Modified-atmosphere packaging (MAP) has the ability to extend the shelf life of foods, and has brought about major changes in the storage and distribution of raw materials, and in the marketing of food products. New developments in MAP packaging materials, machinery and related sensor technology mean that the next generation of MAP systems will offer further improvements in food shelf life, organoleptic quality, product range and safety.

Developments in modified-atmosphere packaging and related technologies

Nick Church

The ability of modified-atmosphere packaging (MAP) to extend the shelf life of foods has been recognized for many years. Indeed, over 100 years ago a patent was granted covering the use of a CO_2/CO gas mixture to extend the shelf life of meat. The first major commercial application of MAP did not take place until 1974, when the French company SCOPA started selling MAP meat.

In the UK, in 1979, the retailer Marks & Spencer Ltd (London, UK) paved the way for the UK's pre-eminence today in the world marketplace for MAP products, with its test launch of MAP meat[1]. Other food retailers at the time felt that MAP was 'a non-starter', 'too expensive for low-value products such as minced beef', 'wouldn't be liked by the consumer', and 'unnecessary'.

However, since then there has been a marked expansion in the use and market share of MAP, partly as a result of the increasing consumer demand for fresh and chilled convenience foods. Today, MAP foods include raw and cooked meats, poultry, fish, crustaceans, vegetables, fruit, fresh pasta, dairy products, bakery products, crisps, coffee and tea.

For some products, MAP has become the dominant packaging method; ~95% of fresh pasta sold in the UK is MAP. Chilled meat still dominates the MAP market, accounting for 30% of MAP products sold; snacks and dried food account for 14% of the MAP market, cooked meats 13% and seafood 10%. The sector showing the most growth is fresh fruit and vegetables, particularly prepared salads. The use of MAP in the bakery/morning goods market has also begun to develop, including part-baked bread, muffins, croissants, pizzas and quiches[2]. New added-value MAP products have also began to appear, including tropical fruit salads, peeled pineapple, parfried chips and prepared vegetables with dressing.

While MAP has proved beneficial in extending the shelf life of a wide variety of products, with certain products it may have less potential, since processing operations (e.g. curing, freezing, drying and cooking) already help to extend their shelf life. With some products, no increase in shelf life may be obtained by choosing MAP over alternative packaging methods. However, other advantages (e.g. easier slice separation and improved product presentation) may make MAP beneficial. With the exception of microbiologically shelf-stable products such as crisps and nuts, proper refrigeration is required during product storage in order for MAP to be successful and safe. Good manufacturing practices should be followed for all MAP products, and advice is available from a variety of sources[1,3–5].

There are several techniques by which the atmosphere surrounding a product can be modified, and often the terminology is confusing. The various terms and techniques are explained in Box 1.

Gases used in MAP

The choice of gas mixture used is influenced by the microbiological flora capable of growing on the product, the product's sensitivity to O_2 and CO_2, and colour-stabilizing requirements (e.g. the preservation of oxymyoglobin in fresh meat and of nitrosomyoglobin in cured meat products).

The gases normally used in MAP are those found in the atmosphere: O_2, CO_2 and N_2.

Oxygen (O_2)

O_2 generally stimulates the growth of aerobic bacteria and inhibits the growth of strictly anaerobic bacteria, although there is a very wide variation in the sensitivity of anaerobes to O_2. The presence of O_2 is very important in the storage of fresh meats as it maintains the meat pigment myoglobin in its oxygenated form, oxymyoglobin, which gives fresh meat its bright red colour. Typically, fresh meat is modified-atmosphere packaged in an 80% O_2/20% CO_2 atmosphere. For certain products, however, the presence of O_2 may cause oxidative rancidity or colour problems (e.g. fatty fish and cured meats, respectively). For this reason, bacon is typically modified-atmosphere packaged in 35% CO_2/65% N_2. Low levels of O_2 (~0.5%) may cause chilled meat to go brown and cured meat products to go grey/brown, or cause greening in under-cooked meat products[10].

Some researchers recommend the inclusion of 5–10% O_2 to certain MAP products[11], as an added safety factor against the growth of anaerobic pathogens, in particular *Clostridium botulinum*. However, unless the atmosphere within the package is controlled (see Box 1), the gas

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Box 1. Modified-atmosphere packaging and related technology/terminology

Modified-atmosphere packaging (MAP): Often confused with, or mistakenly labelled, controlled-atmosphere packaging (see below). MAP is the replacement of air (N_2 content 78.08%, O_2 content 20.95%, CO_2 content 0.035%, together with water vapour and traces of inert gases) 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 into and out of the pack, and the effects of product and microbial metabolism.

