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Modified Atmosphere Packaging for Perishable Plant Products

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1. Introduction

Packaging perishable plant products is one of the more important steps in the long and complicated journey from grower to consumer. Millions of different types of packages are used for produce around the world and the number continues to increase as the industry introduces new packaging materials and concepts. Packing and packaging materials contribute a significant cost to the produce industry; therefore it is important that packers, shippers, buyers, and consumers have a clear understanding of the wide range of packaging options available (Boyette et al., 1996). This fact chapter describes some of the many types of packaging materials, including their functions, uses, and limitations. Within packaging plastics for plant products, if commodity and film permeability characteristics are properly matched, an appropriate atmosphere can evolve passively through consumption of O_2 and production of CO_2 during respiration (Mir & Beaudry, 2002). Gas exchange and respiration rate through the package material are the processes involved in creating a modified atmosphere inside a package that will extend shelf life of fresh fruits and vegetables. The major methods for measuring respiration rates, along with their advantages and limitations are discussed. Modified atmosphere technologies have great potential in a wide range of applications in plant products. The usual methods of respiration rate determination can be the static system, the flowing system and the permeable system (Fonseca et al., 2002). The respiration rate of fresh produce can be expressed as O_2 consumption rate and/or CO_2 production rate. Factors affecting the respiration rate and respiratory quotient are outlined, stressing the importance of temperature, O_2 and CO_2 concentrations, and storage time (Kader et al., 1989). Modified atmosphere packaging should always be considered as a supplement to proper temperature and relative humidity management. The differences between beneficial and harmful concentrations of oxygen and carbon dioxide for each kind of produce are relatively small, so great care must be taken when using these technologies. Temperature has been identified as the most important external factor influencing respiration (Tano et al., 2007). The internal factors affecting respiration are the type and maturity stage of the commodity. Vegetables include a great diversity of plant organs such as fruits, roots, tubers, seeds, bulbs, sprouts, leaves and stems that have different metabolic activities and consequently different respiration rates. Different varieties of the same product exhibit specific respiration rates. The success of modified atmosphere packaging greatly depends on the accuracy of the predictive respiration rate (Kader, 2002). The main objective of this chapter is to present different packaging materials using modified atmosphere for perishable plant products, focusing particularly on aspects of the respiration process, usual methods of measuring respiration rates and factors can be affect the respiration rate.

2. Modified atmosphere packaging

Modified atmosphere packaging (MAP) of fresh fruits and vegetables is based on modifying the levels of O_2 and CO_2 in the atmosphere produced inside a package sealed with some type of polymer film. It is desirable that the natural interaction that occurs between the respiration of the product and the packaging generates an atmosphere with low levels of O_2 and / or a high concentration of CO_2. The growth of organisms that cause decay is thereby reduced and the life of the product is thus extended. Additionally, the desired atmosphere can reduce the respiration rate, and ethylene production, physiological changes. For example, it can inhibit chemical, enzymatic and microbiological mechanisms associated with the decay of fresh products, thus avoiding the use of other chemical or thermal process such as freezing, dehydration, and sterilization (Kader et al. 1989; Gorris & Tauscher, 1999; Saltveit, 1997; Fonseca et al., 2002).

The use of modified and controlled atmospheres has grown over the past 50 years, contributing significantly to extend the postharvest life and maintain the quality of various fruits and vegetables. So that changing the atmosphere occurs must have a combination of factors that influence the permeability of the product packaging and respiration in order to achieve an atmosphere of great balance for the conservation of the product. This balance is achieved when the respiration of the product consumes the same amount of O_2 entering the packaging and the production of CO_2 by respiration is equal to the amount that leaves the packaging (Day, 1993).

The first studies on modified atmospheres used reduced levels of O_2 in apple packaging in order to slow the ripening of fruits. The first challenge was to control the levels of O_2 in the package. Since then, an enormous variety of polymers with different properties have been developed to offer a wide range of options in features such as gas permeability, tensile strength and flexibility, among others. Presently, diverse systems of modified atmosphere packaging have been developed and used with a wide range of fruits and vegetables in order to provide optimal storage conditions and product longevity. Table 1 summarizes the optimal conditions of temperature and gas composition of O_2 and CO_2 for the transport and / or storage of some fruits and vegetables.

