

# New Film Technologies for Horticultural Products

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ADDITIONAL INDEX WORDS. modified atmosphere packaging, fresh-cut, storage, oxygen, carbon dioxide

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**SUMMARY.** Modified atmosphere packaging (MAP) is a technology that is currently used for most packaged salads and fresh-cut vegetables, and to a lesser extent, fresh-cut fruit such as cantaloupe (*Cucumis melo* L.), pineapple [*Ananas comosus* L. (Merr.)], and apple (*Malus × domestica* Borkh.). In addition, about 750 million lb (340,200 Mg) of strawberries (*Fragaria × ananassa* Duch.), raspberries (*Rubus idaeus* L.) and sweet cherries (*Prunus avium* L.) are distributed in MAP annually. The fresh produce packaging industry has developed new films to respond to increased produce consumption and changes in the use of film packaging within different produce marketing segments. The produce film industry sold 60 million lb (27,200 Mg) of film in 1994, and in 2000 it is forecasted to sell 110 million lb (49,900 Mg), an increase of 83%. The distribution of film usage has also changed since 1994 when film consumption patterns were as follows: 20% [12 million lb (5,400 Mg)] retail, 15% [9 million lb (4,100 Mg)] warehouse clubstores, and 65% [39 million lb (17,700 Mg)] food service. In 2000 it is projected that consumption patterns will be as follows: 25% [27.5 million lb (12,500 Mg)] retail, 20% [22 million lb (10,000 Mg)] warehouse clubstores, and 55% [60.5 million lb (27,400 Mg)] food service. These changes represent a 10% shift in film market segment usage patterns away from food service applications to an increase of 5% for each of the retail and warehouse clubstore segments.

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New packaging film technologies have addressed the need for changes in gas transmission characteristics or temperature responsiveness during produce distribution. However, most other new developments have addressed other issues, i.e., machineability, clarity, antifog, and printability of the films. In this overview of film technology developments, these latter improvements are addressed, since they impact the marketing of whole and fresh-cut produce.

The developments covered in this review are as follows.

## Passive MAP

Passive MAP is the technology of matching film OTR (oxygen transmission rate) to produce respiratory requirements with new film structures and produce types. Films used in this type of packaging system typically cannot compensate their OTR proportionally to changes in product respiration rate over a given temperature span, also called low temperature compensation.

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**MICROPERFORATED PACKAGING:** development of technologies to allow for laser-, heat-, or pin-applied perforations in films to increase film OTR characteristics. Perforated films have low temperature compensation, and a carbon dioxide/oxygen permeability ratio of about 1.0, which results in low to moderate oxygen (O<sub>2</sub>) levels with high (CO<sub>2</sub>).

**MICROPOROUS MEMBRANE PACKAGING:** expanded applications using a highly permeable membrane attached to a film package. Membrane packages have very high OTR with some types having moderate temperature compensation (less change in atmosphere levels during temperature abuse), and others having low temperature compensation. Some membranes may be selective for CO<sub>2</sub> transmission.

## Active MAP

Active MAP is gas-flushing and gas-scavenging technology by adding [e.g., nitrogen (N<sub>2</sub>), CO<sub>2</sub>] and/or removing (e.g., O<sub>2</sub>) gases during packaging or distribution.

## Manufacturing issues of film

Manufacturing issues of film improve machineability (operating efficiently on packaging machines), printability (accepting colorful graphics printed onto the film), sealability (ability of film pieces to hermetically adhere to one other), and puncture/abrasion resistance.

## Consumer issues

Consumer issues include improving consumer appeal of retail and clubstore packages. Characteristics that provide appeal are film clarity, gloss, antifog coatings (to reduce condensation), eye-catching printing, and resealable, easy-open packages.

## Cost issues

Cost issues take into account the cost to benefit ratio when selecting the type of MAP system for a certain value and size of commodity.

## Improving aroma of MAP systems with in-package additives

A company has developed an in-package odor-absorbing material that reduces the pungent odor of processed onions and other types of produce.

MAP can benefit fruit and veg-

etable storage and handling by providing atmospheres (decreased O<sub>2</sub> and increased CO<sub>2</sub>) that can slow down the degenerative processes of senescence (Zagory, 1995; Gorny, 1997) (Table 1). Specific modified atmospheres are attained by choosing a packaging film with an appropriate OTR. When an appropriate package is chosen, MAP provides the following benefits.

