From Kirtil, E., Kilercioglu, M., Oztop, M.H., 2015. Modified Atmosphere Packaging of Foods. Reference Module in Food Sciences. Elsevier, pp. 1–6. doi: http://dx.doi.org/10.1016/B978-0-08-100596-5.03218-2
ISBN: 9780081005965

Academic Press

Modified Atmosphere Packaging of Foods

Emrah Kirtil, Mete Kilercioglu, and Mecit Halil Oztop, Middle East Technical University, Ankara, Turkey

Introduction

Modified atmosphere packaging (MAP) is an indirect food preservation technique that was initially designed to preserve the quality of fresh produce. As the name implies, the gas composition in a package is modified such that microbial growth and chemical deterioration reactions are to be kept at minimum levels. It is noteworthy to mention that in modified atmosphere packages the atmosphere is not controlled but just modified.

There are different storage and packaging techniques that are based on the change in composition of the storage atmosphere. Controlled atmosphere storage (CAS) aims to control the optimum gas composition in a storage room within the specified tolerances. In CAS, a gas generator is usually used to create and control the modified atmosphere in a cold warehouse where the product is kept (Yam and Lee, 1995). However, in modified atmosphere storage initial gas composition is modified in an airtight storage room and the atmosphere changes with time due to respiratory activity and the growth of microorganisms (Robertson, 2012). CAS is capital intensive and difficult to operate; thus, it is more appropriate for foods that are amenable to long-term changes such as apple, kiwifruits, and pears and meat (Robertson, 2012).

In MAP, the product is kept in a carefully designed permeable polymer package, and the modified atmosphere is created and maintained through the respiration of the product and the gas permeation of the package. MAP is a more affordable technology since a gas generator is not needed (Yam and Lee, 1995); however, it is also a more difficult technology to implement since the permeability of the packages to the gases should be considered for the best design.

Vacuum packaging is also considered as a MAP system particularly for fresh produce and for foods containing viable microorganisms such as flesh food since after initial modification of the atmosphere in the package biological action continues to alter the atmosphere in the food (Robertson, 2012).

Why MAP?

Food does not stay fresh forever. Enzymatic reactions, lipid oxidation, and microbial growth are important causes of food spoilage during storage. Food additives can be used to extend the shelf life of foods by preventing the undesirable changes aforementioned. Refrigeration – the lower the temperature, the slower most microbes will grow – or treatments such as pickling, curing with salt are other preservation techniques that are commonly used to increase shelf life. To keep food fresh for as long as possible without additives is a challenge, and one key method for achieving this goal is to seal the food product in a package including mixture of gases in optimized proportions that significantly slow down the biochemical changes inhibiting processes of oxidation and the growth of microbes. Modified atmosphere packages achieve this by decreasing the oxygen concentration and filling the packages with gases such as N_2, CO_2.

Gases Used in MAP

O_2, CO_2, and N_2 are the three gases that are mainly used in MAP systems. The proportion of the gases depends on the food commodity that is packed. Noble or inert gases such as argon can also be used to create a modified atmosphere. It has been evaluated on poultry (Herbert et al., 2013), cooked meat (Pérez-Rodríguez et al., 2013), and mushroom (Lagnika et al., 2011), and satisfactory results were obtained. Research use of carbon monoxide (CO) on meat (Jeong and Claus, 2010; Liu et al., 2014) and sulfur dioxide (SO_2) in the form of SO_2-generating pads for table grapes (Ustun et al., 2012) has also been reported. CO

Reference Module in Food Science, First Edition, 2016, 1–6

has been licensed for use in the United States to prevent browning in packed lettuce. Commercial application has been limited because of its toxicity and the formation of potentially explosive mixtures with air (Mullan and Michael, 2003).