2.1 Passive

Modified atmospheres can be obtained passively between plant material and sealed package or intentionally using determined concentrations of gases. Modified atmosphere is formed as a result of vegetable respiration, which consumes CO_2 and releases O_2 in sealed package. In passive modification, the respiring product is placed in a polymeric package and sealed hermetically. Only the respiration of the product and the gas permeability of the film influence the change in gaseous composition of the environment surrounding the product. If the product's respiration characteristics are properly matched to the film permeability values, then a beneficial modified atmosphere can be passively created within a package. The polymer itself variably restricts gas exchange between the internal and external environments due to its selective permeability to O_2 and CO_2. After a period of time, the system reaches an equilibrium atmosphere containing of lower concentrations of O_2 and higher concentrations of CO_2 than in atmospheric air.

Product	Temperature range (^0C)	Atmosphere %O_2	Atmosphere %CO_2
Apples	0-5	1-2	0-3
Banana	12-16	2-5	2-5
Blackberry	0-5	5-10	15-20
Blueberry	0-5	2-5	12-20
Cherry, sweet	0-5	3-10	10-15
Cranberry	2-5	1-2	0-5
Grape	0-5	2-5	1-3
Kiwifruit	0-5	1-2	3-5
Lemon	10-15	5-10	0-10
Lychee (Lichti)	5-12	3-5	3-5
Mango	10-15	3-7	5-8
Nuts and dried fruits	0-10	0-1	0-100
Orange	5-10	5-10	0-5
Papaya	10-15	2-5	5-8
Persimmon	0-15	3-5	5-8
Pineapple	8-13	2-5	5-10
Plum	0-5	1-2	0-5
Raspberry	0-5	5-10	15-20
Strawberry	0-5	5-10	15-20
Artichoke	0-5	2-3	2-3
Asparagus	1-5	Air	10-14
Beans	5-10	2-3	4-7
Broccoli	0-5	1-2	5-10
Brussels sprouts	0-5	1-2	5-7
Cabbage	0-5	2-3	3-6
Cantaloupes	2-7	3-5	10-20
Cauliflower	0-5	2-3	3-4
Celery	0-5	1-4	3-5
Cucumbers	8-12	1-4	0
Herbs*	0-5	5-10	4-6
Lettuce	0-5	1-3	0
Onions	0-5	1-2	0-10
Parsley	0-5	8-10	8-10
Pepper	5-12	2-5	2-5
Radish	0-5	1-2	2-3
Spinach	0-5	7-10	5-10
Tomatoes	12-20	3-5	2-3

*Herbs: chervil, chives, coriander, dill, sorrel and watercress, Adapted from Kader (2002)

Table 1. Summary of optimal conditions for modified atmosphere and temperature during transport and / or storage of fruits and vegetables

2.2 Active

The concept of active packaging has been developed to adjust the deficiencies in passive packaging such as when a film is a good barrier to moisture, but not to oxygen, the film can still be used along with an oxygen scavenger to exclude oxygen from the pack. An intentionally or actively obtained modified atmosphere occurs when the desired gas mixture is introduced into the container before sealing. In this way, atmospheric balance inside the package is reached faster or almost immediately. Sometimes, certain additives are incorporated into the polymeric packaging film or within packaging containers to modify the headspace atmosphere and to extend shelf-life. Another process is the acceleration of atmospheric balance under partial vacuum packaging is the process of removing the air before sealing, reducing the free space. Although the active modification of the atmosphere within the package incurrs additional costs, the advantage is that the desired atmosphere is securely achieved in considerably less time.