Controlled-atmosphere packaging (CAP) and controlled-atmosphere storage (CAS): The proportion of each gas is maintained (controlled) at the original level introduced throughout the distribution cycle, regardless of temperature or other environmental variations. CAP and CAS techniques are used primarily for the bulk storage and transport of products, and require constant monitoring and control of the gas composition within the package. With recent developments in high-barrier films, intelligent packaging, tray-ready master packs, gas scavengers and gas producers (see 'Developments in MAP', below), the distinction between MAP and CAP is no longer clear.

Equilibrium-modified-atmosphere (EMA) packaging: This technique is used primarily for the packaging of fresh fruit and vegetables. Either the pack is flushed with the required gas mix or the produce is sealed within the pack with no modification to the atmosphere. Subsequent respiration of the produce and the gas permeability of the packaging allow an equilibrium-modified atmosphere to be reached. EMA is also called **passive atmosphere modification (PAM)**.

Vacuum packing (VP): The product is placed in a pack of low oxygen permeability, air is evacuated and the package sealed. Since it is not currently possible to evacuate all the air (~0.3–3% may remain after sealing), the gaseous atmosphere of the vacuum package is likely to change during storage (owing to microbial and product metabolism, and gas permeation) and therefore the atmosphere becomes modified.

Vacuum-skin packing (VSP): Vacuum-skin methods involve draping a softened film over the product and applying a vacuum so that a skin is formed. This allows the vacuum packing of delicate products that would normally be crushed under vacuum, and also of products that would puncture vacuum films, such as lobsters.

Gas-exchange preservation (GEP): Gas-exchange preservation involves pumping air out of the pack and replacing it with a series of gases, each with a different role, in quick succession[6]. CO is added first to inhibit enzymes, followed by SO_2 or ethylene oxide to kill microorganisms, and finally N_2 to flush out the pack. While the initial investigations showed promising results, further work on GEP has been suspended since, because of the lethal and corrosive nature of some of the gases used, it was considered unlikely that such a system would gain worldwide regulatory approval. However, its use as a food-processing aid, rather than a packaging technique, may warrant further investigation. For instance, the HYPAZ company's (Vancouver, Canada) sterilization process uses pure O_2 under pressure (200 kPa) to kill microorganisms in both whole shell eggs and liquid egg[7]. Cooking in atmospheres rich in H_2 might offer a means of minimizing heat treatments, since H_2 accelerates the thermal inactivation of *Clostridium botulinum* spores[8]. Sparging and blanketing soybean oil and milk storage tanks with N_2 also improves product shelf life[9].

composition surrounding the product will change with time. Although O_2 levels will decrease during storage, its inclusion at the beginning of packaging may favour the growth of competitive microflora, helping inhibit the growth of any anaerobic pathogens present. However, further investigation is needed. Furthermore, although *Cl. botulinum* would not be expected to grow on the surfaces of products exposed to air, it could grow a few millimetres below the surface, where anaerobic conditions may exist, and microenvironments may exist where O_2 levels are low enough to permit the growth of anaerobic microorganisms, even though the overall O_2 level in the package headspace might suggest otherwise.

Nitrogen (N_2)

N_2 is an inert, tasteless gas with low solubility in both water and lipid. N_2 is used to displace O_2 in packs and storage vessels so as to delay oxidative rancidity and inhibit the growth of aerobic microorganisms. Owing to its low solubility, it is used as a filler gas to prevent pack collapse ('snuffing'), which can be a problem in atmospheres containing high CO_2 concentrations.

Carbon dioxide (CO_2)

CO_2 is both water- and lipid-soluble and is mainly responsible for the bacteriostatic effect on microorganisms in modified atmospheres. The overall effect on microorganisms is an extension of the lag phase of growth and a decrease in the growth rate during the logarithmic growth phase. This bacteriostatic effect is influenced by the concentration of CO_2, the age and load of the initial bacterial population, the storage temperature and the type of product being packaged[12].