Oxygen (O_2) is a colorless, odorless gas that is highly reactive. It has a low solubility in water (0.040 g kg^{-1} at 100 kPa, 20 °C) (Mullan and Michael, 2003). Oxygen is responsible of several biochemical reactions in foods including lipid and pigment oxidation, browning reactions. Most of the common spoilage bacteria and fungi require O_2 for growth. Therefore, to increase the shelf life of foods, the package atmosphere should contain a low concentration of residual O_2. On the other hand, in some foods a low concentration of O_2 can result in quality and safety problems (for example, unfavorable color changes in red meat pigments, senescence in fruits and vegetables, and growth of food poisoning bacteria), and this must be taken into account when selecting the gaseous composition for a packaged food.

Carbon dioxide could be considered as the most important gas in MAP of foods due to its antimicrobial properties. CO_2 is a colorless gas with a slight pungent odor at very high concentrations. It readily dissolves in water where a small amount is hydrated to carbonic acid (H_2CO_3) (Robertson, 2012). CO_2 is also soluble in lipids and some other organic compounds. Solubility increases with decreasing temperature and the antimicrobial activity is markedly greater at lower temperatures. High solubility in water and fat can lead to discoloration, off-flavors, excess purge by muscle foods, and package collapse.

Nitrogen is a physiologically inert gas with low solubility in water. It is used in MAP as a filler to exclude oxygen and to prevent collapse caused by dissolution of CO_2 in the food.

Methods of Creating MAP Conditions

Passive Modified Atmosphere

Packaging materials used in MAP are mostly plastic polymers. Polymers show different permeabilities for different gases. Permeability values of polymers for MAP gases are available elsewhere (Ashley, 1985; Zeman and Kubík, 2007). Modified atmospheres can develop within a hermetically sealed package as a consequence of a commodity's respiration or due to other biochemical reactions. If oxygen consumption or carbon dioxide formation characteristics are properly matched to film permeability values, then a beneficial modified atmosphere can be passively created within a package. Passive MAP systems are successfully applied on mushrooms (Lagnika et al., 2011), sweet cherry (Lara et al., 2015), strawberry (Barrios et al., 2013), and many other fresh produce (Yam and Lee, 1995). Passive MAP is also named as equilibrium modified atmosphere packaging in the literature (Del-Valle et al., 2009; Villalobos et al., 2014). The concentration of gases at which the headspace atmosphere reaches equilibrium depends on the weight and respiration rate of the commodity and on the surface area and gas transmission rate of the packaging material.

Active Modified Atmosphere

By pulling a slight vacuum and replacing the package atmosphere with a desired mixture of CO_2, O_2, and N_2, a beneficial equilibrium atmosphere may be established more quickly than a passively generated equilibrium atmosphere. In another active MAP system no vacuum is used but a gas mixture is injected into the package and the air swept or flushed immediately prior to sealing resulting in residual O_2 levels of 2–5% (Robertson, 2012). Active MAP systems could also be created using O_2, CO_2 scavengers/emitters (Aday and Caner, 2013; Kartal et al., 2012), and SO_2-generating pads (Ustun et al., 2012). Such scavengers/emitters are capable of establishing a rapid equilibrium atmosphere within hermetically sealed produce packages.

Applications of MAP

1. *Red Meat and Poultry*: For red meat the most important goal in packaging is to maintain the red color of myoglobin. As it is known myoglobin in the muscle tissue when binds to oxygen is converted to oxymyoglobin which results in the so-called 'super market red color.' To maintain myoglobin at that state O_2 concentration in the package should be adjusted properly. Aerobic spoilage bacteria, such as *Pseudomonas* species, normally constitute the major flora on red meats. Since these bacteria are inhibited by CO_2, it is possible to achieve both red color stability and microbial inhibition by using gas mixtures containing 20–30% CO_2 and 70–80% O_2. These mixtures can extend the chilled shelf life of red meats from 2–4 days to 5–8 days. A gas/product ratio of 2:1 is recommended. Carbon monoxide is also useful in fresh meat retailing because it enables merchandising bright red meat in an anaerobic package rather than aerobically packaged (Jeong and Claus, 2010). In another study, it was also observed that steaks and ground beef in 0.5% CO in modified atmosphere packages maintained a desirable red color for 8 weeks of storage (Jayasingh et al., 2001).

