Modified Atmosphere Packaging Design for Fruits and Vegetables

Rahul Kumar Anurag, Sandeep Mann Swati Sethi and Yogesh Kalnar

ICAR-CIPHET, Ludhiana-141004, Punjab

Modified atmosphere packaging (MAP) of fresh fruits and vegetables relies on modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the respiration of the product and the transfer of gases through the packaging, that leads to an atmosphere richer in CO_2 and poorer in O_2. This atmosphere can potentially reduce respiration rate, ethylene sensitivity and production, decay and physiological changes, namely, oxidation (Kader, Zagory & Kerbel, 1989; Saltveit, 1993). Produce physiology, more specifically, postharvest produce physiology, including respiration, senescence, transpiration (or water loss), and environmental stress responses, as well as produce biochemistry, such as ethylene synthesis, enzymatic browning, chlorophyll degradation, metabolism of aroma-active volatiles, and nutrient degradation, directly determine the shelf life and quality of fresh-cut fruits and vegetables stored under modified atmosphere packaging (MAP). Respiration is an essential physiological process that keeps the cells and organism alive or fresh for produce after being freshly cut. In addition, respiration has been hypothesized to be responsible for senescence and/or deterioration of postharvest fruits and vegetables (Kader 1986). In climacteric fruits, the increase in respiration (or CO_2 production) rates coincides with ripening, softening, and/or color changing. During postharvest storage of fruits and vegetables, there generally is an inverse relationship between respiration rate and shelf life. For fresh-cut products either under MAP or air, respiration is the mostly measured physiological activity noted in the research. There have been tremendous efforts in the literature to use respiration rates of fresh-cut products for indicating quality changes, selecting packaging materials, and predicting equilibrium and beneficial headspace O2 and CO_2 contents (Jacxsens et al., 2000,). The plant hormone ethylene has different physiological effects on postharvest fruit and vegetable quality. It accelerates ripening of many fruits, senescence of leaves and flowers, rates of respiration, and changes of leaf and fruit pigments, such as banana, tomato, and broccoli.

Methods of Modified atmosphere packaging

Methods of atmosphere modification within a packaged food product can be sub-divided into two main categories: Active modification & passive modification. Several methods can be used to actively modify the gas atmosphere within the packaged product. This includes vacuum packaging, MAP, the use of gas or scavenger of oxygen, moisture absorbers, or CO_2 and ethanol emitters and of gas injection. In commodity-generated or passive modification, the product is modified as a result of the consumption of O_2 and generation of CO_2 through respiration of the product. Passive modification is commonly used to modify the gas atmosphere of packaged fruits and vegetables. However, in order to maintain the correct gas mixture within the packaged product, the gas permeability of the packaging films must be equal to rate of respiration of product, which allows O_2 to enter the package at a similar rate as respiration of product. This process is also known as equlibrium modified atmosphere packaging EMA. Similarly, CO_2 must be vented from the package to offset the production of CO_2 by the product. Failure to accomplish this gas balance might result in a depletion of O_2 and a buildup of CO_2 resulting in spoilage of products. MAP is simply as extension of vacuum packaging technology, which involves the evacuation of air followed by the injection of the appropriate gas mixture.

The objective of MAP design is to define conditions that will create the atmosphere best suited for the extended storage of a given produce and to minimize the period of time to achieve this atmosphere. A MAP system not properly designed may be ineffective or even shorten the storage life of a product. If the desired atmosphere is not established rapidly, the package has no benefit. For example, high perishable products may deteriorate before the recommended atmosphere is attained. If O_2 and/or CO_2 levels are not within the recommended ranges of O_2 and CO_2 concentrations the product may experience serious alterations and its storage life is shortened. It may even induce anaerobiosis, with the possible growth of pathogens and concomitant effects on product safety.

