MEAT PACKAGING – MAINTAINING THE QUALITY AND PROLONGING THE STORAGE LIFE OF CHILLED BEEF, PORK AND LAMB

A.F. Egan, I.J. Eustace and B.J. Shay,

CSIRO Division of Food Processing, Meat Research Laboratory, Cannon Hill, Queensland, Australia

Meat has long been considered a highly desirable and nutritious food. Unfortunately it is also highly perishable because it provides the nutrients needed to support the growth of many types of micro-organisms.

Whilst spoilage is usually microbial in origin, chemical factors also may be important. Rancidity (oxidation of fat) will develop if meats are stored for extended periods in the presence of oxygen. In the case of fresh meats, biochemical changes continue during storage and these will eventually cause the meat to become unacceptable in flavour and texture, even when no micro-organisms are present.

Appropriate packaging of meat and meat products can bestow any number of benefits. Extended maintenance of quality can be achieved in an hermetic package through exclusion of contamination, delay of microbial spoilage, maintenance of desirable colour and minimisation of water loss. The extension of storage life makes possible a broader geographical distribution of the packaged products. Other benefits include greater handling convenience, improved presentation for retailers and the provision of a surface on which can be printed attractive informative graphics.

Realisation of these benefits is contingent upon the correct selection of packaging materials and systems. The specific requirements depend upon whether the product to be packaged is fresh meat or processed, whether it is beef, lamb or pork, whether it is uncooked or cooked, boneless or bone-in, and on whether it is destined for local retail display or for overseas destinations.

This paper is divided into two sections. The first provides the background information necessary to understand the spoilage of meat and the reasons various packaging strategies are used. The second lists the shelf-lives likely to be attained for fresh and processed meats using a variety of packaging and storage options. The use of various packaging options for different types of meats are discussed.

Consumer acceptance of meat

Appearance is one of the most important attributes by which consumers judge the quality of meat and therefore colour deterioration is one of the main factors that limits storage life, at least until the point of purchase. Meat must be packaged in a manner that retains its appearance and presents it in an attractive way.

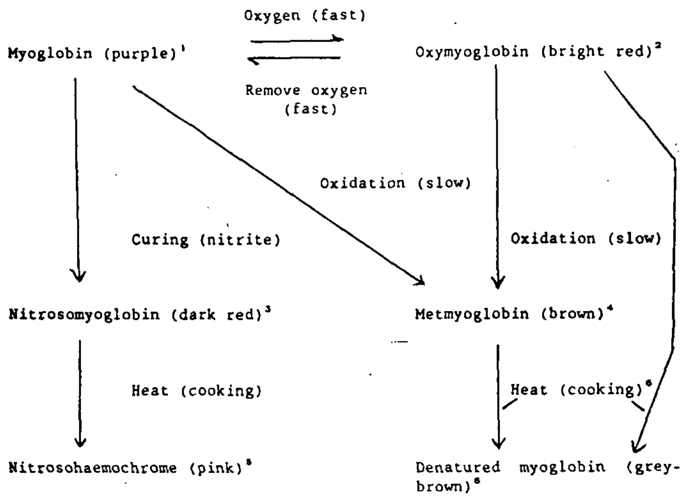
Many studies have shown that there is no direct relationship between colour and other important properties such as tenderness and juiciness. Once the consumer has purchased the meat, the other properties then become important (odour, flavour, tenderness, juiciness, etc.). The growth of micro-organisms may result in changed odour and flavour (ultimately identified as spoilage).

Ideally packaging techniques should maintain the appearance of meats during storage and delay microbial spoilage. The use of various techniques to extend the storage life of fresh and processed meats will be considered in this paper.

Meat colour

Myoglobin, a coloured pigment similar to the haemoglobin of the blood, gives lean meat its colour. The greater the concentration of myoglobin, the darker is the colour of the meat. Its concentration varies from species to species but beef contains about nine times as much myoglobin as pork and this in part explains why beef is red whereas pork is much paler.

Myoglobin is the oxygen-carrying protein of muscle, and can exist in a number of forms which vary in colour. For example, in the absence of oxygen it is in the reduced form which is purple, but in the presence of oxygen it forms oxymyoglobin which is bright red. The relationships between the various forms of myoglobin are shown in Figure 1. The types of meat, of which the various colours are characteristic, are also shown.



Types of meat of which the various colours are typical:

1 Vacuum-packed beef

2 Fresh beef stored in air

3 Non-cooked cured meats (raw hams, salamis)

4 'Stale' fresh meats stored in air

5 Cooked cured meats (cooked hams, cooked emulsion type sausage products)

6 Cooked fresh meats.

Figure 1. The forms of myoglobin, their colours, and the types of meat of which those colours are characteristic.

The reversible conversion of myoglobin to oxymyoglobin is rapid. When beef muscle stored in the absence of oxygen (eg., vacuum packaged) is exposed to air, it rapidly takes up oxygen and changes from purple to bright red (termed "blooming" – occurs within half an hour in air at 0-5°C). However both myoglobin and oxymyoglobin react slowly with oxygen becoming oxidised to metmyoglobin (requires 2-3 days in air at 0-5°C). This compound is brown and the reaction is not readily reversible. The formation of metmyoglobin occurs most rapidly at low oxygen concentrations (about 1 per cent). Thus for meat exposed to air metmyoglobin first forms below the surface (at 0-5°C it is at a depth of 2-5 mm). Because the myoglobin in the outer layer oxidises more slowly, the metmyoglobin layer gradually extends towards the surface and the meat slowly turns brown and is said to "fade". Meat packaging and storage procedures must retard this reaction if the meat is to remain acceptable in colour. This fact is fundamental to an understanding of the reasons certain methods are used to store fresh carcass meats.

