Modified Atmosphere Packaging—Toward 2000 and Beyond

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SUMMARY. Rapid expansion of modified atmosphere packaging (MAP) for horticultural produce has occurred during the last 10 years, especially for fresh cut (minimally processed) products, but limitations to further expansion reside in both responses of products and available technology. We introduce the workshop on Modified Atmosphere Packaging—Toward 2000 and Beyond by reviewing the current status of MAP technology for fresh and minimally processed products, highlighting research needs and future advances, and providing a list of selected references on MAP published since 1989.

Modified atmosphere packaging (MAP) requires little introduction to any reader of the postharvest literature. The concept of using polymeric films that will allow development, and / or maintenance of atmospheres other than air, dates from the first availability of plastics. However, commercial utilization of MAP for storage and transportation of horticultural products has been limited to a few commodities for reasons that are described below. However, in recent years, a rapid growth of MAP for preservation of fresh cut (minimally processed) products has occurred (Lange, 2000). MAP is especially important for these products because of their greater susceptibility to water loss, cut surface browning, higher respiration rates, enhanced ethylene biosynthesis and action, and microbial growth (Gorny, 1997). MAP, for example, has allowed marketing of value added produce such as broccoli florets (*Brassica oleracea* L. Italica Group) and asparagus tips (*Asparagus officinalis* L.) (Lange, 2000).

The use of MAP for both whole and fresh cut products can be restricted for a number of reasons.

- The unavailability of appropriate films that provide safe modified atmospheres (MAs), especially under abusive temperature conditions that can occur in the handling chain. Packages that provide safe atmospheres at one temperature may result in anaerobic conditions at higher temperature (Clarke and DeMoor, 1997).

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• The expense of using MAP technology, both on the basis of film cost and on the need for modifications to packing line systems. These expenses normally fall on the producer / processor and unless costs are recovered, or application of MAP provides penetrations of markets that were previously unavailable, the use of MAP will result in reduced profit margins. For example, use of MAP permits sea freight of persimmons (*Diospyros kaki* L) from New Zealand to Japan (MacRae, 1987), but can rarely be justified on fruit condition alone for export of apples (*Malus domestica* Borkh.) with lower profit margins in the marketplace (Watkins et al., 1998).
• Problems associated with maintaining package integrity during storage and transport operations. The plastic must be flexible and easy to use, but strong enough to survive normal handling operations.

However, the time periods for storage required for cut produce are generally shorter than for whole products, leading to shorter exposure times to atmospheres that might injure products over longer time periods. Also, quality control factors, such as temperature, are more consistently applied because the products tend to be high value, and because of heightened concern about food safety. Therefore, the growth of MAP usage for cut produce is expanding rapidly. Advances in film technology are occurring, but it is also the responses of the commodities that are critical. It can be argued that in some cases it is less the limitation of technology than the ability of the commodities to withstand the technology that is limiting. Therefore, the Postharvest Working Group sponsored a workshop at ASHS-99 to consider the future of MAP. We have taken two approaches. First, in this paper, we briefly review the current applications of MAP technology for fresh and minimally processed commodities, and then Diana Lange outlines new film technologies for horticultural commodities. Second, Randolph Beaudry and Chris Watkins review the responses of horticultural commodities to oxygen (O_2) and carbon dioxide (CO_2), respectively, and then Jim Mattheis and John Fellman review the effects of MAP on aroma and other quality attributes of horticultural commodities. At the workshop, Tom Hankinson of Pure Produces (Worcester, Mass.) outlined interactions between MAP and microbiology of minimally processed fruit and vegetables , but his paper is not reported in these proceedings.

Current applications of MAP technology for fresh and minimally processed products

MA can be created inside a package either passively through product respiration or by actively by replacing the atmosphere in the package with a desired gas mixture. With commodity-generated or passive MA, if product and film permeability characteristics are properly matched, the desired MA can passively evolve within a sealed package through consumption of O_2 and production of CO_2 by respiration. The gas permeability of the selected film must allow O_2 to enter the package at a rate offset by the consumption of O_2 by the commodity. Similarly, CO_2 must be vented from the package to offset the production of CO_2 by the commodity. Furthermore, the desired MA must be established within 1 to 2 d without creating anoxic conditions or injuriously high levels of CO_2 that may induce fermentative metabolism.

Because of the limited ability to regulate a passively established atmosphere, actively establishing the atmosphere is becoming more preferred. This can be done by pulling a slight vacuum and replacing the package atmosphere with the desired gas mixture. This mixture can be further adjusted through the use of absorbing or adsorbing substances inside the package with the respiring commodity that scavenge O_2, CO_2, and / or ethylene (C_2H_4). Although active establishment implies some additional costs, its main advantage is that it ensures the rapid establishment of the desired atmosphere. Ethylene absorbers can help delay the climacteric rise in respiration and associated ripening for some fruit. Carbon dioxide absorbers can prevent a buildup of CO_2 to injurious levels, which can occur for some commodities during passive modification of the package atmosphere. Superatmospheric O_2 levels (>21%) may be used in combination with fungistatic CO_2 levels (>15%) for a few commodities that do not tolerate these elevated CO_2 atmospheres when combined with air or low O_2 atmospheres. There is no evidence supporting the use of argon, helium, or other noble gases as a replacement for N_2 in MAP of fresh produce.