   Color of poultry meat is not as significant to the consumer as that of beef as poultry breast muscles have a low quantity of myoglobin and are considered to be white meat (McKee, 2007). Color of ground chicken and turkey meat was found to be more stable in an oxygen-free atmosphere (Saucier et al., 2000). Thus exclusion of oxygen is recommended in poultry MAP systems in terms of color stability. In addition to the effect on the product's color, different gas concentrations also influence the composition of the spoilage flora (Rossaint et al., 2006). The use of CO_2 and N_2 extends the lag phase of aerobic microorganisms and favors the growth of facultative and anaerobic microorganisms. Thus an oxygen-free environment may not be the optimal choice as well. However, since anaerobic metabolism produces less intense odors than aerobic metabolism, the use of a low oxygen concentration in MAP is recommended (Rossaint et al., 2006).

2. *Fish and Other Sea Food Products*: One processing method that is commonly used to extend the shelf life of seafood is MAP, and based on data from fish and other shellfish, a general shelf life increase of 30–60% could be achieved (Gornik et al., 2013; Sivertsvik et al., 2002). MAP prolongs the shelf life and maintains the general characteristics of fish that make it appear more 'natural' (Mastromatteo et al., 2010; Messina et al., 2015).

   Oxidation reactions are much more important deterioration reactions in fish compared to flesh meat since the amount of unsaturated lipids is much higher. Moreover since fish and shellfish contain much lower concentrations of myoglobin, the oxidation status of this pigment is less important than that in other meats. Consequently, there is potential to use higher levels of CO_2, e.g., 40%. Because of the high moisture content and the lipid content of some species, N_2 is used to prevent pack collapse (Mullan and Michael, 2003). However, exclusion of oxygen from the package could promote the growth of anaerobic bacteria such as *Clostridium botulinum*. Since these bacteria can grow at temperatures as low as 3 °C and do not significantly alter the sensory properties of the fish, there is a potential for food poisoning that can lead to fatalities (Mullan and Michael, 2003). Some fish processors include O_2 in their MAP to further reduce the risk of growth of clostridia. Gas mixtures of 30% O_2, 40% CO_2, and 30% N_2 are used for white nonprocessed fish, i.e., nonfatty fish. Since complete oxygen removal is problematic, natural antioxidants are used with MAP systems to prevent oxidation (Giménez et al., 2004; Mastromatteo et al., 2010; Messina et al., 2015).

3. *Fresh Produce (Fruits and Vegetables)*: Fresh produce is the largest food category where MAP has been applied and research has been conducted. Most of the research has been aimed identifying the optimum gas composition in a package. MAP facilitates the maintenance of the desired atmosphere during the entire postharvest handling time between harvest and use (Kader et al., 1989). A proper combination of product characteristics and packaging film permeability results in the evolution of an appropriate atmosphere within packages (Del Nobile et al., 2007). Fruits and vegetables continue to respire after harvesting. The main goal in a modified atmosphere package for a fresh produce is to minimize respiration while preventing a possible microbial growth. Respiration involves the oxidative breakdown of complex substrate molecules, normally present in plant cells such as starch, sugars, and organic acids, to simpler molecules such as carbon dioxide and water. Atmospheres low in O_2 (1–5%) and high in CO_2 (5–10%) have been used to extend the shelf life of fresh-cut fruits and vegetables by reducing respiration, product transpiration, and ethylene production, as O_2 is involved in the conversion of 1-amino-cycloprane-1-carboxylic acid to ethylene (Rojas-Graü et al., 2009; Yang and Hoffman, 1984). As respiration rates lower, postharvest shelf life increases. Reduced O_2 and high CO_2 levels have also been proved to effectively control enzymatic browning, firmness, and decay of fresh-cut fruits and vegetables. Besides, growth of aerobic spoilage microorganisms can be substantially delayed with reduced O_2 levels (Rojas-Graü et al., 2009). High CO_2 concentrations are also generally effective in controlling the growth of most aerobic microorganisms, specifically Gram-negative bacteria and molds, but fail to inhibit most yeasts (Al-Ati and Hotchkiss, 2002). However, removing O_2 from the package completely or keeping at very minimum levels is also not proper since to prevent the growth of some anaerobic psychotropic pathogens, sufficient O_2 concentration in the package is required. Determining the optimum proportions of MAP gases itself is not enough for designing the best system. Selection of the packaging film has a dramatic effect on MAP, because each polymeric film has unique O_2 and CO_2 permeabilities. Optimum gas compositions for fresh produce has been studied and tabulated by many researchers (Labuza and Breene, 1989; Prince, 1989; Singh and Oliveira, 1994). The data may also be represented in the form of CO_2 versus O_2 plots in which the windows represent the boundary of recommended gas concentrations (Mannapperuma et al., 1989; Yam and Lee, 1995). Using the plots optimum compositions for a specific commodity could be determined and an appropriate packaging material could be selected.