2.3 O_2 and CO_2 limits

Safe levels of O_2 and CO_2 are important for package design. A lower O_2 limit has been associated with onset of fermentation and accumulation of ethanol and acetaldehyde (Beaudry et al., 1993). Fermentation is linked to the development of off-flavors and/or tissue damage. Effect of temperature on lower O_2 limit has been measured for a number of commodities including whole apple, apple slices, blueberry, and raspberry. In each case, lower O_2 limit increased with temperature. Lower O_2 limits vary from 0.15% to 5% and are influenced by temperature, commodity and cultivar (Beaudry and Gran, 1993).

It is necessary to know the main effects of gases on fresh fruits and vegetables and the interactions between gas and produce on the one hand and between gas and packaging material on the other hand to achieve the goal. It is important to recognize that while atmosphere modification can improve the storability of some fruits and vegetables, it also has the potential to induce undesirable effects. Fermentation and off-flavors may develop if decreased O_2 levels cannot sustain aerobic respiration (Kays, 1997). Similarly, injury will occur if CO_2 exceeds tolerable levels. Ranges of non-damaging O_2 and CO_2 levels have been published for a numbers of fruits and vegetables (Kader, 1997; Kupferman, 1997; Richardson and Kupferman, 1997; Saltveit, 1997; Beaudry 1999, 2000), minimally processed products (Gorny, 1997), and flowers and ornamentals (Reid, 1997). Horticultural crops differ in their tolerance for O_2 (Table 2) and CO_2 (Table 3).

3. Types of plastic films used in MAP

In a modified atmosphere packaging, changes start to take place immediately after packing the fresh produce as a result of the respiration of the packaged produce. The gases of the contained atmosphere and the external ambient atmosphere try to equilibrate by permeation through the package walls at a rate dependant upon the differential pressures between the gases of the headspace and those of the ambient atmosphere. It is in this context that the barrier to gases and water vapor provided by the packaging material must be considered. Thus, the success of the modified atmosphere packaging depends upon the barrier material used. MAP for fresh produce must also allow entry of oxygen to maintain the aerobic

O_2 (%)	Commodity
2	Lettuce (crisphead), pear
3	Artichoke, tomato
5	Apple (most cultivars), apricot, cauliflower, cucumber, grape, nashi, olive, orange, peach (clingstone), potato, pepper (bell)
7	Banana, bean (green snap), kiwi fruit
8	Papaya
10	Asparagus, brussels sprouts, cabbage, celery, lemon, mango, nectarine, peach, persimmon, pineapple, sweet corn
15	Avocado, broccoli, lychee, plum, pomegranate, sweetsop
20	Cantaloupe (muskmelon), durian, mushroom, rambutan
25	Blackberry, blueberry, fig, raspberry, strawberry

*Data are from Beaudry (2000), Gorny (1997), Kader (1997), Kupferman (1997), Richardson and Kupferman (1997), and Saltveit (1997)

Table 2. O_2 limits below which injury can occur for selected horticultural crops held at typical storage temperatures

CO_2 (kPa)	Commodity
< 0.5	Chopped greenleaf, Romaine and iceberg lettuce, spinach, sliced pear, broccoli
1.0	Broccoli florets, chopped butterhead lettuce, sliced apple, brussels sprouts, cantaloupe, cucumber, crisphead lettuce, onion, apricot, avocado, banana, cherimoya, sweet cherry, cranberry, grape, kiwifruit, litchi, peach, plum
2.0	Shredded and cut carrots, artichoke, cabbage, cauliflower, celery, bell and chili pepper, sweet corn, tomato, blackberry, fig, mango, olive, papaya, pineapple, pomegranate, raspberry, strawberry
2.5	Shredded cabbage, blueberry
3.0	Cubed or sliced cantaloupe, low permeability apples and pears, persimmon
4.0	Sliced mushrooms
5.0	Green snap beans, lemon, lime, orange
10.0	Asparagus
14.0	Orange sections

* Adapted from Herner (1987), Kader (1997), and Saltveit (1997)

Table 3. CO_2 partial pressures above which injury will occur for selected horticultural crops

metabolism of the product. In addition, some carbon dioxide must exit from the package to avoid build up of injurious levels of the gas. These packages are made of plastic films with relatively high gas permeability.