Meat colour is also affected by the species, sex and age of the animal. Stress prior to slaughtering also plays a significant role, as it affects pH which in turn affects colour. Within a carcass, different muscles contain varying concentrations of myoglobin and so vary in colour.

Sources of microbial contamination

The muscle tissue of healthy animals contains few micro-organisms. During processing, the surface of the carcass is contaminated with micro-organisms which come mainly from the hide or the fleece. These organisms originate from the environment of the animal (soil etc.) and its gastrointestinal tract (faecal contamination). Other sources of contamination include the equipment used in dressing (eg., knives), and the hands and clothes of the workers. Thus some micro-organisms of human origin may reach the meat, but the bulk of the contamination comes from the animals themselves.

The intention of the meat industry is to produce meat with as low numbers of microbes as reasonably possible, in order to maximise shelf-life and minimise the occurrence of organisms associated with food-borne illness. In recent years changing eating patterns and technological changes in animal husbandry, meat production, meat processing and preservation have increased the range of meat products available. Meat eaters have become more conscious of quality and value. Consumers are concerned about "freshness" and health aspects. The presentation of meat must reflect these trends.

The composition of meat and microbial spoilage

Table 1 shows the approximate chemical composition of muscle. It is characteristic that the ratio of nitrogenous compounds (protein, amino acids) to carbohydrate is high and this is an important factor affecting microbial growth. Of even more importance is the high water content which favours the growth of fast growing bacteria at the expense of slower growing yeasts and moulds.

Table 1: The approximate composition of lean muscle (1)

Component	Wet weight (%)
Water	75
Protein	19
Fat	2.5
Carbohydrate glycogen, glucose and sugar phosphates	0.3
Other soluble nitrogen containing amino acids, creatine	1.65
Inorganic salts	0.65
Lactic acid	0.9

(1) Modified from Lawrie (1985)

As indicated above the micro-organisms are largely confined to the surfaces of the meat. They grow primarily by utilising the soluble constituents of the muscle. If nitrogen containing compounds (amino acids) are used then the end products of microbial growth will include malodorous amines (ammonia, putrescine and cadaverine) and sulphur compounds. Together these cause "off" odours and flavours even at low concentrations (typically described as putrid). These may become evident when bacterial numbers are as low as $10^6/cm^2$. Because some of these compounds are volatile, spoilage is usually first noted as an off (putrid) odour which causes rejection, ie., the meat is unacceptable.

If carbohydrates are used for growth, the end products are organic acids, especially lactic and acetic acids. Under these circumstances spoilage is due to the accumulation of these acids and since these compounds do not have a strong odour at the concentrations likely to be produced, spoilage may be first noted as a flavour change (souring).

Although bacteria grow on the fat surfaces of meat, relatively little is known about the significance of such growth and its contribution to spoilage. However it seems that the organoleptic changes caused by the growth of micro-organisms on fat are less significant than those resulting from growth on lean muscle tissue.

Other relevant properties of meat

(i) pH
In the living animal, muscle is neutral in reaction. After death it becomes more acidic, ie., the pH falls below 7. This is caused by the conversion of carbohydrates (glycogen, glucose – the energy stores of the muscle) to lactic acid by a biochemical process known as glycolysis. The greater the content of glycogen in the muscle, the greater the amount of lactic acid formed. A (typical) concentration of about 1 per cent results in the production of lactic acid sufficient to drop the pH to about 5.5. In unstressed animals the normal ultimate pH of muscle is in the range 5.5-5.7 and muscle of this pH has a normal appearance and texture. If the muscle was depleted of glycogen prior to death, the pH fall will be less. Meat of about pH 6.0 or higher has significantly different properties; it is darker in colour, firmer and drier (DFD meat). High pH also permits the more rapid growth of spoilage bacteria, but this is only significant in some circumstances (discussed later). Some muscles routinely have a higher ultimate pH than 5.7.

(ii) Exudate
During storage, liquid, known as weep, exudes from meat. Excess weep is undesirable because it detracts from the appearance of the meat and results in effective loss of product. The volume of weep can be affected by a variety of factors including the area of cut surface (of muscle) and storage temperature. However the most important is pH. As indicated above, high pH favours water retention and less exudate is produced.

(iii) Freezing point
While pure water freezes at 0°C, the water in meat is effectively a solution of salts which begins to freeze at ca. -1.5°C. The optimum storage life of non-frozen fresh meats is achieved at ca. -1°C; at this temperature bacterial growth is extremely slow and the chemical and biochemical changes which occur during storage occur at a minimum rate.

Factors affecting the growth of micro-organisms on meat

Environmental factors play the major role in controlling the growth of micro-organisms on meats.

(i) Temperature
Growth rates at 0-1°C are only about half those at 5°C and are further reduced as temperature falls. A storage temperature as low as is practical (given the product and the circumstances) should be used. As indicated about -1°C is optimal.

(ii) Gas atmosphere
The growth of some organisms may be inhibited by the presence of carbon dioxide and/or by the absence of oxygen, ie., by manipulation of the redox potential. Nitrogen is inert in terms of microbial growth.

