Case Ready Red Meat Packaging Technology

Ian Richardson
Meat Quality Section
Division of Farm Animal Science,
Department of Clinical Veterinary Science,
University of Bristol, Langford,
Bristol, BS40 5DU, UK,
ian.richardson@bristol.ac.uk

SUMMARY

This paper briefly considers some of the properties of meat and gaseous environments that determine the ability of packaging systems to ensure the shelf life of meat. A differentiation is made between aerobic and anaerobic systems and how each might contribute to case ready retail packaging over long or short distances. It summarises some of the problems that have arisen when packaging systems are pushed to their limits and finishes with a summary of some of the commercial packaging systems now being introduced in Europe.

Keywords

case ready, meat, packaging, controlled atmosphere, modified atmosphere, meat shelf life

INTRODUCTION

Multiple-retailers, the major supermarkets in the UK, do not wish to employ skilled butchers or to provide space for non-retailing meat cutting operations in-store. They now dominate UK meat retailing and supply 86% of fresh meats consumed in the home. Their involvement with meat processing companies has had a fundamental effect upon the way that fresh meats are packed, distributed and presented to the general public. As the final retail pack (case ready) is prepared away from the retailers at the premises of the supplier (centralized packing), then the shelf life of the pack needs to be longer (currently up to 9 days for red meats) than that required if the meat was packed in its final retail pack in-store (2-3 days). As more people are only shopping once a week then shelf life is of prime importance and any technologies that can give 1-2 days extra shelf life would be an advantage. Packaging equipment and materials are available to satisfy most types of retailing applications. However, consumer expectation currently determines the type of pack that can be used in the retail situation. The current European consumer expects their beef and lamb to be a fresh, bright red colour and this requires oxygen in the pack (Jeremiah, 1982).

With the increased cost of production of meats within the UK, some retailers look to source their meat from cheaper supplies such as are produced in South America, Australasia and Africa. The time and distances involved in transporting such meats means that traditional case ready packaging, containing a high oxygen concentration, is not suitable. Even sourcing from

Ireland, where over 90% of beef is exported, much of it to the UK, may be too far for high oxygen packs to be a suitable packaging system and primal cuts are sent to the UK mainland for final retail packing. Retailers in the UK have aligned themselves with chosen suppliers, in order to specify, control and audit the specific type(s) of meat packaging used. These suppliers may have several slaughtering and cutting plants but they have moved towards centralized packaging at only a few sites to allow tighter control, more automation and economy of scale. This packed meat then has to be distributed throughout the UK. The requirement is for three days at 0±1°C, simulating pack and distribution via retailers' distribution warehouses and into the retail shops, three days at 4±1°C to simulate display in the store and three days at 7±1°C to simulate moderate temperature abuse by the consumer in domestic refrigerators! A longer retail and consumer shelf-life would require oxygenation closer to the final point of sale, or to convince the consumer that beef, in particular, does not have to be bright red.

If retailers wish to have case-ready supplies, sourced from long distances, then packaging technology will be stretched to its limits. A fundamental understanding of the constraints and limitations of each system is necessary. The shelf life of fresh red meats in a packaging system will be determined by the properties of the meat and the effect of the packaging system and the environment around the meat that it creates upon those properties (Taylor, 1996). The end of storage life is determined by off-odours or discolouration associated with microbial growth in anoxic storage systems. It is suggested that the same applies for high oxygen packaging systems, but for fresh red meats, such as beef, colour is likely to deteriorate before microbial numbers reach unacceptable levels (Shay and Egan, 1987). Hence, loss of colour is a good self-limiting system for red meats packed in oxygen-containing systems.

Properties of meat determining shelf life

Packaging has a fundamental role in protecting meat from contamination, drying out and remaining fresh looking for as long as possible. In the case of red meats the bright red colour is dependent upon the state of the muscle pigment, myoglobin. There are many good reviews of packaging systems for red meats, which explain how the properties of meat and the different packaging systems interact to produce different systems for different purposes (see for instance, Hood and Mead, 1992; Jeyamkondon, Jayas and Holley, 2000; Jeremiah, 2001) and so basic principles will only be dealt with briefly.

In the anoxic state myoglobin is in its reduced state and a dark purple colour (Mb). On exposure to an atmosphere containing oxygen it rapidly converts to the oxygenated form, oxymyoglobin (OxyMb). Over time oxymyoglobin is oxidised to the dark brown metmyoglobin (MetMb). Mb can also oxidise directly to MetMb (Seidemann et al., 1984). MB is more susceptible to oxidation than OxyMb and so meat discolours most rapidly at low oxygen concentrations (< 10mm Hg O_2 or <500ppm). Hence, meat colour can be stabilized either by removing oxygen entirely from the pack or increasing its concentration above atmospheric (Gill, 1995).