Respiration rate

Control of respiration is an important effect of atmosphere modification on post-harvest life of fruits and vegetables. High respiration rates are associated with rapid deterioration of the product. There are three methods for measuring respiration rates: the flow-through system, the closed system, and the permeable system. Design of a MAP system that will prolong the storage or shelf life of fresh product requires the mathematical equation for predicting the respiration rate at the various influencing factors. Thus, the respiration rate model is central to the design of MAP for fresh fruits and vegetables The live tissue of fresh fruits and vegetables respires and transpires. The respiration rate varies greatly among different species, and depends heavily on temperature. As a result, MAP of fresh produce requires a different approach as compared to other products. The main goal of modified atmosphere applied to fruits and vegetables is to minimize the respiration rate of the product. This includes suppressing the production of ethylene, a gas responsible for accelerating ripening and deterioration, and hastening the onset of senescence in fruits and vegetables.

On the other hand, the use of MAP techniques with fresh produce, especially fruits, has a few potential hazards. The complete elimination of oxygen from the package quickly results in anaerobic respiration, the production of ethylene, and, subsequently, a fast and dramatic deterioration of the product quality. This is normally due to the accumulation of acetaldehyde, ethanol, and organic acids, the development of off flavours, and, finally, the discoloration and the softening of the tissue.

The closed system method is more efficient for measuring respiration rates as a function of gas concentrations. This method involve monitoring the O_2 and CO_2 concentrations inside a closed jar contain in the product as a function of time (Haggar et al., 1992). The initial gas concentrations inside the jar are usually those of air, but other gas concentrations may also be used. As the product respires, the gas concentrations in the jar change with time - from high O_2 and CO_2 now CO_2 concentrations at the beginning to low O_2/high CO_2 concentrations toward the end.

Modified atmosphere package design methodology

Fruits and vegetables being respiring produce when stored in a package comprised of a plastic film, it serves as the regulator of O2 flow into the package and the flow of CO2 out. Assuming that there is no gas stratification inside the package and that the total pressure is constant, the differential equations of mass balance for O2 and CO2 in MAP containing a respiring product are (balance with N2):

These two first-order linear differential equations are useful in describing the unsteady state behaviour in passive MAP. When the accumulated term is zero, the above Equations1 and 2 are reduced to the steady state as

$$V_f \times \frac{d(y_{O_2})}{dt} = \frac{P_{O_2}}{e} \times A \times (y^e_{O_2} - y_{O_2}) - R_{O_2} \times M \qquad \text{Eq. 1}$$

$$V_f \times \frac{d(y_{CO_2})}{dt} = \frac{P_{CO_2}}{e} \times A \times (y^e_{CO_2} - y_{CO_2}) + R_{CO_2} \times M \qquad \text{Eq. 2}$$

$$y^e_{O_2} = y_{O_2} + \frac{R_{O_2} \times e \times M}{P_{O_2} \times A} \qquad \text{Eq. 3}$$

$$y^e_{CO_2} = y_{CO_2} - \frac{R_{CO_2} \times e \times M}{P_{CO_2} \times A} \qquad \text{Eq. 4}$$

The above equations describe the dynamic equilibrium behaviour of the MAP system, when the CO2 evolution rate equals the efflux rate of CO2 through the package and the O2 consumption rate equals the influx rate of O2 through the package. In most commercial package situations, steady state or dynamic equilibrium is approached within two days. For long storage of the product, the dynamic equilibrium behaviour is more important than the unsteady state behaviour. To use Equations 3 and4 as design equations, it is necessary to keep track of how many independent or design variables are available. As per Table1, there are a total of 11 variables: there are a total of 11 variables: RO_2, RCO_2 and M are associated with the product; PO_2 , PCO_2 are associated with the package; e and A are associated with the environment. Once the product and the temperature are selected, six out of the 11 variables are already decided: RO_2, RCO_2 from the respiration rate model as reported in the literature; yO2 and yCO_2 are assumed to be the optimum O_2 and CO_2 concentrations and y^eO_2 and y^eCO_2 are constant, i.e., 0.21 atm and 0.0003 atm, respectively. With six variables fixed and two equations to satisfy, there are only (11-6-2) = 3 design variables. That is, only three out of the remaining five variables (M, e, A, PO_2 and PCO_2) can be specified arbitrarily. Combining Equations 3 and 4 we get:

$$\frac{y^e_{CO_2} - y_{CO_2}}{y^e_{O_2} - y_{O_2}} = -\frac{RQ}{\beta}$$

Table 1. Variables used in designing modified atmospheric package

	Surrounding-related	y^e O2, y^e CO_2
Input variables	Package- related	A, e
	Commodity- related	M
Calculated variables	Package-related	PO_2 and PCO_2
	Commodity-related	RO_2 RCO_2
Response variables	System-related	yO_2, yCO_2

Where, RQ is the respiratory quotient and â is the permeability ratio, defined as RCO_2 /RO_2 and PCO_2/PO_2, respectively. For any packaging design, the product characteristics such as its weight, respiration rate, density and the optimum conditions for the best shelf life are needed for the mathematical calculations.

