23) MODIFIED ATMOSPHERE PACKAGING

The shelf-life of perishable foods as meat, poultry, fish, fruits and vegetables and bakery products is limited in the presence of normal air by two principal factors-the chemical effect of atmospheric oxygen and the growth of aerobic spoilage micro organisms. These factors either individually or in association with one another bring about changes in odour, flavour, colour and texture leading to an overall deterioration in quality. Chilled storage will slow down these undesirable changes but will not necessarily extend the shelf-life sufficiently for retail distribution and display purposes.

The modified atmosphere concept for packaged goods consists of modifying the atmosphere surrounding a food product by vacuum, gas flushing or controlled permeability of the pack-thus controlling the biochemical, enzymatic and microbial actions so as to avoid or decrease the main degradations that might occur. This allows the preservation of the fresh state of the food product without the temperature or chemical treatments used by competitive preservation techniques, such as canning, freezing, dehydration and other processes.

MAP is the replacement of air in a pack with a single gas or mixture of gases; the proportion of each component is fixed when the mixture is introduced. No further control is exerted over the initial composition, and the gas composition is likely to change with time owing to the diffusion of gases into and out of the product, the permeation of gases in to and out of the pack, and the effects of product and microbial metabolism (Church, 1994).

The normal composition of air is 21% oxygen, 78% nitrogen and less than 0.1% carbon dioxide. Modification of the atmosphere within the package by reducing the oxygen content while increasing the levels of carbon dioxide and/or nitrogen has been shown to significantly extend the shelf-life of perishable foods at chill temperatures.

History

MAP was first recorded in 1927 as an extension of the shelf-life of apples by storing them in atmospheres with reduced oxygen and increased carbon dioxide concentrations. In the 1930s it was used as modified atmosphere storage to transport fruit in the holds of ships and increasing the carbon dioxide concentration surrounding beef carcasses transported long distances was shown to increase shelf-life by up to 100% (Davies, 1995). However, the technique was not introduced commercially for retail packs until the early 1970s in Europe. In the UK, Marks and Spenser introduced MAP meat in 1979; the success of this product led, two years later, to the introduction of MAP, bacon, fish (both fresh and cured), sliced cooked meats and cooked shellfish. Other food manufacturers and supermarket chains followed, resulting in a sharply increased availability of MAP food products reflecting the increase in consumer demand for longer shelf-life foods and less use of preservatives. MAP techniques are now used on a wide range of fresh or chilled foods, including raw and cooked meats and poultry, fish fresh pasta, fruit and vegetables and more recently coffee, tea and bakery products.

Advantages and disadvantages of MAP

Advantages of MAP:

a) Increased shelf-life allowing less frequent loading of retail display shelves;
b) Reduction in retail waste;

c) Improved presentation-clear view of product and all round visibility;
d) Hygienic stackable pack, sealed and free from product drip and odour;
e) Easy separation of sliced products;
f) Little or no need for chemical preservatives;
g) Increased distribution area and reduced transport costs due to less frequent deliveries;
h) Centralised packaging and portion control;
i) Reduction in production and storage costs due to better utilisation of labour, space and equipment.

Disadvantages of MAP:

a) Capital cost of gas packaging machinery;
b) Cost of gases and packaging materials;
c) Cost of analytical equipment to ensure that correct gas mixtures are being used;
d) Cost of quality assurance systems to prevent the distribution of leakers, etc.
e) increased pack volume which will adversely affect transport costs and retail display space;
f) potential growth of food-borne pathogens due to temperature abuse by retailers and consumers;
g) benefits of MAP are lost once the pack is opened or leaks.

Gases Used in MAP

The basic concept of the MAP of fresh foods is he replacement of the air surrounding the food in the package with a mixture of atmospheric gases different in proportion from that of air.