When a freshly cut red meat surface is exposed to air (21% O_2), the oxygen penetrates into the meat to a depth of 3-4mm. This is a balance between the rate of diffusion of the oxygen and the rate at which it is consumed by the meat. Hence, there is a point at 3-4mm into the meat that the concentration of O_2 is low (<500ppm) and the formation of MetMb predominates. Cutting through a beef steak which has been exposed to air for a few hours will show a bright red outer layer, a ring of brown MetMb 1-2mm thick and then an inner core of reduced dark red/ purple Mb. Over a few days this Mb layer thickens and rises towards the surface. As meat is translucent, the brown colour can be seen a few mm below the surface and hence the appearance begins to dull and colour shelf life will finish when the brown colour breaks through the surface and discolours the meat (MacDougall and Taylor, 1973). Increasing colour shelf life can be attained by increasing the depth of penetration of O_2 into the meat, which is achieved by increasing the concentration of O_2 in the atmosphere around the meat. This is one form of modified atmosphere packaging (MAP), hereafter referred to as high oxygen MAP. Sometimes referred to as controlled atmosphere packaging (CAP), this is not a true usage of the term as the permeability of the packaging material the solubility of gases in meat and the biological respiration of the meat will change the atmosphere from that initially applied to the pack, but CAP has become synonymous with meat packs with high concentrations of CO_2, **vide infra**. Brooks (1929) showed that the relationship between O_2 concentration and depth of penetration is a square root function. Hence, increasing the O_2 concentration to 80% will quadruple the concentration around the meat and double the depth of penetration. Despite the high O_2 concentration, oxidation to MetMb is still occurring at a slow rate and this steady diffuse browning of the pigment in the surface layer will lead to the end of colour shelf life in7-8 days depending upon meat species, muscle type and temperature of storage.

During aerobic storage in air, the predominant microbial spoilage will be due to pseudomonads and leads to putrefactive smells. Modern slaughter and cutting plants produce meat with low initial counts and so competition for oxygen on the surface of retail meat samples is low. However, higher levels of contamination will lead to competition between meat and microbes and hence a lower depth of penetration of oxygen into the meat and this reduces shelf life. In MA packs, 100% O_2 is not used as the microbial induced odours will develop around the time that colour shelf life is finished. Hence, carbon dioxide is incorporated into the pack to inhibit aerobic bacteria. Concentrations of 20-25% CO_2 and 75-80% O_2 were suggested as optimum concentrations for MA packed red meats. (Georgarla and Davidson, 1970). Extending the shelf life of such packs must be by means other than by the amount of oxygen that can be used in the pack.

Vacuum packs

Vacuum packaging is traditionally used for storage of primals during conditioning or distribution. The longer meat is stored in anaerobic conditions, the shorter is its subsequent retail display in air or high O_2 MAP. (Taylor, 1996). However, these packs could be used for retail distribution, especially for large roasting joints of several kilograms in weight. MA packs need a gas to product ratio of about 3: 1 and so a 5Kg joint would be packed in a 15l pod, which would be very bulky for the consumer to carry. Although it is currently only a small volume market compared to MAP, there is an increasing amount of vacuum packed being sold from retail display shelves. This system has obvious advantages for retailers as it gives them more flexibility with the shelf life being extended to weeks rather than days. Interest has been expressed in developing a vacuum pack made from plastics which can be put directly into the oven for roasting. Such a pack is produced by Marden Wolfe/ Dupont. As the cooking temperature increases, pores in the pack open allowing some of the cooking vapours to escape and the meat surface to brown.

It has already been noted that low concentrations of oxygen are detrimental to the colour of the surface of red meats. When meat is initially packed in vacuum bags there is a small volume of residual air and the meat surface will have 'bloomed' to a brighter red colour due to exposure to air during cutting and trimming. Although meat respiration will convert the O_2 to CO_2, its initial presence will have caused surface discolouration as the oxygen concentration falls. The MetMb can be converted back to Mb over a period of 2-4 days by enzyme systems grouped under the banner name of metmyoglobin reducing activity (MRA) (O'Keefe and Hood, 1982). This activity depends upon the muscle type, as some muscles have more MRA than others, and the age of the meat, as enzyme activity is reduced with time (O'Keefe and Hood, 1980-81). When primal cuts are conditioned to improve tenderness and flavour development, the joint surfaces will have been exposed to air and their MRA reduced. When fabricated into retail portions such as joints or steaks, the 'old' surface will tend to be on the edges and a new cut fresh surface will be on display. Hence, the colour of the product will tend to deteriorate from the edges first. If meat was conditioned in vacuum and then repacked into a retail vacuum pack, its greater age would mean that reduction of surface MetMb would take longer.