- Reduced, and optimized, level of O<sub>2</sub> in the package which slows respiration and aging and extends shelf life.
- Prevention of high respiration rates and rapid senescence rates of the produce, which would normally occur at atmospheric O<sub>2</sub> levels, and loss of visual quality due to enzymatic browning.
- Maintenance of aerobic respiration and prevention of anaerobic respiration which may lead to rapid deterioration and enhanced microorganism growth of the produce.

## Passive MAP: Matching OTR to produce requirements

OTR factors which need to be considered when designing a MAP system are construction characteristics of each film (polymer composition, film thickness, and layer ratio) and product factors such as optimal target atmosphere for that commodity, O<sub>2</sub> consumption rate, storage temperature, and produce volume/film surface area, package surface area, package void volume, printing, antifog coating, etc.).

General film performance requirements also must be considered such as assurance of appropriate heat seal strength and consistency, maintenance of abrasion and pinhole resistance, requirements for high clarity and gloss, good machinability, good printability, action as a moisture barrier, and antifog characteristics for retail applications.

As an example of film polymers available, Dow Chemical Co. (Midland, Mich.) manufactures resins which can be manufactured into monolayer, coextruded, or laminated films for use in fresh-cut produce packaging.

**LOW-DENSITY POLYETHYLENE (LDPE).** LDPE is the oldest type of polyethylene. It is manufactured in a high pressure, high temperature manufacturing process. Its molecular structure provides easy extrudability into film and good optical properties. It is frequently used in blends with LLDPE (linear low-

density polyethylene), but because it has poor mechanical strength, it is not generally used alone.

**LINEAR LOW-DENSITY POLYETHYLENE (LLDPE).** LLDPE provides excellent package abuse resistance and the proper OTR for many common salad mixes. It also provides good optical properties and sealability. It is the most widely used polymer in the flexible packaging of fresh-cut produce and other food products. LLDPE can be used alone or in blends with other materials. It can be extruded into a monolayer film or coextruded with other polymers to provide better combinations of physical properties. LLDPE is manufactured via reaction of ethylene and a comonomer such as octene, hexene, or butene using a coordination catalyst. It is most often manufactured using either a gas phase or solution process.

**ULTRA LOW-DENSITY POLYETHYLENE (ULDPE).** ULDPE resins are similar to LLDPE resins, but contain a greater amount of comonomer, which decreases the resin's density and crystallinity. This change increases OTR, improves sealability, improves optics, and improves abuse resistance, but decreases modulus or stiffness. ULDPE is frequently used in combination with other polymers to provide the right combination of properties (higher end of OTR range is possible).

**POLYOLEFIN PLASTOMERS (POPs).** POPs are manufactured using single-site catalysts. They provide superior sealability and optical properties, and higher OTR than other polymers used for fresh-cut produce packaging. POPs are frequently coextruded with LLDPE or ULDPE to improve overall package sealability and optics. Because POPs have lower melting points than LLDPE and ULDPE resins, they provide superior sealability and package integrity when used as the sealant layer (can have better sealing properties).

**ENHANCED POLYETHYLENE RESINS (EPES).** EPE resins provide molecularly designed combinations of properties in a single resin that can replace blends or coextruded films. They have OTR rates similar to LLDPE resins, and would be used in applications where a specific performance property improvement (such as dart impact) is required versus LLDPE.

The new catalyst and process technologies for the manufacture of polyolefins has supported the growth in sales of fresh-cut produce through im-

**Table 1. Extent of modified atmosphere packaging (MAP) use for selected USA and Mexican fruit in pounds. Sources: Transfresh Corp. (Salinas, Calif.), Stemilt Growers, Inc. (Wenatchee, Wash.), and XPEDX, An International Paper Co. (Purchase, N.Y.).**

Commodity and production area	Total shipment (million lb)	MAP shipment (million lb)	Extent of MAP use (%)
Strawberries			
California	900	660	73
Baja California (Mexico)	36	18	50
Florida	103	31	30
Raspberries (Calif.)	13.5	11.5	85
Blackberries (Calif.)	NA	NA	85 <sup>z</sup>
Blueberries (U.S.)	NA	NA	10 <sup>z</sup>
Cherries (N.W. U.S.)	102	25.5	25

<sup>z</sup>Estimates only for blackberries (*Rubus allegheniensis* L.H. Bail.) and blueberries (*Vaccinium angustifolium* Ait.).