(iii) Water activity (a_w)
Micro-organisms need water to grow, and as water content is reduced, growth rates are reduced. Water activity is the term used to specify the amount of water that is available or "active" in a food, ie., water which is not chemically bound. The water activity of carcass meat is 0.99. The minimum water activities at which important spoilage and pathogenic micro-organisms can grow are shown in Table 2.

Table 2: Minimum water activities supporting the growth of micro-organisms under aerobic conditions (1)

0.96	*Pseudomonas*
0.95	*Clostridium botulinum*
	Enterobacteriaceae *(Enterobacter, Escherichia, Salmonella)*
0.94	*Brochothrix thermosphacta*
0.93	*Lactobacillus, Streptococcus*
0.91	*Staphylococcus* (no oxygen)
0.90	*Pediococcus, Micrococcus, Lactobacillus* (few strains)
0.87	Yeasts
0.86	*Staphylococcus* (oxygen present)
0.85	*Penicillium*) (fungi)
0.65	*Aspergillus*)

(1) Many strains cease growth at higher a_w values.

(iv) pH
Whilst most micro-organisms can grow over the range of pH values of muscle (5.4-7.0), this factor becomes important in combination with others. For example, if lean red meat is placed in an environment where oxygen is no longer available, the composition of the flora which develops is greatly dependent upon muscle pH.

(v) Other micro-organisms
Some micro-organisms may inhibit the growth of others. This may be an active (the production of antibiotic type compounds or toxic end products) or passive (competition for nutrients) process.

(vi) Chemical inhibitors
In the case of processed meats, the addition to the meat of various ingredients may result in a modification of the microbial flora. For example the concentration of salt used in processed meats is usually high enough to prevent the growth of *Pseudomonas* and the sodium nitrite used in curing may also reduce the growth rate of some species.

The interaction of factors as discussed above may be synergistic, eg., pH and gas atmosphere. Overall, good control of temperature remains the factor of prime importance for the storage of meats which are not shelf-stable.

Micro-organisms of significance in spoilage

The major types of bacteria important in meat spoilage, are listed below. The nature of the spoilage they cause in the presence and absence of oxygen is also indicated.

Pseudomonas bacteria grow rapidly, dominate the flora of fresh meats stored in air and cause putrefactive spoilage. They do not grow in the absence of oxygen and are inhibited by 20 per cent carbon dioxide. Thus they do not grow on vacuum-packaged meats or meats stored in modified atmospheres containing carbon dioxide.

Enterobacteriaceae cause putrefactive spoilage in both the presence and absence of oxygen. They are resistant to inhibition by carbon dioxide and to prevent growth high concentrations (>40 per cent) are needed.

Brochothrix thermosphacta causes chemical and dairy odours when oxygen is present but souring in its absence. Its growth may be restricted by a combination of a low concentration (<1 per cent) of oxygen and a high concentration (>40 per cent) of carbon dioxide.

Lactic acid bacteria *(Lactobacillus, Pediococcus, Streptococcus, Leuconcstoc)* cause spoilage by souring under all conditions of growth. They grow readily in the absence of oxygen and are very resistant to inhibition by carbon dioxide.

Aeromonas and *Alteromonas hydrophila* are unable to compete with faster growing organisms such as *Pseudomonas* if oxygen is readily available. When only traces of oxygen (eg., ca. 0.1 per cent) are present they may grow and become significant on meat of high pH. They produce hydrogen sulphide and cause spoilage because of a putrefactive odour. They are also the major causes of greening of high pH packaged meats.

The bacterial flora which develops on carcass meats stored in air under refrigeration conditions is composed of Gram-negative rods. Provided the water activity is ca. 0.96 or greater, *Pseudomonas* organisms dominate because of their very rapid growth rate in the presence of oxygen. They cause spoilage when their numbers reach 10^6-10^8/cm^2, and this is characterised first by putrefactive odours which are followed by slime production.

The time taken for these organisms to cause spoilage is directly related to the numbers initially present. Even with a low initial count the storage life of fresh meat stored in air is only about two weeks at 0°C.

Strategies used in meat packaging

The properties of the various groups of spoilage organisms suggest strategies to be used in attempting to preserve meats by the use of packaging systems. For example, Table 3 lists the growth responses of the major groups to a combination of two environmental factors, the availability of oxygen and (lean) muscle pH.

Table 3: The effect of oxygen availability and pH on the growth of the major types of meat spoilage bacteria at 0-5 ℃. (on lean fresh meat)

	pH 5.5-5.7		pH 6.0 or higher	
	Oxygen	No oxygen	Oxygen	No oxygen
Pseudomonas	+	-	+	-
Enterobacteriaceae	+	-(1)	+	+
Brochothrix thermosphacta	+	-(1)	+	+
Lactic acid bacteria	+	+	+	+
Aeromonas	-	-	+	+
Alteromonas putrefaciens	-	-	+	+

(1) Some growth may occur, especially at intermediate pH values (5.8-5.9) and at 5°C, but this is usually not sufficient to contribute significantly to spoilage.

On meat of normal pH, the environment restricts bacterial growth and only the lactic acid bacteria grow to a population capable of causing spoilage. However if muscle pH is high other organisms may grow and cause more rapid spoilage. To restrict growth on high pH fresh meat, atmospheres of carbon dioxide may be used.

Another option that can be used with processed meats, is to combine manipulation of water activity with control of the gas atmosphere. For example, the minimum water activity at which *Brochothrix thermosphacta* can grow in the presence of oxygen at 0°C is 0.94 whereas in its absence it is 0.97. Less salt need be added to meat products to prevent the growth of this organism when no oxygen is present. Similarly this organism is much more sensitive to inhibition by nitrite when no oxygen is present. These facts point to the advantages of packaging processed meats so that little or no oxygen is present.