Although the bacteriostatic effect of CO_2 has been known for many years, the precise mechanism of its action is still a subject of considerable scientific interest. With high-moisture foods such as meat, poultry meat and seafood, excessive absorption of CO_2 can cause pack collapse. Pack collapse is used to good advantage by the dairy industry in packaging wedges of hard cheese. The absorption of CO_2 by the cheese collapses the film around the cheese, which produces a pack with a soft vacuum appearance. However, packaging in high CO_2 concentrations can cause increased drip in fresh meat, fluid release in ham, product separation in cream, physiological damage to fruit and vegetables, and a 'sherbet-like' taint in fatty fish[1]. In the past, adverse colour reactions (e.g. greying/browning) were also attributed to packing in 100% CO_2, but it is now recognized that these reactions are due to the low levels of oxygen in the pack, rather than to the presence of CO_2 *per se*[10].

Other gases

A wide variety of other gases have been investigated experimentally for their potential use in MAP applications. Other gases that have been considered include

SO_2, nitrous oxide (N_2O), nitric oxide (NO), ozone (O_3), He, H_2, Ne, Ar, propylene oxide, ethylene and Cl_2. However, the use of these gases has been limited by safety concerns, legislation, adverse consumer response, cost and negative effects on the organoleptic properties of packaged products[10].

Packaging materials

Although an increasing choice of packaging materials is available to the MAP industry, most packs are still constructed from four basic polymers: poly(vinyl chloride) (PVC), poly(ethylene terephthalate) (PET), polypropylene (PP) and polyethylene (PE)[2].

Pack design and packaging equipment

Another area of increasing diversification and innovation within the MAP industry is pack design and packaging equipment, though there are still only three basic retail MAP formats available: the semi-rigid tray (e.g. for meat); the pillow pouch format (e.g. for fresh salads); and the flowpack format (e.g. for cheeses and bakery products)[2]. In addition to these retail formats, there is increased use of 'bag-in-box', 'master pack' and 'mother pack' systems, which allow centralized packaging operations. The machinery used to produce these packs can be divided into four types: rigid and semi-rigid lidded tray packers; flexible horizontal flow-wrap packers; flexible vertical form-fill seal packers; and bulk box/drum packers.

Microbiology of MAP

Microbial spoilage

Gram-negative bacteria are generally more sensitive to CO_2 than are Gram-positive bacteria[12]. In chill-stored proteinaceous foods such as meat and fish, this generally results in the inhibition of the Gram-negative *Pseudomonas* spp., Enterobacteriaceae, *Acinetobacter* spp. and *Moraxella* spp., while the Gram-positive lactic acid bacteria and *Brochothrix thermosphacta* instead become the dominant organisms.

As moulds have an absolute requirement for O_2, packaging in an anaerobic modified atmosphere can be extremely successful in extending the shelf life of foods for which mould spoilage is the major concern, such as bakery products or hard cheeses. If CO_2 is used to produce the modified atmosphere, there is also the additional benefit of the antibacterial and anti-mould activity of CO_2. However, there is concern that the increased shelf life may give rise to safety problems, as discussed below.

Microbial safety – *Clostridium botulinum*

Most of the research on MAP products has concentrated on the extension of product shelf life. Concerns have been expressed as far back as 1933, and more recently by regulatory authorities and food industry groups (the National Food Processors Association, Washington, DC, USA) that MAP may represent an undue safety hazard for certain products[10,13]. It has been suggested that the suppression of spoilage microflora might result in products containing large numbers of pathogenic microorganisms or toxin while still appearing to be organoleptically acceptable[14]. Historically, the non-proteolytic, psychrotrophic strains of *Cl. botulinum* have been the major safety concern. These strains can grow and produce toxin without producing overt signs of spoilage.

Historically, fish and fish products have been the greatest cause for concern with respect to *Cl. botulinum* growth in MAP products, resulting in the US National Academy of Sciences recommending that fish should not be packed under modified atmospheres until the safety of the system has been established[15]. The concern results from the fact that all strains of *Cl. botulinum* are found in marine environments, and although the distribution varies greatly with the geographic location and season, it is common enough that fish processors must assume it is present[3].

One approach that may provide the required safety with respect to *Cl. botulinum* in MAP fish is the use of a pretreatment step in combination with MAP. Potassium sorbate, sodium chloride and irradiation have all been shown to be effective[16]. Since treatments such as potassium sorbate dips, although effective, are not currently legal in the majority of countries involved in MAP, other possible safeguards are the incorporation of time–temperature indicators or gas indicators on packs (see below, under 'Developments in MAP') to warn consumers of packs that have been temperature abused[17]. However, unless automatic scanning technology is used to identify such products at the time of sale, the effectiveness of indicator technology will be dependent on the consumer noticing and following the advice given by the indicator.