Table 1. Gaseous composition of dry air at sea level (Parry, 1993)

Gas	Percentage
Nitrogen (N_2)	78.03
Oxygen (O_2)	20.99
Argon (Ar)	0.94
Carbon dioxide (CO_2)	0.03
Hydrogen (H_2)	0.01

Oxygen (O_2)

Food deteriorates due to physical, chemical and microbiological factors. Oxygen is probably the most important gas in this context being used metabolically by both aerobic spoilage micro organisms and plant tissues and taking part in some enzymic reactions in food including the compounds such as vitamins and flavours. For these reasons, in modified atmosphere packaging, oxygen is either excluded or the levels set as low as possible. The exceptions occur where oxygen is needed for fruit and vegetable respiration, colour retention as in the case of red meat or to avoid anaerobic conditions in white fish (Parry, 1993). In MAP, oxygen levels are normally set as low as possible to reduce oxidative deterioration of foods. Oxygen will generally stimulate the growth of aerobic bacteria and can inhibit the growth of strictly anaerobic bacteria, although there is a very wide variation in the sensitivity of anaerobes to oxygen. One of the major functions of O_2 in MAP meats is to maintain myoglobin in its oxygenated form, oxymyoglobin. This is the form responsible for the bright red colour, which most consumers associate with fresh red meat (Farber, 1991).

Carbon dioxide (CO_2)
Carbon dioxide is both water and lipid soluble and although it is not a bactericide or fungicide, carbon dioxide has bacteriostatic and fungistatic properties. The overall effect on micro organisms is an extension of the lag phase of growth and a decrease in the growth rate during the logarithmic growth phase. However, the former effect is greater and therefore as bacteria move from the lag to log phase of growth the inhibitory effects are reduced. Thus, the earlier the product is gas packaged the more effective CO_2 will be (Brody, 1989). This bacteriostatic effect is influenced by the concentration of CO_2, the partial pressure of CO_2, volume of headspace gas, the type of micro organism, the age and load of the initial bacterial population, the microbial growth phase, the growth medium used, the storage temperature, acidity, water activity, and the type of the product being packaged (Church, 1994; Farber, 1991; Phillips, 1996; Church and Parsons, 1995). Yeasts which produce carbon dioxide during growth are stimulated by high levels of carbon dioxide and thus for some products where they are potentially a major cause of spoilage, MAP may not be an advisable option. Also the food-associated pathogens *Clostridium perfringens* and *Clostridium botulinum* are not affected by the presence of carbon dioxide and their growth is encouraged by anaerobic conditions. In general carbon dioxide is most effective in foods where the normal spoilage organisms consist of aerobic, gram-negative psychrotropic bacteria (Hotchkiss, J., 1998; Phillips, 1996).

For maximum antimicrobial effect, the storage temperature of MAP product should be kept as low as possible, because the solubility of CO_2 decreases dramatically with increasing temperature. Thus, improper temperature control will usually eliminate the beneficial effects of elevated CO_2. The absorption of CO_2 is highly dependent on the moisture and fat content of the product. If product absorbs excess CO_2, the total volume inside the package will be reduced, giving a vacuum package look known as “pack collapse”. Excess CO_2 absorption in combination with “pack collapse” can also reduce water holding capacity of meats, resulting in unsightly drip. Some dairy products (e.g. cream) are very sensitive to CO_2 concentrations and will be tainted if packed in MA with high CO_2 levels. Fruits and vegetables can suffer physiological damage due to high CO_2 levels.

For practical purposes, in most foods, gaseous CO_2 is applied to a biological tissue would exist in the liquid phase of the tissue primarily dissolved CO_2 gas and carbonic acid (about 2%). At pH ? 6.0, carbonic acid will dissociate to form bicarbonate and hydrogen ions, the latter of which likely causes the small pH drop (? 0.1 pH unit) often observed in muscle tissue packaged in a CO_2 atmosphere (Daniels et al, 1985). This minimal pH decrease would not cause any significant biostatic activity.

Although the bacteriostatic effect of CO_2 has been known for many years, the precise mechanism if its action is still a subject of considerable interest. There have been many theories regarding the way in which CO_2 exerts its influence on a bacterial cell. These can be summarized as follows (Daniels et al, 1985; Dixon and Kell, 1989):

a) Alteration of cell membrane function including effects on nutrient uptake and absorption;
b) Direct inhibition of enzymes or decreases in the rate of enzyme reactions;
c) Penetration of bacterial membranes, leading to intracellular pH changes;
d) Direct changes to the physio-chemical properties of proteins.