The appropriate final atmosphere is formed by the interplay between the respiration of the product (for respiring products), the initial atmosphere (air or gas mixture) and the gas transfer through the packaging material. The choice of an adequate packaging material is the key to achieve that appropriate atmosphere, and this will be dependent on:

1. gas and water vapour permeability
2. thickness of the packaging film
3. package surface area

$$\beta = \left(P_{CO_2} \big/ P_{O_2} \right)$$

The permeability ratio (β) of a film is the ratio of its permeabilities to CO_2 and O_2. The β value of a film is a predictor of the relative amounts of CO_2 and O_2 that will accumulate in the package.

i. Films with a high β value will allow CO_2 to escape the package relatively quickly, resulting in an atmosphere with low CO_2 and O_2 levels.

ii. Films with a low β values will not allow CO_2 to escape the package relatively quickly, resulting in an atmosphere with high CO_2 and low O_2 levels.

Most of the commercially available films have β values ranging from 3 to 6. A β value of 3 means that the film will allow CO_2 to exit the package 3 times faster than O_2 enters the package. Since polymeric films commonly have much higher CO_2 permeability than O_2 permeability (Table 2), the level of CO_2 that may be obtained inside the package is limited by the O_2 concentration. An important factor in determining the correct packaging material is the oxygen transmission rate (OTR). Packaging materials are classified according to their barrier properties to oxygen in to:

Table 2. permeability ratio (â) of different types of packaging film

Packaging Film	β value
Low density polyethylene, LDPE	6.3
Linear low density polyethylene, LLDPE	5.2
High density polyethylene, HDPE	6.0
Polypropylene, PP	5.6
Bi-oriented polypropylene, BOPP	5.4
Polyvinyl chloride, PVC	6.1
Polyvinyl chloride, PVDC	4.8
Polyethylene terephthalate, PET	
Unoriented	5.1
Oriented	4.9
Nylon 6	4.2
Nylon 11	4
Ethylene vinyl alcohol, EVOH	
32 mol % ethylene	31.0
44 mol% ethylene	30.0

1. low barrier (> 300 cc/m^2 day atm.)
2. medium barrier (50-300 cc/m^2 day atm.)
3. high barrier (10-50 cc/m^2 day atm.)
4. ultra high barrier (< 10 cc/m^2 day atm.)

Polymeric films used for MAP of fresh fruits and vegetables

Many of the films used in MAP, singly do not offer all the properties required for a modified atmosphere pack. To provide packaging films with a wide range of physical properties, many of these individual films are combined through processes like lamination and co-extrusion. There are several groupings in MAP films. Polyethylene is most commonly used to provide a hermetic seal and also as a medium of control for characteristics like anti-fogging abilities, peelability and ability to seal. Using polymeric films, MA packaging systems for products with low to medium respiration rates have to some extent been successfully developed. Products such as broccoli, mushrooms, leeks, etc exhibit very high rates of respiration such that conventional films can potentially over modify the pack atmosphere and thus result in fermentation. Accordingly, there has been a lot ofcommercial interest to develop films with high gas transmission. Films that have improved rates of gas transmission by virtue of their polymeric nature are usually blends of two or three different polymers, where each polymer of a blend performs a specific function such as strength, transparency and improved gas transmission to meet certain product descriptions. Furthermore, films can be laminated to achieve needed properties. Among this class are high (6–18%) ethylene–vinyl acetate content, low-density polyethylene (Elvax, DuPont, Wilmington, DE), oriented polypropylene laminates (OPP, BP Amoco, Lisle, IL), styrene butadiene block copolymer films (K-Resin, Phillips Chemical Company, Houston, TX) and ultra low-density ethylene octene copolymer films (Attane series, Dow Chemical Company, Midland, MI) and polyolefin plastomer octene copolymer films (Affinity series, DowChemical Company, Midland, MI).