Some UK retailers specify 10-21 days conditioning on the bone followed by further storage in vacuum bag to a total of 35 days conditioning or longer to produce top of the range guaranteed tender product, which is seen as being more traditional. Occasionally primals are stored much longer, up to 10 weeks as this allows the accumulation of certain cuts for special promotions, e.g. sirloin and rump for steaks during barbeque season and roasting joints around festivals such as Christmas or Easter. This requires an extremely good cold chain and meticulous attention to hygienic processing with a robust HACCP system in place. Primals are packed in good quality, shrink vacuum bags that are than passed through an ice-water dip taken to remove heat added during the packing process. Bags are inspected for leaks and transferred to a rapid chill to bring them back down to near 0°C. They are held overnight, all leaking packs removed and then transferred to a holding warehouse. Optimum storage temperature is –1.5°C (Gill and Jones, 1992) with 50% of storage life lost at 2°C (Gill, 1996). Leaking packs are repackaged but are not put back into long-term store but are used within a few weeks.

Towards the end of this storage period the rate of diffusion of oxygen into the pack will become faster than the rate at which meat can remove it by respiration and the meat surface will brown. It would be possible to use a cheaper barrier bag, with reduced barrier properties, which is then enclosed in a bag flushed with 100%CO_2. This would dilute the concentration of O_2 exposed to the surface of the inner pack and so O_2 diffusion into the inner bag would be small. The CO_2 could diffuse into the inner pack and add to the CO_2 already produced by respiration, which, although low in volume, quickly reaches 10-40% concentration (Taylor, 1985; Holley et al., 1993). This helps to keep the microbial population anaerobic and restricted to lactic acid bacteria, which grow more slowly and produce milky/cheesy off-odours that are less unpleasant than with aerobic storage. We have noted that such packs have less surface discolouration and bloom to a brighter red than conventional barrier bags (unpublished observations). Similar systems were tested for sub-primal samples of export beef and were found to have no advantage over conventional vacuum packs (Bell, Penny and Moorhead, 1996).

Controlled atmosphere packaging

The longer conditioning of pork or lamb in vacuum packs is more of a problem as they are often packed bone-in which leads to dangers of puncture and leaks. Bone guard, various forms of strengthened and waterproofed papers that cover the bones and prevent punctures are available, but their use is more labour intensive. Barrier bags with built-in thicker areas are also available but are not proof against very sharp splintered bone. An alternative has been to bulk pack these primals in a gas atmosphere of CO_2 or CO_2/N_2, in a 'mother bag' (Gill and Jones, 1994) thus mimicking a vacuum bag, but without the pressure of the bag on the meat which has led to increased drip, or punctures. Initially it was thought that using 100% CO_2 was not advisable as the gas 'scorched' and discoloured the meat surface but it is now clear that this colour change is due to residual oxygen at low concentration, which is very difficult to remove and requires very good evacuation machines. There has been considerable work with this type of system especially for pork from the laboratory of Gill in Canada (Gill, 1995). When beef steaks were stored in either vacuum packs or 100%CO2 CAP, it was found that a case life (retail display) of 30h could be obtained after 13 weeks for the CAP but only 8 weeks for vacuum packs (Jeremiah and Gibson, 2001). Storage time was limited by off-odour development. This system was successfully developed for the long-term storage and distribution of New Zealand lamb to export markets, with a subsequent retail shelf life in high oxygen MAP acceptable to UK retailers. In the CAPTEC system whole lambs, or collections of 10-12 leg or shoulder primals, are packed in a foil laminate bag that is impermeable to oxygen. The chamber and pack are evacuated in phases to prevent air entrapment, back flushed with sufficient CO_2 that after a few days it has all dissolved in the meat and the pack collapses to form a tight skin on the product. This system achieves very low residual O_2 (<300ppm). The product is held and transported at –1.5°C. In this way fresh New Zealand lamb is sent to the UK and has a wholesale storage life of >42 days (reviewed by Zhao, Wells and McMillan, 1994). The only problem that has occurred with this system was that when legs or shoulders of lamb were unpacked and retail packed in high oxygen retail packs, the CO_2, dissolved in the meat, attempted to equilibrate with the O_2/CO_2 (75:25) atmosphere in the retail pack and the packs expanded and blew up like footballs (personal observation). It is necessary to open the CAPTEC packs and allow the meat to equilibrate with air before retail packing

CAP has also been developed for case-ready products. Meat is butchered into its final form, packed on trays and over wrapped with a permeable barrier material and then placed in an outer bag, both being flushed with 100%CO_2 for beef (Gill and Jones, 1994) or pork (Gill and Jones, 1996). Residual O_2 can be removed with an oxygen scavenger (Gill and McGinnis, 1995), but these must be placed in the inner pack, close to the meat, since they become less efficient at lower oxygen concentrations (Tewari et al., 2002). The development of scavengers that can be built into the drip pad or packaging material itself are a possibility (Sealed Air Corporation quoted in Jayas and Jayamkondan, 2002). Such systems could be used for beef to give even longer conditioning before retail packing, as the earlier removal of residual oxygen would reduce the damage to enzyme systems and allow the surface pigments to retain their integrity for longer. These systems have also used N_2 as an inert filler gas as CO_2 is very soluble in meat; it is suggested that up to 2l of CO_2 is required for every kilogram of meat (Gill and Penney, 1988).