Nitrogen (N_2)

Nitrogen is an inert tasteless gas, which displays little or no antimicrobial activity on its own. Because of its low solubility in water and fat, the presence of N_2 in a MAP food can prevent pack collapse that can occur when high concentrations of CO_2 are used. In addition, N_2, by displacing O_2 in the pack, can delay oxidative rancidity and also inhibit the growth of aerobic micro organisms. In foods such as nuts, removing oxygen to <%1 by nitrogen flushing helps prevent oxidative rancidity of fats. Nitrogen can also indirectly influence the micro organisms in perishable foods by retarding the growth of aerobic spoilage organisms (Farber, 1991; Phillips, 1996). The second role of nitrogen in MAP is to act as a filler gas and keeps flexible packages from developing a vacuum.

Exactly what combination of gases is used depends on many factors, such as the type of the product, packaging materials and storage temperature. The packaging system selected must have sufficient headspace to provide enough gas to interact with the entire product. The headspace must contain a reservoir of CO_2 to compensate for gas absorbed by the product and lost across the packaging material (Parry, 1993). The longer the required shelf-life then the larger the headspace should be.

Carbon monoxide (CO)

This has been found to be very effective in maintaining the red colour in fresh meat due to the formation of carboxymyoglobin. It has not been used commercially for this purpose however since carbon monoxide, a highly toxic gas is not approved by the regulatory authorities owing to the possible health hazard to packaging machine operatives. Its use has, however, been sanctioned in the United States to prevent browning in packed lettuce. Carbon monoxide has little inhibitory effect on micro organisms.

Other Gases

The potential of various other gases such as chlorine, etyhlene oxide, nitrogen dioxide, ozone, propylene oxide and sulphur dioxide for modified atmosphere packaging have been investigated experimentally but their commercial use for packaging foods is unlikely to meet with approval from the regulatory authorities.

Gas Mixtures

There are three types of gas mixtures used in modified atmosphere packaging (Goodburn and Halligan, 1988):

1) Inert blanketing (N_2)
2) Semi-reactive blanketing (CO_2/N_2 or $O_2/CO_2/N_2$)
3) Fully-reactive blanketing (CO_2 or CO_2/O_2)

The gas mixtures recommended for a typical range of products are listed in Table 2.

Table 2. Recommended gas mixtures of MAP (Parry, 1993)

Product	% Oxygen	%Carbon dioxide	%Nitrogen
Red meat	60-85	15-40	-
Cooked/cured meats	-	20-35	65-80
Poultry	-	25	75
Fish (white)	30	40	30
Fish (oily)	-	60	40

Salmon	20	60	20
Hard cheese	-	100	-
Soft cheese	-	30	70
Bread	-	60-70	30-40
Non-dairy cakes	-	60	40
Dairy cakes	-	-	100
Pasta (fresh)	-	-	100
Fruits and vegetables	3-5	3-5	85-95
Dried/roasted foods	-	-	100

Packaging Materials

There are six main characteristics to consider when selecting packaging material for MAP foods:

1) Resistance to puncture
2) Sealing reliability
3) Antifogging properties
4) Carbon dioxide permeability
5) Oxygen permeability
6) Water transmission rate

Although an increasing choice of packaging materials is available to the MAP industry, most packs are still constructed from four basic polymers: polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyproylene (PP) and polyethylene (PE).

Machine Systems for MAP

The first element for optimum gas packaging is appropriate equipment. There are two different techniques to replace the air:

1) Gas flushing
2) Compensated vacuum.