Packaging films that provide 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 such as in the plural, Vinyl Polymers, Styrene Polymers, Polyamides, Polyesters and other polymers. Polypropylene is part of the Polyolefin group and used largely in MAP, in both forms: continuous and perforated. Sanz et al. (1999) studied the quality of strawberries packaged with polypropylene film, with proper perforations, during commercial postharvest practices. They concluded that perforated-mediated MA packaging helped to preserve fruit ripeness degree better, maintaining its nutritional value, measured as ascorbic acid content.

Many type of plastic films for packaging are available, but relatively few have been used to pack fresh fruits and vegetables, and even fewer have a gas permeability that makes them suitable for modified atmosphere packaging. The permeability of CO_2 should be 3 to 5 times the permeability of O_2. Many polymers used to formulate packaging films are within this criterion (Table 4).

Film type	Permeabilities (cc/m²/mil/dia a 1 atm)		
	CO_2	O_2	CO_2:O_2 ratio
Polyester	180-390	52-130	3.0-3.5
Polyethylene, low density	7,700-77,000	3,900-13,000	2.0-5.9
Polypropylene	7,700-21,000	1,300-6,400	3.3-5.9
Polystrene	10,000-26,000	2,600-7,700	3.4-3.8
Polyvinyl chloride	4,263-8,138	620-2,248	3.6-6.9

*Adapted from Kader (2002)

Table 4. Permeability for packaging fresh fruits and vegetables

4. Package parameters

Modified atmosphere (MA) packaging systems designed to produce optimum O_2 and CO_2 concentrations at suitable temperatures have been mathematically modeled (Chinnan, 1989; Lee et al., 1991; Exama et al., 1993; Talasila et al., 1995; Cameron et al., 1995).

The composition of the atmosphere inside the packaging results from the interaction of several factors including the permeability characteristics of the packaging material, the respiratory behavior of the plant material and the environment. Packaging films are selected so that the package has specific permeability characteristics and so that changes to these characteristics (temperature and humidity) over time, following the laws of physics. The concentration of gases within the packaging can be controlled to provide specific conditions. In contrast to these known and controllable factors are the often unknown and uncontrollable responses of the plant material. The plant species, the cultivar, cultural practices, the development stage, harvest management, the tissue type and post harvest handling all contribute and influence the response of the material to the atmosphere generated.

The scope of plant responses can be modified by the initial flow of gas before sealing the packaging as well as by the inclusion of chemical treatments to slow undesirable processes or decrease contamination. Each component of the packaging process needs to be examined separately to improve the understanding of what it contributes to potential packaging strategies.

Mathematical models can integrate the film permeability to O_2, CO_2 and H_2O, and the respiratory response of the commodity to O_2, in some cases, CO_2, along with its lower O_2 limit and upper CO_2 limit (Beaudry et al., 1992; Cameron et al., 1994; Lakakul et al., 1999; Fishman et al., 1996; Hertog et al., 1998). These models permit the identification of limiting features of the film, package design, and product and environment conditions.

The major factors to be taken into account while selecting the packaging materials are the type of package, the barrier properties needed (permeabilities of individual gases and gas ratios when more than one gas is used), physical properties of machinability and strength, integrity of closure (heat sealing), fogging of the film as a result of product respiration, printability and others.

4.1 Respiration rate

Respiration is a process in which chemical reactions oxidize lipids and carbohydrates to carbon dioxide and water to produce energy, while the organelle responsible for aerobic respiration known as mitochondria. Part of the released energy is stored as chemical energy adenosine triphosphate (ATP) and part is lost as heat. This complex process can be influenced by several intrinsic factors such as product size, variety, maturity, type of tissue and extrinsic factors such as temperature, concentration of O_2 and CO_2 and mechanical damage (Day, 1993).

Knowledge of the minimum required for O_2 aerobic respiration is very important to avoid that the anaerobic pathway is the predominant route of respiration, which causes the accelerated loss of product quality. In order to maintain food safety, it is important to know the potential hazards of each product, the permeability of the films and the rate of respiration of fruits and vegetables (Watada et al., 1996).