improvements in package design and performance (J.J. Wooster, personal communication). Resins made from single-site catalysts exhibit excellent molecular uniformity; they have narrow molecular weight distributions and narrow comonomer distributions. This molecular uniformity provides a combination of performance properties (more uniform OTR control and better sealing) not achievable in conventional polyethylene resins such as LLDPE. One example of the new generation of materials are AFFINITY polyolefin plastomers, made by Dow's INSITE technology (Dow Chemical Co., Midland, Mich.). AFFINITY polyolefin plastomers provide a combination of properties ideally suited to their use in fresh-cut produce packaging. Useful properties include high OTR, low heat seal initiation temperature, high heat seal strength and superior seal integrity, high hot tack strength, excellent optical properties, excellent toughness, excellent flex-crack resistance, and no significant contribution to off-taste and odor. AFFINITY polyolefin plastomers can be easily coextruded with other resins to provide a superior combination of properties useful in the packaging, distribution, and marketing of fresh-cut produce. Dow's resin technology is only one example of resins that are available in the marketplace; another example of a resin vendor is Exxon Chemical Co. (Baytown, Texas).

Packaging for high-respiring produce (microperforated or microporous membranes)

To increase OTR above that of

film alone, microperforated (MPF) packages were developed. These package types provide higher OTR but by the addition of perforations using laser, flame, or mechanical technologies. This technology is good for high-O<sub>2</sub>/high-CO<sub>2</sub> applications, however it may result in damaging levels of CO<sub>2</sub>, especially under temperature abuse. Package atmospheres can be expected to change due to temperature abuse, since this package OTR and CO<sub>2</sub>R (CO<sub>2</sub> transmission rate) change much less than product respiration rates over a given temperature range (low temperature compensation). Package atmospheric modification is a result of gas diffusion rather than permeation.

Very high OTR applications may require the use of a microporous membrane. The first membrane commercially marketed was FreshHold (exclusively used by River Ranch Fresh Foods, Inc., Salinas, Calif.), an uncoated membrane that provides similar atmospheres and permeability CO<sub>2</sub>/O<sub>2</sub> ratio as MPF, and also has little temperature-compensating ability. FreshHold membranes typically have very high OTRs. Oxygen may be nonselectively diffusing through the membrane, rather than permeating.

Landec Corp. (Menlo Park, Calif.) developed a polymer-coated, moderately temperature-compensating, semi-permeable membrane called *Intellipac* technology, which can provide additional value to a produce package (see below).

Active MAP: Gas flushing and scavenging technology

Active MAP can be used with any of the above packaging systems, but it

is most effective when used in combination with permeable film packaging systems, since higher OTR and CO<sub>2</sub>R packaging systems allow rapid permeation of the gas flush through either the perforations or the permeable membrane. Even so, there are commercial applications of MAP that combine microperforated film with a gas flush. Commercial examples of active MAP systems currently being marketed are Air Liquide (Countryside, Ill.) and Transfresh Corp. (Salinas, Calif.). The gas flushing technologies from these companies extend shelf life by creating optimal atmospheres initially. The form of the active MAP may be a specific O<sub>2</sub>/CO<sub>2</sub> mixture, a N<sub>2</sub> flush, a vacuum pack, or a gas-scavenging technology. Active MAP is the most important for short-shelf-life fruit crops for which mold or decay is the limiting shelf-life factor (e.g., strawberries). Active MAP does not change the equilibrium atmospheres, and therefore, temperature abuse will still alter the preset atmospheres and may potentially create harmful conditions.

Manufacturing, consumer, and cost issues related to film packaging

Manufacturing issues that need to be addressed are machinability (handling on automated equipment), printability (laminated films print well and do not scuff), seal integrity, strength, slip (decreases frictional forces to avoid catching or snagging of film through machines), and modulus (stiffness must be sufficient for film handling on automated equipment). Cryovac Sealed Air Corp. (Duncan, S.C.), has concentrated on manufacturing issues related to high-speed packaging of fresh-cut produce (M.D. Hughes, personal communication).

Consumer issues of interest are the need for packages to have high clarity and low haze for consumer appeal, eye-catching gloss to show off printing, antifog properties for improved product visibility, ready-to-microwave packaging, and appealing crispness of the package.

Cost issues include the need to match the level of value-added packaging to the value of the commodity, consider the capital expense of packaging equipment (sealers, automated bag making equipment, gas flush systems, etc.), and weigh the MAP benefits

(maintenance of quality, extension of shelf life, etc.) against the associated materials and equipment costs.

