fruits (Ozdemir and Floros 2004). Toppan Sheet™, Thermarite™, and Luquasorb™ are examples of commercial absorption sheets and blankets (Day 2008). Film perforations, that is, microholes of a defined number and size, are another approach to control moisture around fruits and vegetables. Composite polymeric films with high vapor permeabilities and boxes with large openings on the sides and bottom have been developed. However, they do not function effectively enough to prevent the deterioration of quality due to high release of water and uneven distribution of moisture inside the container. Dijkink et al. (2004) developed a novel system for maintaining relative humidity around 90.5 ± 0.1% inside a storage room of bell peppers. After 3 weeks of the controlled atmosphere experiment, the system reduced fungal development without increasing shriveling. Both weight loss and shriveling were found to be functions of vapor pressure.

Various moisture scavengers can modify package humidity, including silica gel, natural clays (e.g., montmorillonite), calcium oxide, calcium chloride, and modified starch (Day 2008). Pitchit™ consists of a layer of humectants sandwiched between two layers of polyvinyl alcohol (PVA) and is used to wrap high moisture foods. CSIRO
developed a moisture control system used in the form of a liner inside any box to control humidity (Ozdemir and Floros 2004). Antifogging films allow the consumer to clearly see the product through the packaging films, which incorporate humidity absorbers, hydrophilic liners, or microperforations in the film. These films are usually used for respiring products such as fresh-cut fruits and vegetables to reduce the internal vapor pressure and prevent water condensation (Ozdemir and Floros 2004).

**Ethylene Absorbers**

Ethylene (C$_2$H$_4$), the growth-stimulating hormone, is responsible for initiating fruit ripening especially in the climacteric fruits but has a negative effect after complete maturation. During the senescence stage, ethylene causes the increase in fruit respiration rate and textural and color changes in climacteric fruits more than in nonclimacteric fruits. It also accelerates chlorophyll degradation in leafy vegetables (Toivonen and Brummell 2008). Therefore, controlling the concentration of the ethylene in the package headspace extends the shelf life (Martinez-Romero and Bailén 2007). Adequate ventilation has been used traditionally to alleviate ethylene concentration in the headspace using open boxes for fresh fruits and vegetables (Terry 2008).

Potassium permanganate is the most extensively studied and commercially used ethylene absorber. It removes the exogenous ethylene from the atmosphere surrounding the produce by oxidizing it to ethylene glycol, which later decomposes to carbon dioxide and water (Martinez-Romero and Bailén 2007). Both the carbon dioxide and water produced have a secondary effect on extending the shelf life. Carbon dioxide reduces the fruit respiration rate and blocks the synthesis of endogenous ethylene. High concentration of water vapor inside the package lowers the transpiration rate (Day 2008; Sammi and Masud 2008). Potassium permanganate cannot be used in contact with food products due to its toxicity, but it is usually imbedded in silica that is incorporated inside devices (sachets, films, or filters) that have a high permeability to ethylene. The ethylene diffuses through these devices and is quickly absorbed by potassium permanganate. Potassium permanganate can also be impregnated into polymeric films used to wrap fruits and vegetables. Sammi and Masud (2008) found that plastic films incorporated with potassium permanganate were effective in delaying tomato ripening as determined by color development. The shelf life and quality properties were improved for up to 84 days. Howard et al. (2006) reported that potassium permanganate removed ethylene effectively from the headspace of packaged diced onions and reduced the levels of sulfur volatiles and carbon dioxide produced by the produce. These diced onions were kept at 2°C for 10 days without spoilage. Palladium (Pd) and light-activated titanium dioxide (TiO$_2$) are metal catalysts used to accelerate the oxidation reaction of potassium permanganate, thus increasing its adsorption capacity about 6-fold higher (Martinez-Romero and Bailén 2007).