Other gases

Argon has been suggested as one alternative gas to be used in anoxic systems. It is 1.43 times denser than N_2 and is more soluble in water and fats. Hence, it will displace oxygen four times more readily than nitrogen (Anonymous, 2003) and has been suggested as a replacement for nitrogen in bulk packs where the elimination of oxygen is of prime importance. It is reported to inhibit oxidase enzymes, despite its being inert. Although more expensive than nitrogen, it has found applications in specialist packs containing high value processed products where low O_2 concentration is essential. It use for food packaging was originally patented by L'Air Liquid but licences for its use in the UK have been bought initially by Safeway supermarkets and Geest and later by BOC gases (Harker, BOC gases, personal communication). Internal trials on potato crisps, thinly sliced ham, ready meals have shown reduced concentration of O_2 when Ar was used to replace N_2 giving improved appearance and flavour. Pork mince had a 2d shelf life improvement.

Another alternative is the use of Carbon monoxide. Carbon monoxide reduces MetMb formation and fat oxidation by combining with Mb to form the bright red pigment carboxymyoglobin (COMb). The CO binds more tightly to the iron-porphyrin site and consequently COMb is more stable than OxyMb (Wolfe, 1980). Hence, CO can extend the colour shelf life of red meats in high oxygen MAP (Luno, Beltran and Roncales, 1998; Luno et al., 2000). They report that the O_2 concentration can be decreased, allowing the CO_2 concentration to be increased, thus retarding microbial growth further. Others have reported the use of CO to replace O_2 completely. Clark, Lentz and Roth. (1976) and Jayasingh et al. (2001) pre-exposed beef to CO and then vacuum packed it. They reported a colour shelf life of up to five weeks. Replacing O_2 with low CO and high CO_2, allows greater control of microbial growth and the presence of CO protects against the deleterious effects of low concentrations of O_2 on colour. (Sorheim, Nissen, and Nesbakken, 1997,1999; Jayasingh et al., 2001).

Red meat packers in Norway have been using mixtures containing 60-70% CO_2, 30-40% N_2 and 0.3-0.4% CO for some 16 years for the retail packing of pork and beef (Sorheim, Nissen. and Nesbakken, 1997, 1999). The nitrogen is a bulk filler to prevent pack collapse as the CO_2 dissolves in the meat. It is also a useful carrier of the CO, present at 1% in the nitrogen cylinders used for gas mixing, hence reducing its toxic effect for workers in the packing plant. These concerns over the toxic effects of CO also extend to the consumer. However, Sorheim, Aune and Nesbakken (1997) argue that it is present in such low amounts as to pose a negligible addition to a consumers daily intake of CO from their environment.

Case-ready distribution

Currently the preferred packaging system in the UK and much of Northern Europe is high O_2 MAP with over 85% penetration in the UK and Netherlands. Good temperature control on centralised packaging lines and throughout distribution allows 7-8 days retail shelf life for most cuts including mince. Higher volume throughput and tight quality control lead to higher efficiency being achieved at centralized locations (Schotz et al., 1992). Marks and Spencer introduced both low and high oxygen MAP in the UK in 1979 (Parry, 1993) whilst Tesco stores were the first to covert its entire fresh red meat operation to centralised, high oxygen MAP (Brody, 1996)

The ability to further extend the shelf life of products in such systems is limited. It will involve scrupulous attention to hygiene and temperature control. Ensuring optimum concentrations of Vitamin E in the meat through forage feeding or the incorporation of a-tocopherol acetate in concentrate feeds will help maximise colour shelf life (Liu, Lanari, and Schaefer, 1995).

The pods used for this system are expensive and take up a large volume. An alternative system might be to pack product on polystyrene trays, overwrap and place several packs in a mother pack containing a CO_2/N_2 mixture, as mentioned above. This system has been used commercially in Europe, but it involves secondary packaging, which is contrary to environmental and recycling requirements.