These principles demonstrate methods that may be used to control microbial spoilage. The practical end result to be aimed at in all cases is the creation of conditions under which lactic acid bacteria become the only group which grow readily. The presence of a flora dominated by lactic acid bacteria can normally be expected to signify a maximum shelf-life for packaged fresh meats. Their significance on processed meats is discussed later.

FRESH MEAT

Vacuum-packaged primal cuts

It is common to store and distribute chilled beef as primal cuts (2-9 kg) vacuum-packaged in bags made of plastic materials with low permeability to gases. Meat packed in this manner is easy to handle, its colour is preserved and its storage life is greatly increased. Inside a vacuum-package the residual oxygen is consumed, presumably by tissue and microbial consumption of the oxygen, and carbon dioxide is produced. Provided packaging has been performed correctly, there is little head space within a vacuum-package. This makes accurate gas analysis difficult, but the atmosphere contains less than 1 per cent oxygen, some 20-40 per cent carbon dioxide with the remainder being nitrogen.

Beef stored vacuum-packaged in low-permeability films should be purple in colour since the myoglobin is in the reduced form. Development of a brown colour during storage indicates excess oxygen has penetrated the pack. This is caused either by the use of a film which is excessively permeable or due to the pack being a "leaker". When vacuum packs of beef are opened the purple colour should turn to red (return of the "bloom").

Table 4 gives estimates of the maximum commercial storage life at a temperature of 0°C of vacuum-packaged primal cuts of beef, pork and lamb. These are only obtained provided:

1. the meat is produced using good manufacturing practice (initial total count of organisms able to grow at 0-5°C is 10^2-10^3/cm^2 or less);

2. the packaging film used has a low permeability to gases (<50 ml of oxygen per square meter of film per day per atmosphere of gas pressure, measured at 25°C and 98 per cent relative humidity);

3. there is good control of temperature during the storage period.

Table 4: The storage life at 0 °C of vacuum-packaged primal cuts beef, lamb and pork.

	Muscle pH	Storage life(1) (weeks)	Spoilage defect
Beef	5.5-5.8	10-12	Flavour (souring)
Pork	5.5-5.8	6	Flavour
	6.0-6.3	4-6	Colour (greening)
Lamb	N/A(2)	6-8	Colour, appearance of fat

(1) Vacuum packaged using films with oxygen permeabilities less than 50 ml/m^2/24 h/atm (measured at 25°C and 98% RH)
(2) Not applicable

Vacuum-packaged beef of normal pH shows little sign of visual deterioration during 12 weeks storage at 0°C. The use of analytical taste panels has shown that spoilage is largely due to aroma and flavour changes. Most significant is the development of an "off" or atypical flavour in the cooked meat which became significant after storage for about ten weeks. When first detected this flavour is commonly described as cheesy, sour and acid, but later in storage also as bitter and liver-like. These changes are attributed to the accumulation of acidic end products resulting from the growth of lactic acid bacteria which comprise the flora (typical maximum population 2-5 x 10^7/cm^2).

Studies using meat which carries only a very small population of bacteria (<100/cm^2), have shown that an "off" flavour develops and becomes significant after 14-16 weeks at 0°C. This flavour is also described as bitter and liver-like and is probably due to chemical changes in the meat caused by enzymic activity. Because of this there is little point in trying to further extend storage life at 0°C by eliminating the lactic acid bacteria. In addition, a storage life of 10 weeks is sufficient to get the meat from Australia to any export market with an adequate safety margin.

Taste panel studies have shown that vacuum-packaged pork of normal pH also spoils due to the development of a flavour defect. However this occurs after only about six weeks at 0°C. The bacterial flora on vacuum-packaged pork develops much as it does for beef with lactic acid bacteria becoming dominant. It is likely then that the early manifestation of spoilage is due to non-microbial changes which occur more rapidly in pork than they do in beef.

When meat pH is about 6.0 or higher, a number of other types of bacteria may reach populations high enough to cause spoilage. In particular the growth of *Alteromonas putrefaciens*, *Aeromonas*, or some types of Enterobacteriaceae may cause spoilage due to a colour defect called greening. These organisms produce hydrogen sulphide which reacts with myoglobin to form sulphmyoglobin which is green. This results in discolouration of the weep and green areas appear over the fat surfaces. This defect is more noticeable with beef, because the higher concentration of myoglobin means the green colour is more intense. This type of spoilage has resulted in rejections of vacuum-packaged meats in overseas markets. It can be avoided by not packaging for export meat of high pH.

Holding the meat at higher temperatures reduces storage life. There are few detailed studies of the storage of primal cuts at 5°C, but the available information suggests that it would be wise to assume a storage life of only about half that obtained at 0°C. Storage at about -1°C is recommended whenever possible. Again there are few quantitative studies available but an increase in storage life of up to about 50 per cent should be achievable.

Vacuum-packaged telescoped lamb carcasses

Lamb carcasses may be reduced in size using a process known as telescoping. In this process, the hind legs are folded up into the thoracic cavity and by this means there is a considerable volume reduction with significant savings in transport costs. Such carcasses are vacuum-packaged for export from Australia. However there are still voids in the packs and gas analyses typically show the presence of 1-3 per cent oxygen in the atmosphere of these cavities. This, together with the considerable volume of exudate (typical pH 5.9-6.1) which commonly collects, creates problems of a microbiological nature. The storage life of carcasses packaged in this manner is about six weeks at 0°C. Greening may terminate storage life.