Other pathogens

More recently, concerns have been expressed about the ability of the other psychrotrophic pathogens (e.g. *Aeromonas*, *Listeria* and *Yersinia* spp.) to grow in MAP products[18].

At the Leatherhead Food RA, we have recently completed two European Community projects (not yet published) that examined pathogen growth/survival on MAP fish (funded by the European Community, the UK Ministry of Agriculture, Fisheries and Food, and individual member companies of the Leatherhead Food RA), and MAP meat and meat products (funded by the European Community, the UK Ministry of Agriculture, Fisheries and Food, the UK Meat and Livestock Commission, and individual member companies of the Leatherhead Food RA).

The studies with fish concentrated on cod (*Gadhus morhua*) and rainbow trout (*Oncorhynus mykiss*), with storage at 0°C, 5°C and 12°C. In no instance was the growth/survival of any of the pathogens examined (*Listeria monocytogenes*, *Aeromonas* spp., *Yersinia enterocolitica* and *Salmonella typhimurium*) greater under MAP than in the aerobically stored control, and frequently growth was reduced under MAP.

The studies on meat concentrated on raw beef but also included cooked and dry-cured hams, lamb, pork, chicken and other poultry meat. With one exception, microbial growth/survival in MAP beef was never greater than that in the vacuum-packed control, and occasionally growth was reduced by using MAP. The one exception was verotoxigenic *Escherichia coli* (VTEC) on minced beef stored at 12°C, in which growth was more rapid in one of the modified atmospheres (80% O_2/20% CO_2) examined than in the vacuum-packed control, although it was slower than that in the aerobically stored product. Pathogen growth was never greater in MAP ham than in the vacuum-packed control, and was frequently reduced. Studies of pathogen growth/survival on MAP/VP lamb gave variable results between replicates, possibly as a result of pH differences and/or bacteriocin production; however, MAP often decreased pathogen growth/survival in lamb and poultry meat.

Overall, our results and the majority of those reported in the literature indicate that the risks from foodborne pathogens in MAP are no greater and are frequently less than those from aerobically stored foods. These findings are substantiated by the excellent safety record, to date, of MAP[10]. However, it must be stressed that the above European Community projects did not include studies of *Cl. botulinum*.

As is the case for almost all aspects of food production, the hazard analysis and critical control points (HACCP) system is likely to play a major role in ensuring the safety of MAP foods[17].

Developments in MAP

A number of recent developments offer the potential to improve further the safety of MAP and extend the technology available to a wider range of products and countries.

The development of 'smart'[19] films, more recently described as 'active'[20] or 'intelligent'[21] packaging, is probably the most significant area of advancement of MAP technology. Intelligent packaging has been defined as 'an integral component or inherent property of a pack, product or pack/product configuration which confers intelligence appropriate to function and use of the product itself and has the ability to sense or be sensed and to communicate'[21]. Intelligent packaging techniques have been categorized under ten headings[22]:

- O_2 removal;
- O_2 barrier;
- water removal;
- gas indicator;
- ethylene removal;
- CO_2 release;
- antimicrobial action;
- preservative release (e.g. ethanol generators);
- aroma release;
- taint removal.

Time–temperature indicators and edible films should now be added to the above list.

O_2-scavenging technology and low-permeability films

Of the above techniques, O_2 scavengers have probably received the widest attention and greatest commercial success.

Like MAP, the use of O_2 absorbers is not a new idea; there have been reports on the removal of O_2 within packages as far back as 1920. Two approaches to the development of O_2-scavenging systems have been examined. The most successful commercially has been the use of sachets and labels that are included in the pack. The second and most exciting area has been the development of O_2-scavenging films. Immobilization of oxidizing enzymes (glucose oxidase and alcohol oxidase) on the inner surface of the packaging film has also been shown to be technologically feasible as a method of scavenging O_2; the cost of this system, however, makes commercial application unlikely.

The most commercially successful system, under the trade name 'Ageless', was introduced in Japan in 1977 by the Mitsubishi Gas Chemical Company (Tokyo, Japan)[23]. Depending on the method of MAP used, residual O_2 contents can be reduced to 2000–70 000 ppm[24].

Scavengers are available that are capable of scavenging up to 2000 ml of O_2 from 10 000 ml of air. Some O_2 scavengers currently available can be 'poisoned' by high CO_2 concentrations[1], rendering them incapable of absorbing O_2.