Bulk gas packs may be replaced by individual MA packs containing CO_2 or a CO_2/N_2 mixture. The pack has a gas impermeable top web that can be stripped away in the retail store just before putting on display, revealing a highly permeable second skin, which allows ingress of air and thus the product to bloom. This second layer would have to have a very high oxygen transmission rate, such is as available with oriented polypropylene, or to be micro-perforated polypropylene, as used in some vegetable preparations and reported by Lee et al. (2003) to be suitable for short term display of pork loin joints. This is similar in principle to the Flavaloc Fresh system described by Jeyamkondan, Jayas and Holley (2000). Meat is packed on a polyethylene terephthalate tray with a PVC O_2-permeable film cover and a domed gas impermeable polyethylene terephthalate lid sealed on top. The sealing is carried out in a chamber where both sections are flushed with a CO_2/N_2 gas mixture with at least 30%CO_2 and < 300ppm residual oxygen. The domed top lid is peeled off in-store just before retail display. The permeable cover allows the ingress of oxygen for the meat to bloom (Zhao, Wells, and McMillan, 1994). In the Windjammer system in the USA, meat was packed in CO_2/N_2 MAP for up to 21 days. At the store, a patented gas exchange system is used to withdraw the anaerobic atmosphere and replace it with a high O_2 MAP mixture (Zhao, Wells, and McMillan, 1994).

Vacuum skin packing

Sometimes innovative systems or processes do not find immediate application and this is no less true in packaging technology. Vacuum skin packing (VSP) is an alternative version of vacuum packing but involves the use of a stretchable top web which, when heated and applied under vacuum, forms closely to the shape of the meat product and seals closely to the base web. It comes into close proximity with meat and leaves no spaces for drip to form. Plastics with the property to function like this are not usually oxygen permeable so meat will be in the Mb form but gives extended shelf life of three to four weeks (Taylor, Down and Shaw, 1990). Its use has been limited due to the lack of a bright red, bloomed colour but in the last few years, developments in plastics technology has allowed the production of films that not only have both the ability to form around the product and seal to a base web, but are semi-permeable to oxygen, thus allowing the meat to bloom. This limited permeability has restricted its use to pork, as seen in the Safeway retail chain in the UK. Marks and Spencer used vacuum skin packing with a permeable film over the meat surface within trays enclosed in a gas impermeable bag containing O_2:CO_2, 80:20 as wholesale distribution system. VSP is also useful for holding offal such as heart and liver tightly in the pod so that they do not move around and smear the pack sides with blood (Anonymous, 1989).

More recently, the Sainsbury retail chain has test marketed beef products under a brand name of the celebrity chef, Jamie Oliver. It is presumed that his familiarity and popularity will convince consumers that darker beef is acceptable or even indicates a more tender, tastier product. The dark colour of beef is explained on pack information and/or partially hidden by an outer sleeve. Sealed-air Cryovac sells this material under the brand name DARFRESH and one can envisage the production of a sheet of steaks where a selected number can be cut off or opened without compromising the seal integrity of the rest, or the sheet is cut into individual products which are then placed in a re-sealable bag so that a selected number can be withdrawn as required.

VSP steaks in pairs sealed on a gold coloured base web have been imported from Ireland and marketed under the brand Nature's Isle. Information on the back of the pack explains why the beef in this 'Smart Pak' is a dark colour and how it will bloom to a brighter red when opened. It claims the control of bacteria and the maintenance of freshness.

Labellock is a similar product from Sealed-air Cryovac with a different function. Again the pack has a gas impermeable, tamper proof top web, which is stripped away by the consumer to reveal a secondary seal. This is pulled from the corner to open the pack, but can be resealed by peeling against the bottom web. Once opened, the ability to re-seal will reduce de-hydration, but the entry of air reduces subsequent storage life to a few days. This will probably have more applications for sliced cured meats than fresh meats.

Other system to extend retail shelf life

In Europe, greater fundamental advances such as active or so-called intelligent packaging have been more limited in their acceptance, probably due to legislative curbs and the lack of confidence of consumers' acceptance of the efficacy, economic and environmental consequences of these new technologies. The use of oxygen scavengers has already been mentioned. Other advances will add to, or enhance, current packaging techniques to further extend the available shelf life. For instance, other hurdles will be used in conjunction with MAP to extend colour shelf life. Antimicrobials can be incorporated into the pack material and released at a defined rate into the pack environment or the product itself by close proximity of the wrapping material to the product (reviewed by Vermeiren, Devlieghere and Debevre, 2002; Quintavalla and Vicini, 2002). They will enhance colour shelf life by reducing microbial numbers and hence competition for oxygen at the surface of the meat. Other suggested means for increasing colour shelf life are the use of natural anti-microbials, such as essential oils from herbs (Skandamis and Nychas, 2002), or bacterial toxins (Cutter, 2002).

There will be a greater pressure to recycle and the use of bulk packaging has probably been restricted due to the use of secondary packaging. However, it would be easier to collect this secondary packing bags from stores, where its composition will be known, than to collect from individual houses or from household refuse collection where a very mixed batch of plastics will make it very difficult to make use of the plastic other than for fuel or landfill. Recycling of packaging materials has been reviewed by Arvanitoyannis and Bosnea (2001).