Gas-flushing of primal cuts and telescoped carcasses

Because there is little head space and only a very low concentration of oxygen remaining, gas flushing with 100 per cent carbon dioxide results in only a marginal improvement of the storage life and quality of vacuum-packaged primal cuts. However in the case of telescoped carcasses, it largely removes the residual oxygen and there is an improvement in storage life to about eight weeks at 0°C.

Decontamination of primals and telescoped carcasses

The problem of obtaining an adequate storage life for vacuum-packaged high pH meats has already been discussed. One approach to this problem is to treat carcasses or cuts of meat so as to reduce the microbial population prior to processing (decontamination). Hot water may be used but dilute solutions of lactic or acetic acid are more effective.

Lamb carcasses may be treated "on line" in the abattoir prior to chilling. If such unchilled carcasses are immersed in a 1.5 per cent solution of acetic acid at 55°C for 10 seconds, there is a reduction of 95-99 per cent in the population of bacteria on the meat. The acid treatment not only reduces the number of bacteria present, but also has a residual effect. It delays the onset of the growth of putrefactive bacteria, ie., it has a bacteriostatic effect. These effects result in an extension of the storage life of telescoped carcasses to about 10-12 weeks.

Lactic acid may also be used. Immersion in a 2 per cent solution of lactic acid at 55°C for 10 sec causes a similar reduction in the degree of contamination to that obtained with acetic acid. However the residual effect during storage of the vacuum-packaged meat is not as great.

Multiple pieces of meat vacuum-packaged in one bag

There may be a need to extend the storage life of boneless fresh meat, and the muscles involved may be too small to warrant individual packaging. For example, this is sometimes done with meat from the forequarters of pig carcasses.

The storage life of smaller muscles bulked and packaged together will always be shorter than that of a single muscle or cut, of the same weight and pH. The shorter storage life is largely caused by the greater surface area on which bacteria can grow when multiple muscles are present, ie., the surface to volume ratio is greater. If some of the meat is of high pH, and this is likely with pork, this then becomes the limiting factor. In the case of pork, packs containing multiple muscles should be stored at 0°C (when the storage life under commercial conditions will be 2-3 weeks) or as close to this temperature as possible. If stored at 5°C, storage life could be as short as 7-10 days and this may not be sufficient to make the practice worthwhile.

Storage in 100 per cent carbon dioxide

The primary function of carbon dioxide is to inhibit microbial growth and it becomes more effective as its concentration increases. Meat contains about 75 per cent water and when carbon dioxide is injected into packs of meat, some of it dissolves in the water and forms carbonic acid. Part of the anti-microbial action of carbon dioxide is thought to be due to this phenomenon and the reduction in pH that it causes. However the situation is more complex than this and to be fully effective the gas must have access to all the meat surfaces during storage, ie., there must be excess gas present.

The amount of carbon dioxide which dissolves in the product and hence the volume of the head space required depends upon factors such as storage temperature, the nature of the meat surface (lean or fat) and the surface to volume ratio. Lean meat surfaces have a higher water content than fat or skin and will absorb more gas. The effectiveness of carbon dioxide as an inhibitor increases as the temperature decreases. This is due in part to the fact that its solubility increases as the temperature decreases.

Generally speaking the storage life of fresh meat stored in an atmosphere of 90-100 per cent carbon dioxide should be at least as long as that obtained by vacuum packaging. Swedish workers have claimed that pork stored in an atmosphere containing more than 90 per cent carbon dioxide would keep for 3 months at 0°C. For primal cuts or whole lamb carcasses stored at 0°C, at least two months should be achievable provided certain criteria are met. In particular excess gas, above the volume which will dissolve in the meat, must be present. The volume of gas used should be 1.5 litres per kilogram of meat for maximum effect (at least 15 litres for a 12 kg lamb carcass) and the residual concentration of oxygen should be as low as possible. This can be achieved by including a flushing step in the process.

The use of atmospheres of carbon dioxide presents a number of technical problems. Holding meat in an excess of the gas can be achieved by using rigid sealed containers, but these present problems in commercial use. The meat may be stored sealed in plastic bags made of films of low gas permeability. After packaging, gas is absorbed by the meat, the amount depending upon the temperature, ie., the volume of the pack depends upon storage temperature. An added complication is that it takes some hours for the contraction in volume to occur. Both these factors leave significant implications for cartoning, final storage volume etc. It is possible to vary the gas to meat ratio such that just sufficient gas is added so that it is absorbed during the initial stages of storage, the pack tightens and has the visual appearance of a true vacuum pack. Unfortunately this amount of gas is not optimal microbiologically and further, if the temperature rises, some gas will be released from the meat and the packs will become slack, ie., they look like "leakers".

Colour problems have been reported with beef stored in high concentrations of carbon dioxide. However recent studies have shown that the lean surface of beef does not discolour provided no oxygen is present. If only 0.5-1 per cent of oxygen is present the rate of formation of metmyoglobin is high and browning occurs. Under commercial conditions it is difficult to exclude all oxygen and colour changes remain a problem, especially with beef because of its high pigment content. In addition to discolouration of the lean surface, problems with the appearance of fat surfaces may occur (brown-grey discolouration). With lamb a brownish discolouration of the fell surfaces may develop after several weeks storage at 0°C and if this occurs the appearance is inferior to that of fresh primals.