Since both the rate of respiration and the permeability of the film are sensitive to temperature variations, and respond to these changes differently, it is expected that the package under modified atmosphere remains determined only within an atmosphere given temperature range (Zagory, 2000).

The maximal rate of respiration for most fruit and vegetable products undergoes a 4- to 6-fold increase from 0 to 15 °C (Beaudry et al., 1992; Cameron et al., 1994, 1995; Lakakul et al., 1999). This means that product respiration increases at two or three times the rate of LDPE permeability, and thirty times the rate of perforation permeability with increasing temperature. When respiratory demand for O_2 increases faster than O_2 permeation as temperature increases, O_2 levels decline and may pose a risk to product quality. This limits the usefulness of MAP in some situations.

Variation in the respiration rate of the product and the variation in film or permeability can influence package design. Variation in product respiration and package permeability has been measured for broccoli and the effect on package O_2 modeled (Cameron et al., 1993). Cameron et al. (1993) concluded that there is an estimable risk of the package O_2 falling sufficiently low to promote fermentation in any product. Packages should be designed to generate O_2 levels well above the lower limit to ensure aerobic conditions. Products such as broccoli, mushrooms, leeks and others have very high rates of respiration, and most continuous films do not have the capacity to provide enough O_2 to avoid fermentation.

Accordingly, there is commercial interest to develop films with high gas transmission rates. Films that have improved rates of gas transmission by virtue of their polymeric nature are often blends of two or three different polymers, where each polymer performs a specific function such as strength, transparency and improved gas transmission. Similarly, films can be laminated to achieve needed properties.

4.2 Temperature

Temperature is one of the most important factors in extending the shelf-life of perishable products. Optimum storage temperature must be established for every product. Permeability of polymeric packaging films is also a function of temperature and it generally increases with the increase in temperature.

The effects of temperature on chemical reactions, including respiratory rate, traditionally quantified by Q_{10}, which is a coefficient by which it is possible to calculate how many times increases the rate of a reaction for each increase in temperature of 10 °C. The effect of temperature can also be quantified by the Arrhenius model, where the effect of temperature increase is given by the activation energy (Ea) (Cameron et al., 1995). The temperature quotient is useful because it allows us to calculate the respiration rates at one temperature from a known rate at another temperature. However, the respiration rate does not follow ideal behavior, and the Q_{10} can vary considerably with temperature. At higher temperatures, the Q_{10} is usually smaller than at lower temperatures.

The storage temperature is very important for the evolution of microbial and visual quality of fresh fruits and vegetables. Knowledge of weather conditions and temperature in the cold chain for fresh produce is needed to determine the influence of the cold chain in real loss of quality and shelf life of these products (Cortez et al., 2002).

The temperature of the produce in the package is managed by circulating cool air around the outside of the package. The film and the headspace atmosphere are barriers to heat movement, prevent rapid cooling, and reduce the effectiveness of refrigeration. A 'safe radius' for the distance from the center of the package to the circulated air can be calculated based on the heat of respiration and the rate at which heat can be removed by the cooler air (Sharp et al., 1993). For instance, the center of a package of broccoli must have a radius of less than 14 cm to keep it within 1 °C of the refrigerated air.

Temperature control, when combined with correct use of packaging and modified atmosphere technology, is effective in controlling metabolic processes described above. However, the ideal temperature handling, storage and marketing of fresh fruits and vegetable is generally not respected. Some examples of the ranges of temperature and relative humidity are to be respected in Table 1.

If it is necessary to choose between mild temperatures that cause symptoms of chilling injury and temperatures accelerate senescence and microbial growth, the first must be chosen (Watada and Qi, 1999).

4.3 Permeability

The permeability of the packaging material determines the atmospheric conditions in the headspace and ultimately the shelf-life of the product. If an atmosphere higher in carbon dioxide and / or lower in oxygen is required, the material should be impermeable to the gases. Vegetables and fruits require a certain amount of oxygen in the headspace for maintenance of quality, therefore, packaging material for these products should be quite permeable to the oxygen, to allow atmospheric oxygen to replenish the gas in the package.