Many types of plastic films are available for packaging, but relatively few have been used to wrap fresh produce. Low-density polyethylene, polyvinyl chloride, and polypropylene are the main films used to package fruit and vegetables. Polystyrene has been used, but polyvinylidene, and polyester have such low gas permeabilities that they would be suitable only for commodities with very low respiration rates. However, perforating these films can expand their use to many commodities. Recent advances in the technology of manufacturing polymeric films have permitted tailoring films for specific gas diffusion needs of some fruit, vegetables, and their products. MAP is most commonly used for fresh-cut (minimally processed) fruit and vegetables and for highly perishable, high value commodities, such as cherry (*Prunus avium* L.), fig (*Ficus carica* L.), raspberry (*Rubus idaeus* L.), and strawberry (*Fragaria ×ananassa* Duch.).

Benefits of film packaging, other than creation of MA conditions can include maintenance of high relative humidity and reduction of water loss; improved sanitation by reducing contamination of the products during handling; minimized surface abrasions by avoiding contact between the commodity and the material of the shipping container; reduced spread of decay from one produce item to another; use of the film as carrier of fungicides, scald inhibitors, ethylene absorbers, or other chemicals; facilitation of brand identification and providing relevant information to the consumers.

In many cases the benefits of using MAP relate more to one or more of these positive effects than to the changes in O_2 and CO_2 concentrations within the package. In contrast, the negative effects include slowing down cooling of the packaged products and increased potential for water condensation within the package, which may encourage fungal growth.

The design of modified atmosphere packages requires knowledge of mass transport properties of polymeric films and the respiration rates of fresh produce placed inside the packages. Mathematical models are useful in determining the changes in gas concentrations in a package caused by the respiring products inside the package

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during storage. During the past 10 years several mathematical models have been proposed and tested, but few of them are used commercially. However, researchers (at public and private institutions) have added valuable information on the following six topics, which were identified under "Future Research Needs" in the review article by Kader et al. (1989).

- Most data on film permeability are generated at a single temperature and often at very low relative humidity. The responses of film permeability to temperatures between 0 °C (32 °F) and 20 °C (68 °F)and to relative humidities between 85% and 95% must be determined.
- More information on the respiration rates of fresh commodities in MA must also be generated. For many commodities, respiration rates in air and in a single CA are available, but for very few is information available in several CA or MA conditions.
- The additive effects of reduced O_2 and increased CO_2 on respiration and C_2H_4 production merit further investigation to establish some gen-

eral relationships.

- There is evidence for some fruit and vegetables that exposure to a given atmosphere can affect their respiration and C_2H_4 production rates when subsequently transferred to air or another MA condition. Since MAP will expose a commodity to a continuum of changing atmospheres until equilibrium is achieved, more information is needed on how this residual effect of MA modifies the predicted behavior from steady-state experiments.
- Changes in respiratory quotient in response to changing atmospheres could have a great effect on evolving atmospheres inside packages and so should be studied further.
- Additional information is needed on the resistance of fruit and vegetables to diffusion of O_2, CO_2, and C_2H_4 under different atmospheric and temperature conditions.

A list of selected references published since 1989 is included in Table 1. Today we have a much better understanding of the interactions of temperature, O_2 and CO_2 concentrations, film permeabilities, use of microperforations, and gas diffusion resistance of many commodities. This has resulted in decreased hit-and-miss attempts at identifying a suitable package for each product and increased use of a more rational selection of packaging materials using mathematical models. Products may be packaged in flexible polymeric film or in a rigid plastic container with gas diffusion window(s) as a consumer package, foodservice package, shipping container, and / or pallet cover.

Use of MAP is likely to continue to increase with the increase in number and range of products from fresh-cut (minimally processed) vegetables and fruit. The second most important application is with CO_2-tolerant (in the presence of various O_2 concentrations) fruit, vegetables, and their products for control of pathogens by CO_2-enriched atmospheres. Use of superatmospheric O_2 concentrations may reduce the negative effects of elevated levels of CO_2 without reducing its fungistatic and bacteriastatic effects.

Further advances are anticipated in the technology of polymeric films with greater batch-to-batch uniformity and change in permeability in response to temperature. Additional improvements are needed in incorporating effective O_2, CO_2, and / or C_2H_4 absorbers into the packaging material and in selecting "sense and adjust as needed" mechanisms. Such advances will require greater cooperation and coordination among research and development personnel in private and public sectors to minimize duplication of efforts. An interdisciplinary approach is essential to success in achieving the goals of MAP technology as a tool in maintaining quality and safety of fresh intact and minimally processed products.

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