Activated carbon and zeolites are included in MAP films and small sachets (Bailén et al. 2006). The use of activated carbon with palladium chloride (as a catalyst) prevented the accumulation of ethylene in the headspace of packaged tomato, delayed the deterioration of the quality parameters (including weight loss, color, and fruit firmness), and improved sensory properties (Bailén et al. 2006). The same treatment also effectively reduced the rate of softening of kiwifruits and chlorophyll loss in spinach leaves stored at 20°C (Abe and Watada 1991). Various dispersing materials (clays,
zeolites, and carbons) were incorporated into commercial plastic films and utilized for fruit and vegetable packaging. Commercial examples are Evert-Fresh (USA), Peak-fresh (Australia), Orega (Korea), and Bio-fresh (Israel) (Scully and Horsham 2007). The use of 1-methylcyclopropane (1-MCP) is also commercialized. 1-MCP blocks the ethylene receptors in plant tissues and prevents the activity of ethylene (Scully and Horsham 2007).

Carbon Dioxide Emitters

The high level of carbon dioxide in the headspace of packaged fruits and vegetables retards the growth of aerobic microorganisms and reduces the respiration and senescence processes (Chakraverty 2001). The use of a carbon dioxide emitting package should not induce anaerobic metabolism when carbon dioxide presents at excess amounts. Therefore, the film permeability and the respiration rate should be taken into consideration.

Most carbon dioxide emission processes are activated by moisture that usually comes from packaged foods (Ozdemir and Floros 2004). Therefore, this activation mechanism may have limited applications with intermediate moisture foods but may work well with high moisture foods such as meats, fish, and minimally processed fruits and vegetables. This technology uses the reaction of sodium bicarbonate and hydrating agents such as water with acidulates to produce carbon dioxide (Ozdemir and Floros 2004). One application of this technology is that developed by SARL Codimer (Paris, France) called Verifrais™ package. This package extends the shelf life of fresh meats and fish. It is a standard MAP tray that has a perforated bottom under which is a porous sachet containing sodium bicarbonate and ascorbate. The emission process is achieved by the juice leached from the packaged food (Day 2008).

Antimicrobial Films and Coatings

Surface microbial spoilage is the primary cause of shelf-life termination of fresh-cut produce (Jay et al. 2005). Uncontrolled harvesting, transportation, packaging, and processing operations are the main reasons for microbial contamination (Erdoğrul and Şener 2005). Although freshly harvested fruits and vegetables contain mixed initial flora of coliforms especially Escherichia coli, lactic acid bacteria, Pseudomonas, and Erwinia, yeasts, molds, and Pseudomonas are the primary causes of the spoilage of fresh-cut fruits and vegetables, especially when stored aerobically under refrigeration (Ahvenainen 1996; May and Fickak 2003). The cutting process involves breaking down the natural exterior barrier of produce, which leads to the release of nutrients to microorganisms (FDA 2007). It was reported that 26% of all outbreaks in the United States between 1996 and 2006 were associated with consumption of contaminated fresh-cut produce (FDA 2007).

Adding antimicrobial agents such as hydrogen peroxide, peroxyacetic acid, ozone, chlorinated water, and plant extracts into the washing water demonstrates effective antimicrobial activity but is not successful for the total elimination of the microbial spoilage on fruit surfaces (Akbas and Ölmèz 2007; Alegria et al. 2009; Win et al. 2007). This direct application of antimicrobial agents has a limited effectiveness because most agents interact quickly with food compounds and reduce their effectiveness (Mehyar et al. 2006). Antimicrobial active packaging has controlled release of antimicrobial
agents and keeps the surface concentration of the agent above the MIC (minimum inhibitory concentration) of the target microorganisms (Han 2003; Suppakul et al. 2003). This could be achieved by choosing packaging materials and proper antimicrobial substances with structural compatibility. The antimicrobial substances should be of materials with intermediate polarity (hydrophilicity/hydrophobicity) without strong interaction with the packaging materials or quick release from the packaging materials as a result of being binned or repelled, respectively (Han and Floros 2000).

The antimicrobial agent in active films may either migrate to the food surface or bond chemically to the surface of the film (called immobilized films) (Han 2004). Blending antimicrobial substances into packaging materials or using multilayer films, in which only one layer is impregnated with antimicrobial substances, improved microbial stability of raw chicken, apple cuts, and strawberry (Ozdemir and Floros 2004; Rojas-Graü et al. 2007).