Transparency of packaging material to light is also important.

The choice of packaging material is an extremely important part of the MAP operation. The materials must be cost effective, have low water vapor transmission rate, high gas barrier, mechanical strength to withstand machine handling and subsequent storage and distribution of the finished pack as well as have the capability of giving high integrity seals to ensure retention of gas within the pack until opened by consumer. Also, once a gas atmosphere is applied, the level and proportion of headspace gas/gases is controlled only by judicious selection of packaging material with specified permeability characteristics. . Thickness is also a factor controlling permeability.

There are two ways to create barriers using film. The first strategy employs continuous films that control the movement of gases in and out of the box. The second strategy uses film with small openings or microperforations.

With continuous films, the movement of O_2 and CO_2 is directly proportional to the differences in gas concentration across the film. Constant levels of gases in the package are achieved when the product's consumption of O_2 and production of CO_2 are equal. This situation exists only when the respiration rate is constant (Fishman et al., 1996).

In perforated films, the rate of movement of gas through the perforated film is the sum of gas diffusion and atmospheric air infiltration through the polymer film. Generally, total gas flow through the perforations is much greater than gas movement through the film. The rate of gas exchange through microperforations is much greater than through continuous films. Perforated packaging is more suitable for vegetables that have a high demand for O_2 (Gonzalez et al., 2008).

5. Respiration rate measurement

The respiration rate of fresh fruits and vegetables can be expressed as the rate of O_2 consumption and CO_2 production rate. The usual methods for determining the concentration of respiration are static or closed system, continuous flow system, and permeable system. The respiration rate is measured in permeable system, in other words, the product is within the dimensions and permeability of packaging film known (Beaudry, 1993; Joles et al., 1994; Lakakul, Beaudry, & Hernandez, 1999; Lee, Song, & Yam, 1996; Piergiovanni, Fava, & Ceriani, 1999; Smyth et al., 1998). The concentrations of O_2 and CO_2 are determined and stable mass balance is done on the system in order to estimate respiration rates.

The concentrations of gases in the system depend on the permeability characteristics of permeability, package size and weight of the product that were discussed previously. The time to reach equilibrium can be seen as a limitation of this method to measure the respiration rate. Definition of the steady-state concentration values is another difficulty of the permeable method.

For all methods have limitations, but this involves a greater number of variables, since the size of the packet are involved other parameters such as free volume, surface area and thickness of the gas exchange and the permeability characteristics. None of methods is clearly preferable over the others. When choosing the respiration rate determination method for a specific study, the benefits and limitations of each method should be taken into consideration. Fonseca et al. (1992) studied three different methods (closed, flow through and permeable systems) to measure respiration rate and observed their advantages and limitations. The main characteristics of these methods are summarized in Table 5.

Characteristics	System		
	Closed	Flow through	Permeable
Non-destructive	✓	✓	✓
Complexity of experimental set-up	✓	✓	✓
Ability to test different combinations of gases	Simple	Complex	Complex
Concentration is kept constant during the experiment	x	✓	✓
Suitable for low respiring products	✓	x	
Suitable for high respiring products	x	✓	✓
Accuracy is very sensitive to determination of	Free volume	Flow-rate	Permeability package dimensions, steady-state concentrations

*Adapted from Fonseca et al. (1992)

Table 5. Main characteristics of the three methods of respiration rate measurement

5.1 Factors affecting respiration rate

The factors affecting respiration are type and maturity stage of the commodity. Vegetables include a great diversity of plant organs such as roots, tubers, seeds, bulbs, fruits, sprouts, stems and leaves that have different metabolic activities and consequently different respiration rates. Even different varieties of the same product can exhibit different respiration rates (Fidler & North, 1967; Gran & Beaudry, 1992; Song et al., 1992). In general, non-climacteric commodities have higher respiration rates in the early stages of development that steadily decline during maturation (Lopez-Galvez, El-Bassuoni, Nie, & Cantwell, 2004). Respiration can also be affected by a wide range of environmental factors that include light, chemical stress, radiation stress, water stress, growth regulators, and pathogen attack. The most important postharvest factors are temperature, atmospheric composition, and physical stress.