The Mitsubishi Gas Chemical Company also markets an O_2 indicator system ('Ageless eye'). The indicator is pink when there is no ($\leq$0.1%) O_2 in the environment and blue if O_2 is present at concentrations of $\geq$0.5%. The indicator can be used to check the efficiency of packaging systems in maintaining low O_2 levels[10]. In addition, O_2 indicators based on O_2-sensitive inks are being developed by Dia Nippon Printing (Tokyo, Japan). These change colour at a range of preset O_2 levels; they may prove useful in checking pack integrity, giving a non-intrusive measurement of O_2 level at any given time, and may also provide an indirect indication of the microbial status.

For products in which the removal of O_2 could permit anaerobic food pathogens to survive in the product, creating a safety hazard, it is recommended that one or more of the following criteria should be met[25]:

- a_w (water activity) <0.92;
- pH <4.5;
- addition of sodium nitrite (level governed by legislation);
- temperature maintained below +3°C.

The use of in-package O_2 scavengers, and the resistance encountered to their adoption in the USA, has been critically reviewed[26]. The greater fear in the USA of litigation arising from accidental ingestion of the scavenger, the relatively greater cost of packaged food in Japan, and the more receptive nature of the Japanese to having a package of chemicals placed in their food package have been the major factors in the greater acceptance of this technology in Japan. Packages have now been developed in which the O_2-scavenging sachet is presented in a separate sealed compartment to the product, so as to prevent its accidental consumption[17]. Recently, O_2-absorbing labels have been introduced into the UK market for smoked and processed delicatessen meat products[10]. Marks & Spencer Ltd has incorporated 'Freshmax' O_2-absorbing labels from Multiform Desiccants (Buffalo, NY, USA), which help to keep O_2 levels in packs below 100 ppm (0.01%) in a range of sliced meat products. The product is presented with a paper label; the O_2-absorbing label is positioned on the lidstock under this paper label. Information on the outside product label tells the consumer that the absorber inside helps to retain product freshness. The O_2 absorber cannot be seen by the consumer until the pack is opened. It is claimed that this application opens the door for future usage in the USA because the fear of ingestion is eliminated.

New types of O_2 absorbers have recently been developed. These include some for use with frozen foods, which overcome the slow absorption speed of the standard types at low temperatures, and others that are microwaveable[10].

O_2 scavengers can now be found in packages of many foods, including bakery items like bread, cakes, cookies, pizza crust and pastry, as well as precooked pasta, cured or smoked meats and fish, dry tea, dried fish, cheese, soft cookies, beans, potato chips, dried eggs, spices, nuts, coffee and chocolates[27].

Another approach to preventing O_2 ingression problems in MAP, often used in conjunction with O_2 scavengers, is the use of barrier films with low O_2 permeability. Currently, only aluminium foil (9 μm or thicker) provides an 'absolute' flexible barrier to O_2, but it does not let the consumer see the product[28]. To get round this problem, some foil packs have been developed with clear windows built in, but the windows allow some O_2 ingression. As an alternative, considerable effort has been invested in developing clear high-barrier films. The Swiss meat company Bell of Basel has launched pasteurized, chilled 'Quick meats' in stand-up, glass-coated microwaveable film pouches ('Ceramis' from Lawson Mardon Flexi, Avon, UK). Other silica-coated films commercially available include 'Techbarrier films' from Mitsubishi Kashei (Tokyo, Japan), which have water vapour transmission rates of <1 g/m^2 and O_2 transmission rates of <1 ml/m^2. Quartz-like films are available from Airco Coating Technology (Fairfield, NJ, USA), who are actively pursuing commercialization[29]. Glass-coated films from Himacs (Danbury, CT, USA) are cost-competitive and are available in commercial quantities, overcoming previous problems that have hampered the development of this particular market. A rival to silicon oxide coatings, aluminium oxide coatings can also provide good barrier properties together with transparency. A.D. Tech (Taunton, MA, USA) is spearheading this technology, and predicts that 'Strong environmental legislation will force the use of oxide coatings as replacements for foils and metallized films'[29]. Allied Signal (Morristown, NY, USA) has added four new nylon-based films, called 'Oxyshield', to its product line. The new films are based on a variety of different co-extrusions, including a co-extrusion of uniaxially oriented nylon/amorphous nylon/nylon with a permeability of 0.48 ml/m^2/24 h/atm at a relative humidity of 0%.