In the case of edible coating systems, the coating materials should be colorless, tasteless, and stable to high relative humidity, and made of generally recognized as safe components (Krochta and De Mulder-Johnston 1997). The coating should also adhere well and spread uniformly on the food surface (Mehyar et al. 2006; Ribeiro et al. 2007). The effect of antimicrobial packaging materials and edible coatings on produce shelf life is still under investigation. Rojas-Graü et al. (2007) found that lemongrass, oregano, and vanillin essential oils in alginate coatings reduced the growth of psychrophilic aerobes, yeast, and molds on apple cuts by more than 2 log cfu/g. Natamycin in a bilayer coating of chitosan significantly decreased fresh melon decay caused by two strains of spoilage fungi (Cong et al. 2007). Clove, cinnamon, and oregano essential oils totally inhibited the growth of Candida albicans, Aspergillus flavus, and Eurotium repens in vitro when they were used in paraffin coating of paper packaging materials and completely protected strawberry from visible fungal growth during storage for 7 days at 4°C (Rodriguez et al. 2007). Chitosan is a natural antimicrobial compound and is capable of forming stable coatings on fresh-cut papaya that suppress microbial growth (González-Aguilar et al. 2009).

Combinations of more than one active function in a single packaging have been applied to fresh produce. Combinations of oxygen scavengers, carbon dioxide emitters, and antimicrobial agent releasers or with ethylene absorbers in microperforated films have been found more effective than a single system (Ozdemir and Floros 2004). It was concluded that the higher effectiveness of the combinations could be a result of controlling multiple deterioration processes at the same time. Ever-Agless™ type E, Fresh Lock™, and Freshilizer™ type CV are examples of dual-action carbon dioxide and oxygen scavengers, and Agless™ type G and FreshPax® type M are dual-action oxygen scavengers and carbon dioxide emitters (Day 2008). Fresh Bags® consist of environmentally friendly materials that absorb ethylene, carbon dioxide, ammonia, and moisture (Anonymous 1995).

Recently, antimicrobial gas releasers were developed and commercially utilized. Allyl isothiocyanate in cyclodextrin matrix in inner liners of plastic films is released to the headspace of the package after triggering by moisture. This system was practically tested by American Air Liquide and its Japanese partner against various pathogenic bacteria. Sulfur dioxide releasing pads were commercialized by Quimica Osku (Chile), and sulfur dioxide releasing plastic films were developed by Food Science Australia
from a mixture of organic acid and calcium sulfite (Steale and Zhou 1994). Chlorine
dioxide releasing films are commercially available for the disinfection of packaged
fruits and vegetables (Scully and Horsham 2007; Han and Floros 2007). Han and
Floros (2007) listed commercial active packaging technologies and patents including
antimicrobial packaging systems in their report.

Intelligent Packaging Technology for Fruits and Vegetables

Time–Temperature Integrators
Temperature is definitely the most influential factor for respiration, microbial, and
chemical reactions that affect plant metabolic activity (Erturk and Picha 2008). Precise
control of temperature can retard the deterioration process of fruits and vegetables. As
a general rule, the respiration rate of plants increases nearly twice for each increase
of 10°C (Atkin and Tjoelker 2003). Temperature controlling packaging could be a
good application to prevent temperature changes in the produce. A time–temperature
integrator (TTI) is used as an indicator of product safety and quality (Taoukis 2008).
The TTI reaction is highly accurate and precise, and is based on simple irreversible
mechanical, chemical, enzymatic, or microbial changes (Ozdemir and Floros 2004;
Taoukis 2008). For effective application of TTI, the TTI response should exactly mimic
the quality deterioration reaction that usually terminates the shelf life of the produce.
Systematic kinetic models for both the TTI reaction and quality deterioration reaction
of each particular produce were developed and used for the prediction of the shelf life
in the market (Vaikousi et al. 2008). Most TTIs are in the form of self-adhesive labels
that can easily adhere inside the package or on the product, and they must satisfy some
practical requirements such as easy activation by exposure to UV light, as an example.
TTI has an important application in highly perishable fresh fruits and vegetables, in
particular fresh-cut salads to prevent rapid deterioration when the storage temperature
fluctuates out of the optimum temperature range (Taoukis 2008).