One method to improve these problems would be to choose a film with permeability changes for O_2 similar to that of the respiration of the product, so if temperature increases, respiration and permeability of the film increase an equivalent amount.

5.2 Influence of temperature

Indeed the most important factor affecting postharvest life is temperature. This is because temperature has a profound effect on the rates of biological reactions, specifically metabolism and respiration. Over the physiological range of most crops, 0 to 30 °C increased temperatures cause an exponential rise in respiration.

Temperature of the product affects storability more than any other factor. Pre-cooling and temperature maintenance during handling and shipping are critical in preserving quality. Temperature also significantly affects film permeability and thereby the O_2 and CO_2 content of the package.

The elevated rate of respiration at high temperature could be used to rapidly establish the desired package atmosphere, but this would only be useful in the few situations in which it would be more important to rapidly establish the atmosphere than to slow physiological processes, eg., to reduce cut-surface browning.

Another solution to the MAP temperature problem is to develop a package system that senses either the environment or the physiological status of the enclosed product and responds by increasing the permeability to O_2 (Cameron et al., 1993). Such 'sense-and-respond' packaging is technically difficult to develop, and progress has only been conceptual at this time (Smyth et al., 1999). A third approach is to design packages to function at the highest temperatures typically encountered in the distribution and retail cool chain and, as far as possible, maintain control over the temperature of the packaged product, thereby adapting to the limitations imposed by the film. Most companies using MAP have adopted this simple solution. Generally, the lowest temperature feasible is maintained, since temperature has a much more significant influence on preserving quality than the application of low O_2 (Kays, 1997).

Reações metabólicas, entre elas a respiração, são reduzidas em 2 a 3 vezes para cada decréscimo de 10 °C na temperatura, o que permite retardar a maturação e a senescência do produto (Brecht, 1995).

5.3 Influence of gas composition

In MAP, the pack is flushed with a gas or a combination of gases. The common gases used are oxygen, nitrogen and carbon dioxide. Traces of carbon monoxide, nitrous oxide, ozone, argon, ethanol vapour and sulphur dioxide are also used. Minimum oxygen levels are used to pack plant under MA because oxygen can react with the fruits and vegetables resulting in the oxidative breakdown of them into their constitutive parts. Nitrogen is an inert gas. Carbon dioxide is responsible for the bacteriostatic and fungistatic effect in MA packaged fruits and vegetables. It retards the growth of moulds and aerobic bacteria. The inhibitory effect of carbon dioxide to micro-organisms is increased as the temperature is lowered.

The tolerance of any plant tissue at low O_2 tension is smaller as the storage temperature increases, since the requirements for aerobic respiration of the tissue increases with increasing temperature. Depending on the product damage associated with CO_2 can both increase and decrease with rise in temperature. CO_2 production increases with temperature, but its solubility decreases. Thus, the CO_2 concentration in the tissue may decrease or increase with increasing temperature. In addition, the physiological effect of CO_2 could be temperature dependent.

The activation energy is a parameter that has been used to characterize plastic packaging. Knowledge of the activation energy of the breath of product and packaging serves as an important tool to predict the effects of temperature fluctuations on the concentration of gases inside the package (Cameron et al., 1995).

6. Plant responses of MAP

Some of the most important factors that affect shelf life of fresh horticultural products are ripening and/or senescence, decay, and cut surface browning. The effect of modified atmosphere on these factors has been studied for different crops. The application of MA to affect these limiting factors can be restricted for some crops by adverse and/or non-beneficial physiological responses. Additionally, the good temperature management should be associated to by atmosphere modification.