A system recently developed in New Zealand is claimed to overcome this problem. The lamb cuts are vacuum-packaged in permeable bags which are heat shrunk. These are stored in a "master pack" consisting of a large bag made from very impermeable film that is filled with an excess of carbon dioxide and sealed. (The packaging of the cuts in permeable film is to allow access of the carbon dioxide to the meat). Storage at -1°C is reported to yield a life of some 16 weeks.

Consumer cuts

In many countries, including Australia, there is still a strong preference for meat that is bright red in colour. This applies to beef and lamb but may be less critical with pork because of its lower pigment content. A major objective of meat marketing has been to ensure that the consumer is presented with meat, the colour of which matches his expectations.

There are three types of packaging suitable for the presentation and display of consumer portions of meats. These are conventional overwrapped trays, modified atmosphere packaging (MAP) and vacuum-packaging. MAP and vacuum-packaging have been little used in Australia, but are common in some European countries. Some characteristics of beef presented using these packaging systems are shown in Table 5. This meat was from the carcasses of animals slaughtered two days prior to boning and was of normal pH (5.4-5.8).

Table 5: The characteristics of consumer portions of beef (pH 5.4-5.8) displayed using different methods of packaging

	Microbial flora	Meat colour	Retail display life (days)	Nature of spoilage
Overwrapped trays	*Pseudomonas* *Brochothrix*	red	3	Colour (browning)
MAP	*Brochothrix* Lactic acid bacteria	red	>7	Colour (browning)
Vacuum packaged	Lactic acid bacteria	purple	>7	Colour, or possibly bacterial souring

(i) Conventionally-overwrapped trays

Supermarkets traditionally present retail cuts for display in semi-rigid plastic trays overwrapped with a clear plastic film, which is readily permeable to oxygen. *Pseudomonas* bacteria grow and cause rapid spoilage and *Brochothrix* may also be a problem. However bacterial spoilage of consumer cuts in overwrapped trays stored under retail display conditions does not limit storage life; this is usually caused by deterioration in appearance. Development of browning causes "fading" and a "tired" appearance and this limits display life to a maximum of three days. In practice supermarkets restock retail display cabinets daily to ensure the meat has a fresh appearance.

(ii) Vacuum-packaging

With vacuum-packaged consumer portions the ratio of residual air to meat may be higher than with joints or primal cuts. This means oxygen may be depleted more slowly, with the possible consequences of metmyoglobin formation and browning. If retail cuts are to be vacuum-packaged, it must be done immediately after cutting and packs must contain the minimum volume of air. The use of films of very low permeability is recommended.

The colour of vacuum-packaged consumer cuts of beef and lamb is purple, and this causes consumer resistance in some markets. The purple colour is stable during storage and that gives this packaging method a considerable advantage over the others available. The storage life of vacuum-packaged consumer portions is about two weeks at 0-1°C. This is sufficient to allow distribution from centralised packing plants. Under conditions of retail display, storage life of one week is readily achieved.

Vacuum skin packaging uses films which, on heating, soften and contour around the meat. An extremely close fit to the meat is achieved by applying a vacuum whilst the film is soft. The meat is positioned between the two layers of the film. A major advantage of vacuum skin packaging is that this technique minimises the release of weep. Vacuum skin packaging is also used for consumer cuts which are to be frozen. In this case the films used are permeable. The meat retains its red colour but will spoil rapidly unless it is frozen. The colour is stable for long periods when the meat is stored frozen in the dark but following exposure to light, the red colour gradually darkens.

(iii) Modified-atmosphere packaging

The gas atmosphere used for consumer portions stored using MAP should contain 20-30 per cent carbon dioxide with the remainder being oxygen. Because of the high oxygen content the colour remains bright red.

To achieve the optimal effect, there must be excess gas present (1.5-2 times the volume of the meat). A deep draw pack made of impermeable material is used and the base is dimpled to allow access of the gas to the lower surface of the meat. Spoilage is usually due to colour deterioration which limits retail display life to 5-6 days.

There are several factors to be considered in using MAP for consumer portions. These are:

1. Bulkiness. Because of the large head space needed, the volume of a pack is greater than that of a conventional overwrapped tray and more storage space may be needed.

2. Increased exudate. The longer display period means that accumulation of weep may be a problem.

3. Unsuitability for frozen storage. Even when the meat is stored frozen, the high oxygen concentration causes accelerated rancidity.

4. Temperature control. Good control of temperature is essential otherwise the desired extension of storage life may not be achieved.

5. Under some circumstances bacterial spoilage may precede colour deterioration, ie., consumers may purchase meat of good colour but find it is "spoiled" when they open the package.

Retail display following vacuum-packaged storage of primals

Vacuum-packaged primal cuts are broken down to consumer cuts prior to sale. Whilst there have been many studies of the storage of vacuum-packaged meats, little attention has been paid to the quality of consumer cuts prepared from them.

Table 6 lists the retail display life of consumer cuts of beef (stored at about 5°C) in conventionally overwrapped and MAP packs as a function of the time of storage of the meat in the vacuum pack at 0°C. The longer the period of prior storage in the vacuum pack, the shorter is the display life of the consumer portions. The advantage of longer display life achieved by the use of MAP, becomes less as the period of prior storage increases. In the case of beef, there appears to be no advantage in using MAP, after eight weeks vacuum-packaged storage.