Problems encountered with long-term meat storage

Whilst much research has concentrated on maintaining or extending colour shelf life and reducing microbial proliferation, other problems have arisen from the techniques used to attain these, particularly when the storage life is extended to its limits.

When CO_2 was used at high concentrations to extend the storage life of beef joints it was found that the meat developed pores along the bundles of muscle fibres which gave a porous appearance to slices of the cooked product (Gill and Penny, 1990). These authors suggested that this was due to the ionic effect of dissolved CO_2 dissociating the adhesion between the perimysium and muscle bundles. However, Bruce et al. (1996) have shown that a simpler explanation may be that the rapid evolution of CO_2 gas, as it comes out of solution during cooking, congregates in the relatively weak perimysium and forces it apart.

'Bubbles' of gas are also seen in vacuum packs during storage. These appear in the drip but also over the fat surfaces and can be seen soon after packing. It is suggested that these are bubbles of nitrogen that has been dissolved in the fat during life and when exposed to air during slaughter and cutting. The high vacuums now applied during packing, to reduce residual air and thus keep oxygen concentration to a minimum, draw this nitrogen out into the pack. The gas bubble also includes CO_2 and this is probably formed by meat tissue respiration converting residual oxygen (Anonymous (2001) and personal observations). During storage these packs are not totally impermeable to air and so oxygen will ingress into the packs but slower than the residual respiratory activity of the meat can deal with it. Hence, the gas composition within the pack will always be predominantly N_2 and CO_2 with a small amount of H_2 produced by bacterial fermentation.

Another consequence of extending the storage of beef in vacuum packs or high CO_2 CAP storage into many weeks is the appearance of 'blown pack' spoilage (Dainty, Edwards and Hibbard, 1989; Broda et al., 1996). This is different from greening, seen when high pH beef is stored and H_2S evolves causing the bag to inflate and the formation of sulphmyoglobin turns the surface of meat green (Taylor and Shaw, 1977). Blown pack spoilage is usually caused by **Clostridium spp.**, strict anaerobes that don't begin to replicate until late in the storage life when the dominant lactic acid bacteria have reduced many of the other competing bacterial species. It is suggested that the process of pack heat shrinkage immediately after packing may enhance the on-set of pack spoilage. This is more likely to be due to the greater exclusion of oxygen due to packaging thickening on shrinkage, rather than a direct effect of heat stimulating spores to activate (Bell, Moorhead and Broda, 2001)

CONCLUSION

The latest developments in case-ready, red meat packaging technology are refinements of known technologies. The market is segmenting between those, particularly in Europ,e who use high oxygen MAP to give a fresh case ready shelf life of about a week for most red meats. Conversely, the research in North America has been directed towards high carbon dioxide mother bags, which allow a much longer shelf life, but these must be opened to allow a reduced retail display life in-store. In Europe, developments are towards reducing cost or to extending shelf life further particularly by trying to persuade the consumer to accept darker, non-oxygenated meat. Much of this development is now by packaging companies in association with meat packers.

For as long as high oxygen MAP predominates in the UK and much of Europe, the pressure will be for cheaper, tidier packs. The ability to produce packs or lidding material with all the desired properties of gas permeability, clarity, anti-fogging and sealability has often meant the use of expensive laminates of two to four different types of plastic. A single cheaper plastic with these properties would have a marketing advantage. Monopet polypropylene trays probably come closest to this and those with more modern packaging machines, capable of handling these materials, are taking up shrink materials that give a taut, tidier lid. It may well be that further advances in case ready packaging is in the hands of the polymer chemist rather than the meat technologist.

REFERENCES

Anonymous. (1989). Fresh meat packaging combines VSP and MAP. Food Engineering, 61, 72

Anonymous. (2001) Gas bubbles in vacuum-packed meat. Meat Technology Update, Newsletter 01/3 Food Science Australia

Anonymous. (2003). Putting Argon on the MAP. Food Processing, March Issue

Arvanitoyannis, I.S. and Bosnea, L.A. (2001) Recycling of polymeric materials used for food packaging: Current status and perspectives. Food Reviews International, 17, 291-346.

Bell, R.G., Moorhead, S.M. and Broda, D.M. (2001) Influence of heat shrink treatments on the onset of **clostridial** 'blown pack' spoilage of vacuum packed chilled meat. Food Research International, 34, 271-275.

Bell, R.G., Penny, N. and Moorhead, S.M. (1996). The retail display life of steaks prepared from chill stored vacuum and carbon dioxide-packed sub-primal beef cuts. Meat Science, 42, 165-178.