Another interesting area is the impregnation of packaging films with 'stabilizer' additives such as α-tocopherol. Films containing α-tocopherol (e.g. 'Ronotec 201' from Hoffman la Roche, Basel, Switzerland) have been shown to reduce the rate of film yellowing (a common problem in early clear barrier films), and the problem of 'aroma scalping' [see article by Jägerstad and Nielsen in this issue] in MAP cereal[30]. The impregnation or encapsulation of other stabilizer additives into packaging is an area that is likely to see considerable research effort in the future. For instance, the technology exists to impregnate packaging films with organic acids, so that a metered release of the additive occurs during storage, helping to inhibit microbial growth on the product surface. One day hybrid MAP technologies may become available that enable products to be sterilized simply by being packed, or that enable the packaging process to encompass manufacturing stages, for example converting pork into dry-cured bacon.

High-permeability films

For some applications, such as the equilibrium-modified-atmosphere packaging of fruit and vegetables, high-permeability films are needed; these have been recently reviewed[2]. A number of methods have been used to obtain high permeability, including the use of micro-perforated films or patches. Temperature-controlled smart films, which change in permeability dramatically at preset temperatures, are also being developed[2].

CO_2 scavengers and emitters

In parallel with the development of O_2-scavenging systems, several systems have been developed that are capable of either absorbing or generating CO_2. Some of these systems are also able to absorb or generate O_2, and to absorb off-odours.

A commercially available sachet system ('FreshLock') capable of scavenging both O_2 and CO_2 has been marketed by the Mitsubishi Gas Chemical Company (Tokyo, Japan). The system has been used mainly for freshly roasted coffee beans in flexible bags, and more than triples the shelf life. An alternative method is the incorporation of one-way valves[9], which release CO_2 from the pack without allowing other gases to enter. This system has been used to stop coffee packs from bursting, and for the MAP of mould-ripened cheese. Highly CO_2-permeable pouches can also be used to pack coffee[9].

Pack collapse can be a problem when high-moisture or fatty foods are packed in CO_2. Pack collapse problems are often minimized simply by limiting the proportion of CO_2 to less than 40% and having a large headspace. Valle Spluga (Gordona, Italy) has developed a two-phase process to overcome such problems. A CO_2 tablet is placed in the thermo-formed tray immediately prior to gas flushing and sealing. The CO_2 sublimes, causing the pack to swell. After a few hours, an equilibrium is established in the headspace and the CO_2 is absorbed by the product, and the pack reverts back to its original shape. Other CO_2 pre-saturation systems are being developed[1].

Another commercial system ('Verifrais', by Codimer Tournessi, Gujan-Mestras, France) uses a porous chemical pouch containing mineral salts, which is fixed to the base of a tray and covered by a plastic grid. The pad is activated when water vapour from respiring fruits and vegetables or drip from meat passes through the grid. Depending on the particular salts used, which vary from one product to another, CO_2 and/or O_2 is released, or ethylene and/or CO_2 is absorbed[1].

Ethylene absorbers

Ethylene is a growth-stimulating hormone produced by fruits and vegetables during storage. If it accumulates in the pack, it speeds up product respiration rates, shortening product shelf life. Several ethylene-scavenging systems are available, mainly based on either activated carbon (e.g. 'Freshkeep' from Kurarey, Osaka, Japan) or potassium permanganate (e.g. 'Ace pack' from Nippon Greener, Tokyo, Japan). Silicon dioxide has also been used to scavenge ethylene, and can also be manufactured to act as a desiccant at the same time[1]. An impregnated mineral polyethylene film, capable of scavenging ethylene ('Peakfresh' from Klerk Plastic Industrie, Noordwijkerhoot, The Netherlands) has recently become available. The shelf life of broccoli was doubled when packed in this film[31].

Ethanol vapour generators

Ethanol has well-known antimicrobial properties and has been used to increase the shelf life of bakery products, cheese and semi-dried fish. One of the best-known commercial systems is the 'Ethicap' ethanol generator from Freund Industrial Co. (Tokyo, Japan). The mould-free shelf life of certain baked goods can be doubled by the inclusion of ethanol generators[32].

Tray-ready and bulk MAP systems

Until recently, technological advances have concentrated on single retail display packs. Increasing emphasis is now being placed upon bulk systems. In France, Socar (St Mandé, France) has introduced a large thermo-formed tray system inside an outer corrugated box, which has been used primarily for the MAP of catering portions of meat. Sodebo (St Georges de Montaigo, France) has developed 'Fresh Container', a stackable MAP system featuring special pillar support and film interleave between the top and base webs, which can be adapted for use in a wide variety of applications. It has already been used to pack groups of 12 pizza packs.