Table 6: The approximate retail display life of consumer cuts of beef as a function of the time the meat was stored vacuum packaged

Storage time in the vacuum pack (weeks at 0°C)		0	2	4	6	8
Retail display life display	Overwrapped trays	3	3	2	2	1
	MAP	>7	5-6	4-5	3-4	2

Centralised packing of consumer portions using an MAP master pack

Consumer portions, packaged in conventionally overwrapped trays may be placed in a large impermeable bag (the master pack), which is evacuated and filled with a gas mixture consisting of 20 per cent oxygen and 80 per cent carbon dioxide. The master pack is then stored at a low temperature, preferably 0°C or -1°C. When needed the master packs are opened and the overwrapped trays are placed on retail display.

With meat stored for up to nine days in the master pack at -1°C to 0°C, a retail display life of three days is retained. With longer periods of storage in the master pack, the retail display life is shorter, ie., less than is obtained with fresh meat in overwrapped trays. Master packs of this type are suitable for centralised prepacking operations. Their use reduces some of the disadvantages of MAP (bulkiness, cost, etc.).

PROCESSED MEAT

There is less potential to extend the storage life of processed meats than there is of fresh meats. A major reason for this is that the processing itself is intended to extend storage life. Many processed meats are cured and the prime microbiological characteristic of cured meats is that they should not putrefy. There are many types of processed meats which apparently differ greatly in composition and intended eating quality, but the types of bacteria growing on and in them are surprisingly similar.

Water activity is an important factor controlling the growth of micro-organisms on processed meats and this is an important difference between them and fresh meats. When water activity is reduced to about 0.96, the typical spoilage of chilled meats by *Pseudomonas* is prevented and at 0.92, the growth of putrefactive anaerobes and Enterobacteriaceae is inhibited, even when the meat is stored at room temperature.

Cured meats contain nitrite which is antimicrobial, its activity increasing with reducing pH and redox potential. In this regard the general strategy to be adopted with processed meats parallels that with fresh meats – the lower the pH and the oxygen concentration, the less susceptible the product is to microbial spoilage.

To a large extent, microbial growth on processed meats can be predicted if the pH and water activity of the product are known. Processed meats may be categorised based on these parameters (Table 7). This table covers bacteria but not spoilage because of mould growth. Other factors that influence microbial growth include the chemical composition of the cure and the nature of any smoking and cooking processes.

*Table 7: Storage categories of meat products based on the a_w and the pH of the products**

Category	Criteria	Temperature
Storable (at ambient temperature)	$a_w \leq 0.95$ and pH ≤ 5.2 or $a_w \leq 0.91$ or pH ≤ 5.0	No refrigeration required
Perishable	$a_w \leq 0.95$ or pH ≤ 5.2	$\leq + 10°C$
Easily perishable	$a_w > 0.95$ and pH > 5.2	$\leq + 5°C$

* Data from Leistner, 1978

Processing destroys the enzymes in the meat that convert oxygen to carbon dioxide. This means that packaging does not have the same potential to create atmospheres rich in carbon dioxide as it does with fresh meats. However when processed meats are packaged in plastic films that are impermeable to gases, the concentration of carbon dioxide within the pack does rise. This is presumed to be caused by the metabolic activity of the microbial flora on the meat.

Lactic acid bacteria are a major component of the microbial flora of most types of processed meats and they are resistant to inhibition by nitrite. Some strains grow on products with water activities as low as 0.90. Their growth is not restricted by packaging and the common addition of fermentable carbohydrates as part of the cure, results in a favourable nutrient situation for their growth. In general, the presence of a flora dominated by lactic acid bacteria is considered normal and even desirable for most processed meats. When they cause spoilage it is commonly due to souring, however other more specific types of spoilage may be caused as a result of their growth or metabolism. These are listed in Table 8. Because processing commonly creates conditions under which lactic acid bacteria dominate, and because their growth cannot be readily controlled by packaging, some of these defects are difficult to eliminate.

The low water activity of some types of processed meats favours the growth of yeasts and moulds. These do not compete well with the faster growing bacteria when the water activity is high, but they may be major components of the flora of processed meats.

In recent years the wish to reduce salt consumption has led to the use of milder cures while scrutiny of preservative usage has led to lower nitrite levels. This has resulted in shorter storage lives and increased need for refrigeration.

Dried meats

The water content of meat must be reduced from ca. 75 per cent to 20 per cent to prevent the growth of micro-organisms. Even at this low water content, some moulds would grow slowly over a period of months. At 12 per cent water content (a_w ca. 0.75) mould growth would appear after several weeks, depending upon the temperature. At 20 per cent content (a_w ca. 0.85) the product would be mouldy after about two weeks.

If dried meats are stored in a high relative humidity they will absorb water and mould growth will follow. Vacuum-packaging will prevent this. Gas flushing with carbon dioxide or packaging in an atmosphere of carbon dioxide will also inhibit mould growth. Nitrogen may be used but may be less effective.

Raw cured products

(i) High-a_w products – bacon, raw ham, semi-dry fermented sausage ($a_w > 0.92$).

The organisms which dominate the flora of these products are Gram-positive bacteria especially micrococci, lactobacilli, streptococci and *Brochothrix*.

(ii) Low a_w products ($a_w < 0.92$) – fermented sausages (salami), dried salted meats (Bünderer Fleisch, biltong).

Yeasts and moulds may grow on some products, salt tolerant micrococci and lactobacilli may be present.