Modified atmospheric packaging on different fruits and vegetables

Many plastic films have been in use for modified atmosphere packaging of varieties of produce (Table 3).

Micro-perforations for achieving optimal atmospheric conditions

Most commercial films do not provide adequate permeability to CO_2 to O_2 to achieve optimal concentrations inside typical packages for MA for fruits and vegetables. Atmospheres for products with high CO_2 and low O_2 requirements such as fruits and vegetables can be reached by using micro-perforated films. In micro-perforated films the micro-perforations are the primary route of gas exchange while in continuous films the polymeric material restricts the gaseous movement into or out of the package. Micro-perforated films can provide high OTRs since the ratio of CO_2 to O_2 is roughly 1, and they can mitigate the high/low concentrations of CO_2/O_2, respectively, which might occur in a continuous film packaging system for high respiration rate products. Increased weight loss is expected during postharvest storage for respiring products packaged in the currently available micro-perforated systems. The number, position, area and length of the micro-perforations will control the atmosphere inside the container. Micro-perforations can prevent condensation inside of the package and therefore, conditions favorable for microbiological growth and decay of the produce. Several methods can be used to microperforate packaging materials:

1. Cold and hot needle mechanical punches,
2. Electric spark and
3. Lasers.

Produce requirements are determined by laboratory testing produce packed in a variety of perforated films. The total flux needed by a fresh produce package to maintain a desired O_2 and CO_2 internal atmosphere is based on:

1. The respiration rate of the specific product,
2. The weight of the product,
3. The surface area of the package,
4. The storage temperature.

Table 3 Summary of the type of product, type of plastic, atmosphere composition, temperature of storage during MAP

Type of product	Type of plastic	Atmospheric composition		Temperature of storage (°C)	Storage period under MAP
		% O_2	% CO_2		
Apple (cv. Bravo de Esmolfe)	Polypropylene	5	3	2	6.5 months
Apple (cv. 'Cox's Orange Pippin')	LDPE	3	3	4	5 weeks
Apple (cv. Bramley's Seedling and Cox's Orange Pippin apples)	Cardboard cases lined with LDPE	7	5	15	4 week
Apples (cv Fuji)	Polypropylene, PVC	5	4	10	7 months
Guava (cv. Kumagai)	Multilayer coextruded polyethylene	1.5	4.5	10	3 weeks
Guava (cv. Kumagai)	LDPEm	3	4.5	10	2 week
Guava (cv. Kumagai)	PET	4	5	5	24 days
Banana	LDPE	3	5	15	15 days
Autumn seedless table Grape	Polypropylene	15	10	0	60 days
Table grapes (cv. Autumn Royal)	Oriented polypropylene	8	2.5	1	56 days
Litchi (cv. Mauritius)	BOPP	17	6	2	34 days
Litchi (cv Heiye)	Polyethylene	15	4	3	42 days
Litchi	Laminated polyethylene	15	5	1.5	4 weeks
Litchi (cv. McLean's Red)	BOPP	16	6	2	18 days
Sapota (cv.'Jantung)	LDPE	–	–	5, 10, 15	4 weeks at 10°C and 3 weeks at 15°C, a experienced chillin injury
Strawberries (cv. Camarosa)	PVC, LDPE, PP	6	8	2°C (4 days), followed by 10°C (2 days) and by 18°C (2 days)	8 days Simulated condition of MAP (transport, distribut and retail sale)
Strawberries and raspberries	LDPE, PVC	3	5	7	1 week
Sweet cherry (cv. Sams)	LDPE	0.11, 0.18, 0.04, 0.016, 0.28, 0.13	9.2, 11.5, 12.4, 15.2, 20.3, 20.3	0, 5, 10, 15, 20, 25	3 weeks
Sweet cherries	LDPE	5	14	34°F	14 days
Broccoli (cv. Marathon)	LDPE	1.5	6	15	2 weeks
Broccoli heads	Macroperforated, microperforated and non-perforated PP	3	5	1	28 days
Broccoli	OPP, PVC, LDPE	5	7	10	1 week
Broccoli (cv. Acadi)	Plastic containers (4-L) fitted with diffusion windows for gas exchange	3	8	3	30 days
Mushrooms (U3 Sylvan 381)	Plastic containers (26-L) fitted with diffusion	5	10	4	12 days