A variety of MAP tray-ready systems have also been developed. Early market developments suffered from colour problems (a blotchy product surface appearance) caused by poor temperature storage, poor sealing and pressure from other packs stacked on top. Improved pack design has largely overcome these problems.

The 'Flavaloc System' from Garwood Packaging (Indianapolis, IN, USA) is claimed to give a shelf life of 28 days at 32°F for chilled meats. The meat is loaded into an opaque tray, which is then overwrapped with a permeable film; the tray flange is heat sealed, and after evacuation and flushing with 70% N_2/30% CO_2 a high-barrier dome lid (which contains an O_2 scavenger) is sealed onto the tray. Prior to retail display (~45 min) the dome is removed to allow the meat to 'bloom' [the myoglobin (purple) is oxygenated to oxymyoglobin (red)][33]. The 'Windjammer' system from Pakor Inc. (Livingstone, TX, USA) is similar to the Garwood system but, instead of the removal of a dome, relies on the replacement of an O_2-rich gas mix through a septum in the pack prior to retail display[34]. Another approach, backed by a consumer education programme, has been simply to market purple (vacuum-packed) meat.

Multivac (Swindon, UK) has recently introduced an in-line, high-barrier version of the traditional expanded polystyrene tray, which can be lidded with conventional barrier top-web materials for MAP applications. A similar system ('Freshlife') has been developed by CVP Systems (Chicago, IL, USA). In the UK, a number of other companies are introducing hybrid vacuum-skin/modified-atmosphere packs[17]. Such packs ensure that the product is held in place during consumer handling, which also allows the products to be displayed vertically. The 'Darfresh Double Decker Packs' from Cryovac (Duncan, SC, USA) have been used to pack offal and other products.

The 'Captech' system, marketed by Borden (Columbus, OH, USA), was developed in New Zealand for the transport of lamb, and is now also used for beef transport. The system involves vacuum packing meat in permeable bags, which are heat-shrunk. These are then placed into a large impermeable foil bag, which is filled with 100% CO_2 and sealed. A 10–20% extension in storage life is claimed over vacuum-packed meat. It is suggested that with good manufacturing practice and storage at −2°C, beef may be stored for up to 16 weeks using this system. Preliminary commercial trials with Captech-packed meat products showed that shelf lives were 8–15 times greater than those of meat products stored in air. Roast beef was still considered acceptable after up to 24 weeks stored at −1°C. A similar shelf life has been obtained with a sliced stuffed lamb product. Cook–chill ready meals (meat, sauce, green vegetables and potatoes) were considered acceptable for up to 12 weeks[10].

Easy-opening and -resealing systems

Concerns over seal integrity meant that the first MAP packs were difficult to open. A number of alternative easy-open/reseal systems have become commercially available, such as 'Zipseal', which is being used by the French company Sodebo for packed ham.

Leak detection

One of the most significant advances in equipment has been the development of in-line, non-destructive leak detectors. The detection of leakers is one of the major challenges facing the MAP industry. A quick scan of most supermarket chilled meat product displays will soon reveal MAP packs of bacon that are still well within their use-by dates, but in which, owing to O_2 leakage into the pack, the bacon has changed in colour from pink to grey. Unless the bacon has also been temperature abused, it should still be safe to eat, but its grey colour will make consumer purchase unlikely. A wide variety of leak-detection systems have been developed, which detect leaks by a variety of methods including acoustic emissions, pressure differentials, gas detection or friction[35]. However, not all manfuacturers have installed adequate leak-detection systems. This may be partially due to the fact that such systems were not available in the infancy of MAP, the destructive nature of some test methods, their slowness, the reliance by some manufacturers on off-line checking systems, and costs.

In-line, non-destructive leak detectors capable of checking over 100 packs per minute are now available.

Another alternative, which would enable pack integrity to be checked at any time, would be the inclusion of gas indicator strips linked with scanning technology[10].