4. *Commercial Applications of MAP*: Some recent commercial applications of MAP are listed below:
   a. Flaxseed oil packaged with argon flushing
   b. Freshly roasted coffee packaged with argon flushing
   c. Chopped lettuce and salad leaves
   d. Prawns packaged in an atmosphere typically containing only carbon dioxide and nitrogen
   e. Hermetic seals maintaining modified atmosphere in a meat package by providing O_2 to the package
   f. Processed meat in tray sealing with modified atmosphere
   g. Shredded or grated cheese packaged in modified atmosphere with reclosable zipper pillow pack
   h. Mushrooms packaged in tray sealing in modified atmosphere in rigid trays
   i. Chicken cut-up packaged in flow pack wrapper in modified atmosphere using a cross-linked polyolefin based soft shrink film

Mathematical Modeling of a MAP

In this section, the necessary mathematical models for designing a MAP system for a fresh produce will be formulated. The optimum composition plots aforementioned together with the mathematical models will help to select the appropriate packaging material for a MAP system. Figure 1 shows the schematic of a MAP system for a fresh produce with a weight of *W* g and package free volume of *V* m^3. *Pc*, *Po*, *A*, and *X* represent carbon dioxide, oxygen permeability (ml mm/[m^2 d atm]), area (m^2), and thickness of the packaging

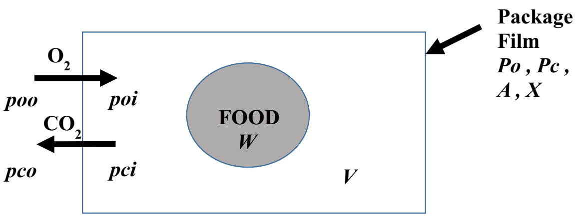

Figure 1 Schematic of modified atmosphere package for a fresh produce. *W*, weight; *V*, volume; *Pc*, carbon dioxide permeability; *Po*, oxygen permeability; *A*, area; *X*, thickness of the packaging film; *poi*, *poo*, *pco*, and *pci*, inside and outside partial pressures of oxygen and carbon dioxide, respectively.

film (m), respectively. Inside and outside partial pressures of oxygen and carbon dioxide (atm) are given as poi, poo, pco, and pci, respectively. Respiration rates (ml kg^{-1} day) of O_2 (Ro) and CO_2 by the produce are also known based on the studies available in the literature. Following the conservation equation for mass, steady-state material balance for O_2 and CO_2 are written as:

$$Po \times A \times \frac{(poo - poi)}{X} = Ro \times W \qquad [1]$$

$$Pc \times A \times \frac{(pci - pco)}{X} = Rc \times W \qquad [2]$$

Equations [1] and [2] can each be rearranged to obtain expressions equal to $W \times X/A$.

$$Po \times \frac{(poo - poi)}{Ro} = \frac{W \times X}{A} \qquad [3]$$

$$Pc \times \frac{(pci - pco)}{Rc} = \frac{W \times X}{A} \qquad [4]$$

If the packaging material that will be used has been already selected; Pc and Po are known; poo and pco are fixed (usually corresponds to atmospheric O_2 and CO_2 partial pressures); poi and pci are determined experimentally in respiration studies to minimize respiration or from the tabulated values, composition plots; Ro and Rc are the respiration rates at the used poi and pci, then for a given thickness and area the amount of the produce that will fit into a package could be calculated.