There is little advantage to be obtained by packaging raw cured meats, at least in terms of preservation, but the packaging film will prevent the products from being contaminated during storage and handling. The growth of moulds can be inhibited by packaging using impermeable films, especially if combined with flushing with carbon dioxide or a mixture of carbon dioxide and nitrogen.

Table 8: Spoilage of cured meats by lactic acid bacteria

Defect	Description and cause	Controllable by packaging	Other possible remedies (1)
Souring	General mechanism of spoilage. Excess acid production due to heavy bacterial growth, especially in packaged sliced cured meats.	No	Reduce (i) storage period (ii) temperature (iii) amount of added carbohydrate.
Slime production	Sucrose in the cure may be converted to slime.	No	Eliminate sucrose from cure.
Greening	Production of hydrogen peroxide which reacts with meat pigments to form a green pigment, choleglobin. A common problem with frankfurters, some types of sausage, ham, bologna.	Yes. By the use of gas impermeable packaging films. But the green colour appears when exposed to oxygen (eg., when sliced or cut).	If due to post cooking contamination this may be difficult to prevent.
Gassing	Excess CO_2 production caused by the growth of particular types of lactic acid bacteria and yeasts may cause swelling or blowing of packaged meats.	Yes. By the use of packaging films of higher permeability to CO_2.	Reduce the amount of carbohydrate available.

(1) In most cases improved hygiene, ie., reducing the level of contamination, will assist.

Cooked cured meats

These products may be heated to an internal temperature of 65-72°C, which destroys most vegetative bacteria, yeasts and moulds. They are recontaminated by slicing, portioning, or, in the case of frankfurters, skinning. Products in this category include whole muscle hams, pressed hams, corned beef and emulsion type sausages (luncheon sausages such as Devon, Strasburg, Windsor etc.).

Emulsion-type sausages, commonly sold as chubs and knobs, are cooked in plastic casings and have a storage life of several months at 0°C. Packaged sliced meats (luncheon meats) have a storage life of only about two weeks under conditions of retail display, if the packaging film is readily permeable to gases. This can be doubled by the use of impermeable films.

Modified atmosphere packaging can be used to advantage with sliced meats. The gas should not contain oxygen as it is not needed to maintain the colour of the cured meat and its absence prevents rancidity. The gas should be nitrogen or a mixture of nitrogen and carbon dioxide. Nitrogen alone has little benefit in terms of increasing storage life. Vacuum-packaging may result in peelability problems with sliced meats and distortion of products such as frankfurters. The addition of an inert gas such as nitrogen to the pack prior to sealing will overcome these problems. Nitrogen used in a mixture with carbon dioxide will minimise distortion of the pack which may occur following absorption of the carbon dioxide.

Products that are vacuum-packaged using films of low permeability may suffer from swelling of the package. This is caused by the excessive growth of lactobacilli, leuconostocs or yeasts, which generate carbon dioxide during growth. This occurs particularly if there is a high concentration of fermentable carbohydrate in the cure (see Table 8).

Packaged frankfurts may spoil due to the appearance of a milky liquid. This is commonly caused by the growth of bacteria and yeasts. Gas flushing with carbon dioxide will inhibit yeast growth and may extend storage life.

It is difficult to guarantee a storage life of more than about four weeks for packaged sliced cooked meats and frankfurts under conditions of retail display (at ca. 5°C), even if gas flushing or MAP is used. To achieve a longer storage life products must be held at 0-1°C. Lighting in retail display cabinets can cause deleterious changes in cured meat colour, and this also may limit storage life.

FURTHER READING

Brown, M.H. ed. (1982). Meat Microbiology, Applied Science Publishers, London, 1982.

Egan, A.F. (1984). Microbiology and storage life of chilled fresh meats. Proceedings of the 30th European Meeting of Meat Research Workers, Bristol, pp.211-214.

Eustace, I.J., Bill, B.A., Gibbons, R.A. and Powell, V.H. (1980). Vacuum-packaged lamb carcasses, extension of storage life by treatment with acetic acid prior to packaging. CSIRO Division of Food Research, Meat Research Report no.8/80.

Gardner, G.A. (1983). Microbial spoilage of cured meats. In. Food Microbiology: Advances and Prospects (T.A. Roberts and F.A. Skinner, eds.), pp.179-202, Society for Applied Bacteriology Symposium Series No.ll, London: Academic Press.

ICMSF (International Commission on Microbiological Specifications for Foods) (1980). Curing salts and related materials. In. Microbial Ecology of Foods, Vol.1: Factors Affecting Life and Death of Micro-organisms, pp.136-59. New York: Academic Press.

ICMSF (International Commission on Microbiological Specifications for Foods) (1986). Meat and meat products. In. Microbial Ecology of Foods, Vol.2: Food Commodities, pp.333-409, New York, Academic Press.

Lawrie, R.A. (1985). Meat Science, 4th ed. Pergamon Press, Oxford.

Leistner, L. (1978). Microbiology of ready-to-serve foods. Die Fleischwirtschaft 58, 2008-11.

Lucke, F.K. (1984). Fermented sausages. In. Microbiology of Food Fermentations (B.J.B. Wood ed.), Vol.2, pp.41-83, London: Applied Science Publishers.

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

Taylor, A.A., Down, N.F. and Shaw, B.G. (1986). Storage and display of fresh meat packed in elevated O_2/CO_2 atmosphere. In. Meat Chilling 1986, pp.223-229. International Institute of Refrigeration, Paris.