Gas and Volatile Indicators
Freshness of fruits and vegetables can be determined by gas and volatile material
measurements in the headspace. This indicator detects volatile metabolites generated
by the produce such as oxygen, carbon dioxide, diacetyl, amines, ethanol, and hydro-
gen sulfide (Brody et al. 2001; Smolander 2003; Han and Floros 2007; Poças et al.
2008). Ethanol concentration in package headspace can be measured by an enzymatic
reaction based on chromogenic substrates from which the color indicates the degree of
fermentation (Smolander 2008). Bromothymol blue and methyl red are chromogenic
indicators of fruit and vegetable fermentation. They react with carbon dioxide produced
by fermentation, and the color density is used to determine the degree of fermentation
(Smolander 2008). Microbial quality indicators that are based on carbon dioxide pro-
duction have limited applications in fresh fruits and vegetables because a large amount
of carbon dioxide is produced by respiration, which masks the amounts produced by
microbial metabolism (Smolander 2008). Indicators based on aroma measurements
have been also developed to monitor the degree of fruit fermentation. ripeSense® is a
polymeric freshness indicator that was developed by Ripesense Ltd. It is designed to
sense the aroma compounds given off by the fruit. By matching the color of the sensor
with a reference color standard, a customer can choose the fruit with the required ripening stage (Poças et al. 2008).

Radio Frequency Identification (RFID)
This technology uses radio waves for product identification and traceability. It includes incorporating an RFID tag into the package, from which a proper sensor is used to collect data about the item’s status. The data stored in tags are activated by the sensor, which is then transmitted to a reader for decoding and processing by a computer system (Brody et al. 2008; Yam et al. 2005). The data are about the product identification (e.g., description of the label content) and its history (e.g., how long the product took to move though the supply chain, its temperature, pressure, humidity, and gas leakage) and can be collected at any point during processing and distribution. The information obtained from data analysis can be used for judgment of the produce status such as traceability in the case of outbreaks of foodborne infections. A new cold chain monitoring service system using the RFID system was developed to monitor fresh produce. This system, which is called X-Track™, is comprised of an RFID label connected to TTI that continuously monitors and stores data about produce temperature and time of exposure. The data are then uploaded via an RFID reader to secure base servers from which the customer can retrieve them anywhere and anytime (Poças et al. 2008). Rodrigues and Han (2003) reported the collective list of various commercial intelligent packaging systems and potential applications.

Legislation on Active and Intelligent Packaging
Active and intelligent packaging has a limited usability in Europe compared to that in the United States, Japan, and Australia. This is due to several reasons including higher legislative restriction, lack of knowledge about the efficacy of these systems, low consumer acceptance, cost, and environmental consequences (Jong and Jongbloed 2004). Most active and intelligent packaging systems consist of two parts, the active or intelligent ingredients and the carrier. In Europe, the active or intelligent ingredients should be authorized as food additives before commercial use. Therefore, the active or intelligent ingredients must comply with Directive 89/107/EEC for the authorization of food additives to be used in foodstuff intended for human consumption (Council Directive 89/107/EEC). In the United States, these active agents could be classified as food additives or food contact substances case by case. The new packages should also undergo risk and safety assessments prior to their authorization. The authorization of food additives is based on agreed scientific and technical criteria laid down by the Council of the European Communities and the Scientific Committee (Council Directive 89/107/EEC). This means only the substances recognized as food additives or food ingredients may be released to the market after authorization. The legislation also requires proper labeling of all food ingredients and additives through framework Regulation 1935/2004 (Regulation (EC) No. 1935/2004). Article 3 of this
regulation requires that the food contact material must be sufficiently inert or should not transfer any of its constituents to foodstuff in quantities that could endanger human health or bring about an unacceptable change causing deterioration of its organoleptic characteristics (Regulation (EC) No. 1935/2004). Also Articles 3 and 4 of this regulation state that active and intelligent substances should also be distinguished from the materials (e.g., wooden barrels) that traditionally used to unintentionally release their natural ingredients.


Conclusions

Although it appears that active and intelligent packaging technologies are efficient in controlling the deterioration reactions of fresh-cut fruits and vegetables, applications of active and intelligent packaging in fruits and vegetables are still in their infancy. Extensive research is required to promote the usability of active and intelligent packaging as effective tools to improve the quality and safety of fresh-cut fruits and vegetables.

References


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