If the appropriate packaging material for a given produce is sought, eqns [3] and [4] could be arranged to a form that is equivalent to compositional plots:

$$Po \times \frac{(poo - poi)}{Ro} = Pc \times \frac{(pci - pco)}{Rc} \qquad [5]$$

$$pci = pco + \frac{Po \times Rc}{(Pc \times Ro)(poo - poi)} \qquad [6]$$

when Rc/Ro is 1:

$$pci = pco + \frac{Po}{Pc(poo - poi)} \qquad [7]$$

The ratio of the packaging film's permeability to carbon dioxide and oxygen, Pc/Po, is often denoted by β:

$$pci = pco + \frac{1}{\beta(poo - poi)} \qquad [8]$$

$$pci = \left(pco + \frac{poo}{\beta}\right) - \frac{poi}{\beta} \qquad [9]$$

If eqn [9] is plotted as pci versus poi, a straight line with intercept $(pco + poo/\beta)$ and slope $(1/\beta)$ results. Thus the slope of the lines passing through the boxes in a composition plot will correspond to the ratio of permeabilities of O_2 to CO_2. Thus for a given weight of fresh produce of which the optimum composition plot is known it is possible to determine whether the desired steady state O_2 and CO_2 levels will be achieved or not with a packaging film of certain thickness and area.

Conclusion

MAP is an indirect food preservation method which does not include the use of any chemicals. The packaged atmosphere is modified such that the biological activities slow down and food show shelf life is extended. The gas composition in the package is either actively changed in the beginning or passively changes during the storage of the food due to respiration, oxidation, or other biological reactions. The optimum gas composition in the package is important to extend the shelf life as much as possible. O_2, CO_2, and N_2 are the most important MAP gases. E-numbers for the gases (additive codes of European Union (EU) regulations) have to be included in the packages. Simple mathematical approaches could be followed to decide the desired gas composition for different food commodities.

Acknowledgment

The authors would like to express their thanks to Emeritus Prof. John Krochta from University of California, Davis, Food Science and Technology Department. His 'Food Packaging' class (FST 131) lecture notes inspired this review particularly for the mathematical modelling section.

References

Aday, M.S., Caner, C., 2013. The shelf life extension of fresh strawberries using an oxygen absorber in the biobased package. LWT Food Sci. Technol. 52 (2), 102–109. http://dx.doi.org/10.1016/j.lwt.2012.06.006.

Al-Ati, T., Hotchkiss, J.H., 2002. Applications of packaging and modified atmosphere to fresh-cut fruits. In: Lami-kanra, O. (Ed.), Fresh-Cut Fruits and Vegetables: Science, Technology, and Market. CRC Press, Boca Raton, FL, pp. 305–338.

Ashley, R.J., 1985. Permeability and plastics packaging. In: Comyn, J. (Ed.), Polymer Permeability. Chapman & Hall, pp. 269–306.

Barrios, S., Lema, P., Lareo, C., 2013. Modelling respiration rate of strawberry (cv. San Andreas) for modified atmosphere packaging design. Int. J. Food Prop. http://dx.doi.org/10.1080/10942912.2013.784328 (January 2014), 131209125248000.

Del Nobile, M.A., Licciardello, F., Scrocco, C., Muratore, G., Zappa, M., 2007. Design of plastic packages for minimally processed fruits. J. Food Eng. 79 (1), 217–224. http://dx.doi.org/10.1016/j.jfoodeng.2006.01.062.

Del-Valle, V., Hernández-Muñoz, P., Catalá, R., Gavara, R., 2009. Optimization of an equilibrium modified atmosphere packaging (EMAP) for minimally processed mandarin segments. J. Food Eng. 91 (3), 474–481. http://dx.doi.org/10.1016/j.jfoodeng.2008.09.027.