Broda, D.M., De Lacy, K.M., Bell, R.G., Bragginns, T.J. and Cook, R.L. (1996) Psychotrophic **Clostridium** spp. associated with 'blown pack' spoilage of chilled vacuum-packed red meats and dog rolls in gas-impermeable plastic casings. International Journal of Food Microbiology, 29, 335-352.

Brody, A.L. (1996) Integrating aseptic and modified atmosphere packaging to fulfil a vision of tomorrow. Food Technology, 50, 56-66

Brooks, J. (1929) Post-mortem formation of methaemoglobin in red muscle. Biochemical Journal, 23, 1391-1400

Bruce, H.L., Wolfe, F.H., Jones, S.D.M. and Price, M.A. (1996) Porosity in cooked beef from controlled atmosphere packaging is caused by rapid CO2 gas evolution. Food Research International, 29, 189-193.

Clark, D.S. Lentz, C.P. and Roth, L.A. (1976) Use of Carbon monoxide for extending shelf life of pre-packaged fresh beef. Canadian Institute of Food Science and Technology Journal, 9, 114-117.

Cutter, C.N. (2002) Microbial control by packaging: A review. Critical Reviews in Food Science and Nutrition, 42, 151-161.

Dainty, R.H., Edwards, R.A. and Hibbard, C.M. (1989) Spoilage of vacuum-packed beef by a **Clostridium** spp. Journal of Food and Agriculture, 49, 473-486.

Georgarla, D.L. and Davidson, C.M. (1970) Food Packaging. British Patent 1,199,998

Gill, C.O. (1988) The solubility of Carbon dioxide in meat. Meat Science, 22, 65-71

Gill, C.O. (1995) MAP and CAP of fresh red meats, poultry and offals, **In** J.M. Faber and K.L. Dodds (eds.) Principles of modified-atmosphere and sous vide product packaging. Technomic Publishing, Lancaster, Penn., pp. 105-136.

Gill, C.O. (1996) Cold storage temperature fluctuations and predicting microbial growth. Journal of Food Protection 4suppl. 43-47

Gill, C.O. and Jones, T. (1992) Efficiency of a commercial process for the storage and distribution of vacuum packaged beef. Journal of Food Protection, 55, 880-887

Gill, C.O. and Jones, T. (1994) The display life of retail-packaged beef steaks after their storage in master packs under various atmospheres. Meat Science, 38, 385-396

Gill, C.O. and Jones, T. (1996) The display life of retail-packaged pork chops after their storage in master packs under atmospheres of N_2, CO_2 or $O_2 + CO_2$. Meat Science, 42, 203-213

Gill, C.O. and McGinnis, J.C. (1995) The use of oxygen scavengers to prevent the transient discolouration of ground beef packaged under controlled, oxygen-depleted atmospheres. Meat Science, 41, 19-27.

Gill, C.O. and Penney, (1988) The effect of initial gas volume to meat weight ratio on the storage life of chilled beef packaged under CO_2. Meat Science, 22, 53-63.

Gill, C.O. and Penny, N. (1990) The effect of storing raw meat under CO_2 on the visible texture of the cooked muscle tissue. **In**: The Proceedings of the 36th International Congress of Meat Science and Technology, Vol 1. Cuba, ICOMST, pp. 232-240

Holley, R.A., Delaquis, P., Gagnon, J., Doyon G. and Gariepy, C. (1993) Modified atmosphere packaging of fresh pork. Alimentech, 6, 16-17.

Hood, D.E. and Mead, G.C. (1993) Modified Atmosphere storage of fresh meat and poultry. Ch 11. **In** R.T. Parry (ed.) Principles and applications of modified atmosphere packaging of foods, Blackie Academic and Professional, London, pp. 269-298.

Jayas D.S. and Jayamkondan, S. (2002) Modofied atmosphere storage of grains, meats, fruits and vegetables. Biosystems Enginering, 82, 235-251.

Jayasingh, P., Cornforth, D.P., Carpenter, C.E. and Whittier, D. (2001) Evaluation of carbon monoxide in modified atmosphere packaging or vacuum packaging to increase color stability of fresh beef. Meat Science, 59, 317-324.

Jeremiah, L.E. (1982) A review of factors influencing consumer selection and acceptability of meat purchases. Journal of Consumer Studies and Home Economics, 6, 137-154.

Jeremiah, L.E. (2001) Packaging alternatives to deliver fresh meats using short- or long-term distribution. Food Research International, 34, 749-772.

Jeremiah, L.E. and Gibson, L.L. (2001) The influence of packaging and storage time on the retail properties and case-life of retail-ready beef. Food Research International 34, 621-631.

Jeyamkondon, S., Jayas D.S. and Holley, R.A. (2000) Review of centralized packaging systems for distribution of retail-ready meat. Journal of Food Protection, 63, 796-804.