The gas flush technique is normally accomplished on a form fill-seal machine. The replacement of air inside a package is performed by a continuous gas stream. This gas stream dilutes the air in the atmosphere surrounding the food product. The package is then sealed. Since the replacement of air inside the package is accomplished by dilution, there is a limit on the efficiency of this unit. Typical residual oxygen levels in gas flushed packs are 2-5% O_2. Therefore, if the food item to be packaged is very oxygen sensitive, the gas flush technique is normally not suitable. So when considering a packaging system it is important to consider the oxygen sensitivity of the food product.

The great advantage of the gas flush technique is the speed of the machine. Since the action is continuous, the product rate can be very high. The compensated vacuum technique removes the air inside by pulling a vacuum on the atmosphere inside the package and then breaking the vacuum with the desired gas mixtures. Since the replacement of the air is accomplished in a two-step process, the speed of operation of the equipment is slower than the gas flush technique. However, since the air is removed by vacuum and not simply diluted, the efficiency of the unit with respect to residual air levels is better. Therefore, if the food product is extremely sensitive to oxygen, a compensated vacuum machine must be used.

Methods of Creating Modified Atmosphere Conditions

Modified atmospheres can be created either passively by the commodity or intentionally via active packaging (Kader et al, 1989; Zagory and Kader, 1988)

Passive modified atmosphere: Modified atmospheres can passively evolve within a hermetically sealed package as a consequence of a commodity's respiration, i.e. O_2 consumption and CO_2 evolution. If a commodity's respiration characteristics are properly matched to film permeability values, then a beneficial modified atmosphere can be passively created within a package. If a film of correct intermediary permeability is chosen, then a desirable equilibrium modified atmosphere is established when the rates of O_2 and CO_2 transmission through the package equal a product's respiration rate.

Active packaging: 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.

Another active packaging technique is the use of O_2, CO_2 or ethylene scavengers/emitters. Such scavengers/emitters are capable of establishing a rapid equilibrium atmosphere within hermetically sealed produce packages.

Application of MAP to Fruit and Vegetables

There are many advantages of MAP fruit and vegetables, but the most obvious one must be the extension of shelf-life. By decreasing the amount of available oxygen to the produce, the respiration rate and the rate of all metabolic processes are correspondingly decreased. This results in delayed ripening and senescence, which may be seen as chlorophyll retention, delayed softening and the prevention of discoloration. The extension of shelf-life is most noticeable with prepared products; this, combined with ease of use for the consumer, makes a MAP pack an attractive form of product presentation. Additionally, MAP packs reduce the quantity of water vapour lost from the produce.

Although fresh fruit and vegetables have been removed from the parent plant and from their normal nutrient supplies, they will continue to respire. Under normal aerobic conditions, the rate of respiration of a product may be determined by either oxygen uptake rate or carbon dioxide production rate. A high respiration rate is usually associated with a short shelf-life. When the rate of packaging film transmission of oxygen and carbon dioxide equals the rate of respiration of the product, an equilibrium concentration of both gases is established.

The equilibrium values attained depend on:

a) The respiration rate of the product
b) Fill weight of product
c) The film surface area which is available for gas exchange

The respiration rate of the product is influenced by:

a) Storage temperature
b) Produce variety
c) Growing area and conditions
d) Injury to the produce

Chill temperatures are generally chosen for fresh produce because fruit and vegetables respire slowly at low temperatures, as do many micro organisms, which are likely to spoil the product (Day, 1989). Some fruits and vegetables, most notably ones from tropical or sub-tropical areas, are susceptible to chilling injury.

Future Research Needs

To utilise MAP technology for wide range of fresh produce, it is necessary to generate some additional information which are (Gorris and Peppelenbos, 1992; Parry, 1993):

a) Film permeability data at realistic temperatures between 0 and 20?C and realistic RHs between 85 and 95%;
b) Respiration rates of fresh and prepared produce under several temperature and MAP conditions;
c) Data on the synergistic effects of elevated levels of CO_2 and depleted information on how any residual effects of MAP may alter a commodity's response to subsequent storage in air;
d) Data on the RQ (respiratory quotient, i.e. the ratio of CO_2 produced to O_2 consumed)
e) Data on the diffusion resistance of various commodities under different atmospheric and temperature conditions.

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