Giménez, B., Roncalés, Pedro, Beltrán, José A., 2004. The effects of natural antioxidants and lighting conditions on the quality characteristics of gilt-head sea bream fillets (*Sparus aurata*) packaged in a modified atmosphere. J. Sci. Food Agric. 84 (9), 1053–1060. Retrieved from: http://www.scopus.com/inward/record.url?eid=2-s2.0-3042802241&partnerID=40&md5=950cdeb2ea1cacc21e99822dabfe86d8.

Gornik, S.G., Albalat, A., Theethakaew, C., Neil, D.M., 2013. Shelf life extension of whole Norway lobster Nephrops norvegicus using modified atmosphere packaging. Int. J. Food Microbiol. 167 (3), 369–377. http://dx.doi.org/10.1016/j.ijfoodmicro.2013.10.002.

Herbert, U., Rossaint, S., Khanna, M.-A., Kreyenschmidt, J., 2013. Comparison of argon-based and nitrogen-based modified atmosphere packaging on bacterial growth and product quality of chicken breast fillets. Poult. Sci. 92 (5), 1348–1356. http://dx.doi.org/10.3382/ps.2012-02590.

Jayasingh, P., Cornforth, D.P., Carpenter, C.E., Whittier, D., 2001. Evaluation of carbon monoxide treatment in modified atmosphere packaging or vacuum packaging to increase color stability of fresh beef. Meat Sci. 59 (3), 317–324. http://dx.doi.org/10.1016/S0309-1740(01)00086-9.

Jeong, J.Y., Claus, J.R., 2010. Color stability and reversion in carbon monoxide packaged ground beef. Meat Sci. 85 (3), 525–530. http://dx.doi.org/10.1016/j.meatsci.2010.02.027.

Kader, A., Zagory, D., Kerbel, E.L., 1989. Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci. Nutr. 28 (1), 1–30. http://dx.doi.org/10.1080/10408398909527506.

Kartal, S., Aday, M.S., Caner, C., 2012. Use of microperforated films and oxygen scavengers to maintain storage stability of fresh strawberries. Postharvest Biol. Technol. 71, 32–40. http://dx.doi.org/10.1016/j.postharvbio.2012.04.009.

Labuza, T.P., Breene, W.M., 1989. Application of "active packaging" for improvement of shelf-life and nutritional quality of fresh and extended shelf-life foods. J. Food Process. Preserv. 13, 1–69.

Lagnika, C., Zhang, M., Wang, S., 2011. Effect of high argon pressure and modified atmosphere packaging on the white mushroom (*Agaricus bisporus*) physico-chemical and microbiological properties. J. Food Nutr. Res. 50 (3), 167–176.

Lara, I., Camats, J.A., Comabella, E., Ortiz, A., 2015. Eating quality and health-promoting properties of two sweet cherry (*Prunus avium* L.) cultivars stored in passive modified atmosphere. Food Sci. Technol. Int. 21 (2), 133–144. http://dx.doi.org/10.1177/1082013213518544.

Liu, C., Zhang, Y., Yang, X., Liang, R., Mao, Y., Hou, X., Luo, X., 2014. Potential mechanisms of carbon monoxide and high oxygen packaging in maintaining color stability of different bovine muscles. Meat Sci. 97 (2), 189–196. http://dx.doi.org/10.1016/j.meatsci.2014.01.027.

Mannapperuma, J.D., Zagory, D., Singh, R.P., Kader, A., 1989. Design of polymeric packages for modified atmosphere storage of fresh produce. In: Fellman, J.K. (Ed.), 5th International Controlled Atmosphere Research Conference, Wenatchee, WA, pp. 225–233.

Mastromatteo, M., Conte, A., Nobile, M.A.D., 2010. Combined use of modified atmosphere packaging and natural compounds for food preservation. Food Eng. Rev. 2 (1), 28–38. http://dx.doi.org/10.1007/s12393-010-9013-5.

McKee, L., 2007. Microbiological and sensory properties of fresh and frozen poultry. In: Nollet, L.M.L. (Ed.), Handbook of Meat, Poultry and Seafood Quality. Blackwell Publishing, pp. 487–498.