Types of modified atmosphere packaging machines for packaging of fresh fruits vegetables and minimally processed fruits and fresh cut vegetables

Horizontal Form-fill-seal (HFFS): The flow-pack machines are capable of making flexible pillow-pack pouches from only one reel of film. HFFS machines can also overwrap a prefilled tray of a product. The air from the package is removed by continuous gas flushing, but gas mixtures containing levels of O_2 > 21% cannot be used due to the use of hot sealing jaws at the end of the machine. For certain very porous products (e.g. some bakery goods), gas flushing is not capable of reducing the residual O_2 within the package enough to low levels. In such cases, a gas injection station can be fitted to the machine infeed so that the product itself is purged with gas immediately prior to packaging. Figure below illustrates a diagrammatic representation of an HFFS machine**.**

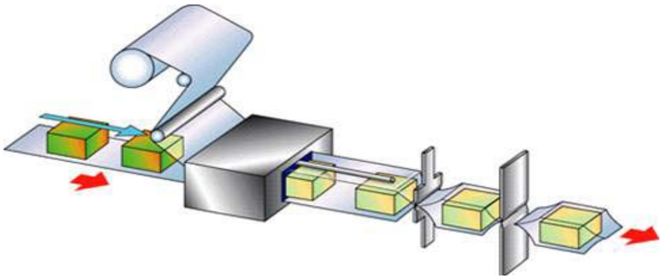

Figure. Horizontal Form-fill-seal (HFFS)

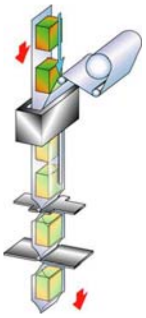

Figure. Vertical Form-fill-seal VFFS machines

Vertical Form-fill-seal VFFS machines: Similar to HFFS machines, VFFS machines are capable of making flexible pillow-pack pouches from only one reel of film. Also, the air from the package is removed by continuous gas flushing so long as the gas mixture does not contain levels of O_2 > 21%. In VFFS machines, gas flushed packages are gravity fed by loose product which has been pre-weighed on a multihead weigher. Pre-flushing with gas may be necessary for porous products. Figure at left illustrates a diagrammatic representation of a VFFS machine.

Thermoform-fill-seal (TFFS): TFFS machines produce packages consisting of a thermoformed semi-rigid tray, which is hermetically sealed to a flexible lidding material. Rollstock film (typically PVC/PE) is automatically conveyed into a thermoforming section where a vacuum or compressed air is used to draw the film into dies, giving the trays their desired shape. The product is then manually or automatically loaded into the trays before evacuation, back flushing with the desired gas mixture, and heat-sealing with lidding material. The hermetically sealed packages are then finally separated by cross-cutting and longitudinal cutting units. Figure above illustrates a diagrammatic representation of a TFFS machine.

Preformed Tray and Lidding Film (PTLF): PTLF machines are essentially the same as TFFS machines (see below), except that preformed trays are used instead of thermoformed semi-rigid trays.

Three-web Thermoform-fill-seal (TWTFFS): TWTFFS machines are essentially similar to TFFS machines (see below), except that the product to be packed is first held in position with a permeable top web skin. After this process, the product enters a second sealing section where a lidding film is placed on top of the thermoformed tray. The space between the top web skin film and the lidding film is gas flushed. TWTFFS machines enable packs to be produced, which combine the advantages of MAP with vacuum skin packaging (VSP). VSP prevents product movement, pack integrity is maximised, juice exudation is limited, and vertical retail display is possible.