Low O_2 and elevated CO_2 concentrations can significantly reduce the rates of ripening and senescence primarily by reducing the synthesis and perception of ethylene (Burg and Burg, 1967; Abeles et al., 1992). Changes in respiration and starch, sugars, chlorophyll, and cell wall constituents during this period can be reduced, and in some cases nearly arrested, by eliminating ethylene action through the use of low O_2/high CO_2 atmospheres.

Chlorophyll loss, a desirable trait for many climacteric fruits, results in quality loss for many vegetables. Chlorophyll degradation during the senescence of green vegetables can be reduced by low O_2 and elevated CO_2 (Ku and Wills, 1999).

Modified atmospheres are most effective at reducing ripening prior to the onset of ripening, rather than at a later stage. At the same time, packaged fruits and vegetables are usually intended for immediate consumption by the consumer and an unripe product is not immediately edible or is of reduced quality relative to the ripe product. Thus, the advantage of extend shelf-life by retarding ripening runs counter to the needs of the consumer when retail MAP systems are used. Nevertheless, MAP can reduce the rate of ripening of some commodities such as tomato even during its later stages (Yang and Chinnan, 1988).

Decay control is a particularly important problem for many crops. Levels of above 10% CO_2 effectively slow or stop the growth of numerous decay organisms (Brown, 1922). Low O_2 has a very limited effect on decay organism activity or survival at levels above the fermentation threshold of most commodities. Strawberry, blueberry, blackberry, raspberry and cherry, they are examples that can be stored at CO_2 atmosphere between 10 and 20%.

A negative plant responses to modified atmosphere packaging is when the respiration is reduced as O_2 becomes limiting. Although there is a limit to which O_2 can be reduced. The lower O_2 limit is frequently considered to be the level of O_2 that induces fermentation. However there are lower O_2 levels that may confer benefits that outweigh the loss in flavor or other quality parameters. Ethanol, acetaldehyde, ethyl acetate and lactate are products of fermentation that can contribute to the development of off-flavors (Kays, 1997; Mattheis and Fellman, 2000).

Synthesis of aroma compounds are generally suppressed by high CO_2 and low O_2 levels, in part by their action on ethylene sensitivity, but also via action of O_2 on oxidative processes, including respiration required for substrate production. But low O_2 MAP may suppress aroma production so consumers perceive reduced quality upon opening the container.

7. Conclusions

The benefits of MAP technology to the manufacturer, retailer as well as consumer far outweigh the drawbacks. Nevertheless some critical points should be considered in this technology. The following list some advantages and disadvantages of MAP.

- Advantages
  - Increased shelf-life allowing lesser frequency of loading of retail display shelves.
- Improved presentation of the product
  - Hygienic stackable pack sealed and free from product drip and odor
  - Shelf-life can be increase by 50 to 400%.
  - Reduction in production and storage costs due to better utilization of space and equipment.
- Disadvantages
  - Capital cost of gas packaging machinery
  - Increased pack volume increases transport costs and retail display space
  - Cost of gases and packaging materials
  - Temperature control is of critical importance and, by itself, has a greater impact than atmosphere modification for most products
  - Potential growth of food borne pathogens due to non-maintenance of required storage temperature by retailers and consumers.

8. References

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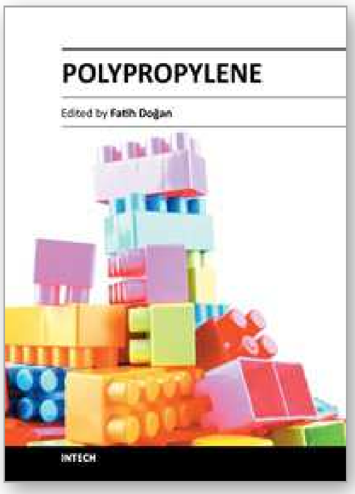

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This book aims to bring together researchers and their papers on polypropylene, and to describe and illustrate the developmental stages polypropylene has gone through over the last 70 years. Besides, one can find papers not only on every application and practice of polypropylene but also on the latest polypropylene technologies. It is also intended in this compilation to present information on polypropylene in a medium readily accessible for any reader.

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