Messina, C.M., Bono, G., Renda, G., la Barbera, L., Santulli, A., 2015. Effect of natural antioxidants and modified atmosphere packaging in preventing lipid oxidation and increasing the shelf-life of common dolphinfish (Coryphaena hippurus) fillets. LWT Food Sci. Technol. 62 (1), 271–277. http://dx.doi.org/10.1016/j.lwt.2015.01.029.

Mullan, M., Michael, M., 2003. Modified atmosphere packaging. In: Coles, R., McDowell, D., Kirwan, M.J. (Eds.), Food Packaging Technology. CRC Press, pp. 303–331.

Pérez-Rodríguez, F., Zamorano, A.R., Posada-Izquierdo, G.D., García-Gimeno, R.M., 2013. Study of the effect of post-packaging pasteurization and argon modified atmosphere packaging on the sensory quality and growth of endogenous microflora of a sliced cooked meat product. Food Sci. Technol. Int. Ciencia Y Tecnologia de Los Alimentos Internacional. http://dx.doi.org/10.1177/1082013212469613.

Prince, T.A., 1989. Modified atmosphere packaging of horticultural commodities. In: Brody, A.L. (Ed.), Controlled/Modified Atmosphere/Vacuum Packaging of Foods. Food & Nutrition Press, Trumbull, Connecticut, pp. 67–100.

Robertson, G., 2012. Modified atmosphere packaging. In: Food Packaging: Principles and Practice, third ed. CRC Press, Boca Raton, FL, pp. 313–340.

Rojas-Graü, M.A., Oms-Oliu, G., Soliva-Fortuny, R., Martín-Belloso, O., 2009. The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: a review. Int. J. Food Sci. Technol. 44 (5), 875–889. http://dx.doi.org/10.1111/j.1365-2621.2009.01911.x.

Rossaint, S., Klausmann, S., Kreyenschmidt, J., 2006. Effect of high-oxygen and oxygen-free modified atmosphere packaging on the spoilage process of poultry breast fillets. Poult. Sci. 96–103.

Saucier, L., Gendron, C., Gariépy, C., 2000. Shelf life of ground poultry meat stored under modified atmosphere. Poult. Sci. 79 (12), 1851–1856.

Singh, R.P., Oliveira, F.A.R., 1994. Minimal Processing of Foods and Process Optimization. CRC Press, Boca Raton, FL.

Sivertsvik, M., Jeksrud, W.K., Rosnes, J.T., 2002. A review of modified atmosphere packaging of fish and fishery products – significance of microbial growth, activities and safety. Int. J. Food Sci. Technol. http://dx.doi.org/10.1046/j.1365-2621.2002.00548.x.

Ustun, D., Candir, E., Ozdemir, A.E., Kamiloglu, O., Soylu, E.M., Dilbaz, R., 2012. Effects of modified atmosphere packaging and ethanol vapor treatment on the chemical composition of “Red Globe” table grapes during storage. Postharvest Biol. Technol. 68, 8–15. http://dx.doi.org/10.1016/j.postharvbio.2012.01.006.

Villalobos, M.D.C., Serradilla, M.J., Martín, A., Ruiz-Moyano, S., Pereira, C., Córdoba, M.D.G., 2014. Use of equilibrium modified atmosphere packaging for preservation of “San Antonio” and “Banane” breba crops (*Ficus carica* L.). Postharvest Biol. Technol. 98, 14–22. http://dx.doi.org/10.1016/j.postharvbio.2014.07.001.

Yam, K.L., Lee, D.S., 1995. Design of modified atmosphere packaging for fresh produce. In: Rooney, M.L. (Ed.), Active Food Packaging. Chapman & Hall, London.

Yang, S.F., Hoffman, N.E., 1984. Ethylene biosynthesis and its regulation in higher plants. Annu. Rev. Plant Physiol. 35, 155–189.

Zeman, S., Kubík, L., 2007. Permeability of polymeric packaging materials. Tech. Sci. 10 (-1), 33–34. http://dx.doi.org/10.2478/v10022-007-0004-6.