The estimated relative order of cost of these different packaging types, from lowest to highest is: passive MAP (film alone) < active MAP < microperforated < membrane packaging. Comparing the cost of different packaging systems is difficult, because each produce packaging system is unique. For instance, it may be justified to use a more costly packaging system for 440 lb (200 kg) bulk packaging of cantaloupe fruit, although it may be hard to justify using the same packaging system for 44 lb (20 kg) of the same fruit. The comparison becomes even more complex when comparing high-value versus low-value commodities. Another factor that makes it difficult to compare costing of these packaging systems is that pricing is dynamic, due to manufacturing cost fluctuations and pricing due to market competition.

### Landec Corp.'s *Intellipac* breathable membrane

Landec Corp.'s (Menlo Park, CA) *Intellipac* membrane technology provides three advantages compared to conventional film packaging systems (Clarke and De Moor, 1997): it has very high O<sub>2</sub> permeability—the breathable membrane has a permeability that is 100 times that of a 0.001-inch (0.0254-mm) low-density polyethylene film; it has adjustable selectivity for CO<sub>2</sub> and O<sub>2</sub> by altering the polymer composition used to coat the membrane, thus it is possible to produce membranes with a CO<sub>2</sub>/O<sub>2</sub> permeability ratio from 3.0 to 12.0; and it has O<sub>2</sub> permeability that increases as temperature increases and, therefore, compensates for temperature abuse.

The first packaging application successes for Landec Corp. have been packaging of high-respiring commodities such as fresh-cut broccoli (*Brassica oleracea* var. *italica* Plenck.) and cauliflower (*Brassica oleracea* var. *botrytis* L.) florets. The other advantage of *Intellipac* packaging for these two commodities is that they are both injured by elevated CO<sub>2</sub> levels (cauliflower is much more sensitive than broccoli), with the symptoms of this injury being off-color and off-flavor development. Another MAP application for this technology has been the packaging of as-

paragus spears (*Asparagus officinalis* L.) spears, which provides for better texture, color, and flavor than conventionally bundled spears (Lange, 1999). Maintenance of flavor quality has also been demonstrated by this technology for both fresh-cut cabbage (*Brassica oleracea* var. *capitata* L.) and strawberries. *Intellipac*-stored samples had levels of ethanol (and ethyl acetate in the case of strawberries) that were similar to fresh samples, whereas the conventionally packaged samples (polybag for cabbage and perforated film for sealing to trays for strawberries) had levels of these fermentative products that were 7 times those of the fresh sample. The other target for this technology has been with fresh-cut products that are challenged by moderate temperature abuse (breaks in the cold chain) during distribution and retail shelf life. Nevertheless, *Intellipac* packaging is not a substitute for good temperature control!

Future developments at Landec Corp. may include commercial application of case and bin liners with breathable membranes.

### Fresh addition packaging's odor-absorbing compound

Another progressive fresh-cut MAP company is Fresh Addition Packaging, Inc. (Vancouver, B.C., Canada). This company has developed a clay absorbent sachet that absorbs off-odors of produce (e.g., fresh-cut onions (*Allium cepa* L.)). This technology retains characteristic aromas of the product while absorbing sulfur-containing, odor-active compounds (Toivonen, 1999). By scavenging volatiles that contribute to development of undesirable aroma, this technology extends shelf life by retaining processed onions in a fresh-tasting state.

### The future of film technology

Some shortcomings of MAP, which warrant further development are the need for: 1) higher moisture vapor transmission rate (MVTR) films to reduce the RH to <100% (for some commodities, e.g., whole cantaloupe fruit), and 2) better sealing quality of case, bin and pallet packages.

Future MAP research and development should include 1) biosensors

to detect ethanol (or other fermentative metabolites, e.g., ethyl acetate in strawberries); 2) aroma-sensitive packages that respond to positive aromas (e.g., retain cantaloupe aroma volatiles in fresh-cut product) and negative aromas (e.g., reduce strong onion odors that contaminate surrounding products); 3) fungicide-impregnated films (reduction and/or delay of surface mold development at the moist film interface); 4) more efficient absorbent packages (e.g., minimize the amounts of unbound ethylene and water that can affect the produce, or regenerate MAP after opening and resealing the package possibly by use of a O<sub>2</sub> scavenger); and 5) maximized ratio of CO<sub>2</sub> to O<sub>2</sub> permeability for commodities that are sensitive to high CO<sub>2</sub>.

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