Lee, K-T., Choi, W-S. and Yoon, C-S. (2003) Effects of micro-perforated films on the quality and shelf life improvements of pork loins during chilled storage. Meat Science, 63, in press

Liu, Q., Lanari, M.C. and Schaefer, D.M. (1995). A review of dietary Vitamin E supplementation for improvement of beef quality. Journal of Animal science, 73, 3131-3140

Luno, M., Beltran, J.A. and Roncales, P. (1998) Shelf-life extension and colour stabilisation of beef packaged in a low O_2 atmosphere containing CO: Loin steaks and ground meat. Meat Science, 48, 75-84.

Luno, M., Roncales, P., Djenane, D. and Beltran, J.A. (2000) Beef shelf life in low O_2 atmospheres containing different low CO concentrations. Meat Science, 55, 413-419.

MacDougall, D.B. and Taylor, A.A. (1973) Colour retention in fresh meat stored in oxygen – a commercial scale trial. Journal of Food Technology, 10, 339-347.

O'Keefe, M and Hood, D.E. (1980-81) Anoxic storage of fresh beef 1.: Nitrogen and Carbon dioxide storage atmospheres. Meat Science, 5, 27-39.

O'Keefe, M and Hood, D.E. (1982) Biochemical factors influencing metmyoglobin formation on beef from muscles of differing colour stability. Meat Science, 7, 209-228.

Parry, R.T (1993) Introduction, p.1-17. **In** R.T. Parry (ed.) Principles and applications of modified atmosphere packaging of foods. Chapman and Hall, Glasgow, Scotland

Quintavalla, S. and Vicini, L (2002) Antimicrobial packaging in meat industry. Meat Science, 62, 373-380.

Schotz, E.M., Jordaan, E., Kruger, J., Nortje, G.L. and Naude, R.T. (1992) The influence of different centralised pre-packaging systems on the shelf-life of fresh pork. Meat Science, 32, 11-29.

Seidemann, S.C., Cross, H.R., Smith, G.C. and Durland, P.R. (1984) Factors associated with fresh red meat colour. Journal of Food Quality, 6, 211-237.

Shay, B.J. and Egan, A.F. (1987) The packaging of chilled red meat. Food Technology Australia, 39, 283-285

Skandamis, P.N. and Nychas, G-J.E. (2002) Preservation of fresh meat with active and modified atmosphere packaging conditions. International Journal of Food Microbiology, 79, 35-45.

Sorheim, O., Aune, T. and Nesbakken, T. (1997) Technological, hygienic and toxicological aspects of carbon monoxide used in modified-atmosphere packaging of meat. Trends in Food Science and Technology, 8, 307-312

Sorheim, O., Nissen, H. and Nesbakken, T. (1997) Shelf life and colour stability of beef loin steaks packed in a modified atmosphere with Carbon monoxide. In: Proceedings of the 43rd International Congress of Meat Science and Technology, Auckland. Meat Industry Research Institute of New Zealand, Hamilton, New Zealand, pp. 694-695.

Sorheim, O., Nissen, H. and Nesbakken, T. (1999) The storage life of beef and pork packaged in an atmosphere with low carbon monoxide and high carbon dioxide. Meat Science, 52, 157-164.

Taylor, A.A. (1985) Packaging fresh meat.. **In**: R. Lawrie (ed.) Developments in Meat Science, 3 . Elsevier Applied Science Publishers, New York, pp. 89-113

Taylor, A.A. (1996) Basic considerations in meat packaging. **In** S.A. Taylor, A. Raimundo, M. Severini and F.J.M Smulders (eds.) Meat Quality and Meat Packaging. ECCEAMST, Utrecht, The Netherlands, pp. 259-284.

Taylor, A.A., Down N.F. and Shaw, B.G. (1990) A comparison of modified atmosphere and vacuum skin packing for storage of red meats. International Journal of Food Science and Technology, 25, 98-109.

Taylor, A.A and Shaw, B.G. (1977). The effect of meat pH and package permeability on putrefaction and greening in vacuum packed beef. Journal of Food Technology, 12, 512-521.

Tewari, G., Jeremiah, L.E., Jayas, D.S. and Holley, R.A. (2002) Improved use of oxygen scavengers to stabilise the colour of retail-ready meat cuts stored in modified atmospheres. International Journal of Food Science and Technology, 37, 199-207.

Vermeiren, L., Devlieghere, F. and Debevre, J. (2002) Effectiveness of some recent antimicrobial packaging concepts. Food Additives and Contaminants, 19, Supplement S, 163-171.

Wolfe, S.K. (1980) Use of CO and CO2 enriched atmospheres for meat, fish and produce. Food Technology, 34, 55-58, 63.

Zhao, Y., Wells, J.H and McMillan, K.W. (1994) Applications of dynamic modified atmosphere packaging systems for fresh red meats: review. Journal of Muscle Foods, 5, 299-328