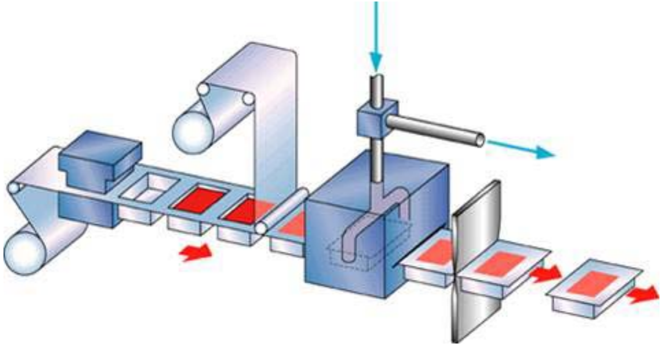

Figure. Three-web Thermoform-fill-seal (TWTFFS)

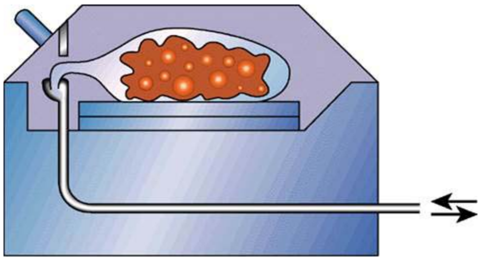

Figure. Vacuum Chamber (VC)

Vacuum Chamber (VC): These machines use preformed bags and utilise the compensated vacuum technique to replace air. Preformed plastic bags are manually placed within the chamber before evacuation, back flushing with the desired gas mixture, and heat sealing. These machines can be used for small-scale production of vacuum or gas flushed catering packs. The figure below illustrates a diagrammatic representation of a VC machine.

Snorkel Type (ST): These machines use the compensated vacuum technique to produce bulk MA catering bag-in-box packs. Alternatively, they can gas flush conventionally packaged retail products, such as over wrapped packs of red meat, into large master packs. In these machines, preformed plastic bags are positioned on a heat seal mandrel and retractable snorkels pull a vacuum and then back-flush with a desired gas mixture before heat sealing.

Conclusion

The recommended percentage of O_2 in a modified atmosphere for fruits and vegetables for both safety and quality falls between 1 and 5%, although the oxygen level will realistically each levels below 1% in MAP produce. The greatest extension of shelf life occurs at the lowest possible oxygen concentration before anaerobic respiration is initiated. It is generally believed that with the use of permeable films, spoilage will occur before toxin production is an issue; MAP of produce, however, should always incorporate packaging materials that will not lead to an anoxic package environment when the product is stored at the intended temperature. The polymeric films of recommended gas transmission rates and other characteristics (strong, flexible, trans- parent, durable and food grade) required for MAP for all commodities should be produced commercially either as single polymer/coextruded/laminated for thesuccess and popularization of MAP technology. Successful control of both product respiration and ethylene production and perception by MAP can result in a fruit or vegetable product of high organoleptic quality; however, control of these processes is dependent on temperature control. Along the whole food continuum, that is, processing, storage, transportation and retailing, one needs to maintain optimum temperatures. Maintaining proper storage temperatures is often most difficult at retail level. Oxygen, CO_2, and N_2, are most often used in MAP/CAS. Among them, CO_2 is the only one with a direct antimicrobial effect, resulting in an increased lag phase and generation time during the logarithmic phase of growth. Although other gases such as nitrous and nitric oxides, sulphur dioxide, ethylene, chlorine, as well as ozone and propylene oxide have been investigated, they have not been applied commercially due to safety, regulatory, and cost considerations. As fruits and vegetables are more sensitive to environmental conditions, the conditions have to be controlled precisely to achieve superior product quality and the development of models for diûerent fruits and vegetables is a pre-requisite. Research is also needed in integrating active packaging with MAP to make this technology economically viable. Current ethylene removing techniques (catalytic or chemical oxidation) are not commercially successful. Active packaging involving ethylene-absorbing substances should be studied. It is an exciting time within the MAP industry. There are emerging technologies and opportunities that will have far reaching impact on the marketplace. Issues such as sustainability in packaging and the impact that packaging has on current food safety issues are already providing both tremendous challenges and opportunities. The challenge will be how to incorporate all of the desired requirements into MAP without diluting its fundamental purpose. A package that tries to become all things to all applications becomes mediocre at best with respect to any one requirement.

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