Time–temperature indicators and gas indicators

Again not a new development, time–temperature indicators (TTIs) still appear to have potential for use with chill-stored MAP products. To date, with the exception of Lifelines Technology's (Morris Plains, NJ, USA) 'Freshcheck indicators' (used by the French supermarket chain Monoprix since 1991, and later by Oscar Mayer and others), market penetration of TTIs has been low, despite over 150 patents on the technology[10]. In the UK, the 'due diligence defense' in attempting to make products as safe as is feasible may act as a catalyst to create further commercial interest.

Changes in the gas composition within the package during storage may provide an indirect indication of the condition of the product. CO_2- and/or O_2-sensitive labels, which change colour at set concentrations of gas, may have considerable potential as non-destructive pre-spoilage indicators, and could also be used to detect faulty packaging and product tampering. Labels that change colour reversibly or irreversibly in response to a certain gas concentration are currently being developed[10] and are expected to be commercially available at the end of 1994. Reports on the so-called 'bacterial indicator labels' (labels that can react with microbial spoilage volatiles such as hydrogen sulfide) are starting to increase[35]. However, no such devices are commercially available, as yet.

Combination treatments

An interesting area that should lead to improvements in both the safety and shelf life of MAP products is the use of a pretreatment in combination with MAP, as reliance on temperature control alone is not desirable, particularly as temperature cannot be effectively controlled beyond the point of sale. While the food industry is governed by temperature control legislation, the consumer is not.

Predictive/mathematical modelling

Mathematical modelling affords the potential to make significant improvements in at least two areas of MAP. The first of these is in the optimization of MAP (the choice of gas-to-product ratio, film permeability, etc.) for specific products, notably fruit and vegetables. The second aspect is in the prediction of the microbial safety and shelf life of MAP foods.

At present, the evaluation of MAP for fresh produce remains a largely empirical, trial-and-error exercise, which is time-consuming, subjective and often lacking in the application of unifying principles to guide future research and development efforts[36]. Many variables interact within a modified-atmosphere produce pack and, because many of these variables feed back to alter related factors, it is difficult to manipulate all the variables simultaneously in a quantitative manner[37]. Computer models have been developed that aid in elucidating the salient variables active in a particular package design, and in optimizing the design while minimizing development time and costly laboratory testing. However, none of the mathematical models to date has been comprehensive enough to include all the salient intrinsic and extrinsic parameters[37].

Predictive microbiology uses mathematical equations to estimate the effects of extrinsic (processing and storage conditions) and intrinsic (e.g. salt concentration, pH or a_w) parameters of the food on the growth, survival or death of microorganisms. To date, few people have developed models that include gaseous atmospheres that would be relevant to most MAP products. However, some models have been developed and efforts are continuing in this area. For example, in the UK, the Ministry of Agriculture, Fisheries and Food initiated a nationally coordinated five-year programme of research into the growth and survival of microorganisms in foods, with the aim of developing a computerized predictive microbiology database in the UK[38]. The database developed ('Food MicroModel') was launched as a commercial service in 1992 and a personal computer based version has recently become available. For certain organisms, the effect of different gaseous atmospheres is being examined, and in the future this will be included within the commercial database.

The future

There remains considerable potential for MAP worldwide. The increased diversification in the product range packaged using MAP is likely to continue and this should expand the market potential. Current developments in films and equipment, particularly intelligent-packaging developments, should also favour an expansion. However, despite a theoretically great potential, MAP is not expected to continue to grow rapidly in Europe during the 1990s unless concrete solutions can be found to a number of factors that have restricted commercial development outside France and the UK. These factors include:

- the lack of a concentrated retail-food and chill-chain distribution structure in many European countries;
- entrenched environmental prejudice against PVC, plastics and 'unnecessary' packaging generally;
- competition from high-quality unpackaged fresh produce;
- competition from vacuum-skin packaging in certain key sectors such as fresh and cooked meats and fish;
- concerns over the safety of some chilled food products.

Several of these factors will obviously also have a major influence on the development of the MAP market outside Europe. Environmental concerns about packaging materials may also hamper development, due to new legislation or to negative consumer perception of the technology.

The impact of the legal requirement to label MAP-packed food sold in the European Union with the phrase 'packaged in a protective atmosphere' (which must be implemented by no later than 1 January 1997) also remains to be seen.

These issues aside, MAP is an excellent way to extend product shelf life. To date, MAP has an excellent safety record. With a proper understanding and control of the technology involved, this will continue to be the case. However, when new applications are proposed, they must be carefully considered and properly researched before commercial introduction. Consumer education concerning product perishability and the need for prompt refrigeration of relevant products is also vital to the continuing expansion and success of this innovative technology.

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