24. Ageing Vacuum-Packing and Storage

Bill Spooncer

Learning objectives

At the end of this topic you should be able to:

- Explain how shelf life of chilled vacuum packed is extended compared with the storage life of chilled meat stored in air
- Understand the processing factors that affect the colour and microbial condition of vacuum-packed meat
- Understand the changes in meat quality that occur during ageing of meat

Key terms and concepts

Aerobic and anaerobic storage of meat; Vacuum-packed chilled meat; Modified atmosphere packing; Limitation of the storage life of meat due to microbial growth; Limitation of the storage life of meat due to colour changes; Oxygen permeability of packaging films; Weep of fluid from post-mortem meat

24.1 Introduction

Meat is a highly perishable food. The meat industry in its current form would not exist if methods of preserving meat during transport and distribution had not been developed. In the early days of the meat industry in Australia, cattle were grown for their tallow and hides and sheep were grown for wool. Most of the meat was discarded because there was no way of getting it to overseas markets in an acceptable condition.

Refrigeration was introduced to Australia in 1851. Initially mechanical refrigeration was used to make ice but the new technology was slow to become established because it could not compete with imported lake ice from North America. The first exports of frozen meat occurred in 1873 but the shipment was unsuccessful and the meat was tossed overboard during the voyage. The first successful shipment of frozen carcase beef was sent to England on the SS Strathleven in 1880. This was a landmark in the development of Australian export meat industry.

Exports of frozen meat suffered set backs and grew slowly. One difficulty was that frozen product had to compete with chilled carcases from South America. South American meat could be exported to England in chilled form because the journey is shorter. Australian frozen product suffered from freezer burn and drip loss when thawed, this was a disadvantage when competing with chilled meat.
Chilled meat was successfully exported to England between 1909 and 1911. The meat was held at -1^{o}C to -1.5^{o}C during the voyage and was exposed to formaldehyde vapour for one hour a day. The British government eventually banned the use of formaldehyde and the trade stopped. Other attempts were made to extend the storage life of chilled meat but they involved unwelcome additives and did not become established.

In 1932 it was discovered that the storage life of chilled meat could be increased by increasing the amount of carbon dioxide in the atmosphere around the meat. This resulted in exports of chilled from Australia in gas tight chambers containing an atmosphere with 10% carbon dioxide. This work was pioneered by Dr J.R Vickery of CSIR (later CSIRO).

In the 1960s the principles of preservation of chilled meat in high carbon dioxide atmosphere were followed to develop vacuum packing. Vacuum-packed chilled meat was first produced in Argentina. Australia took up the technology in the late 1960s. At first primal cuts of meat were vacuum packed, aged for 20 days and then frozen for export to Sweden. This trade developed into the export of chilled vacuum-packed cuts to other countries, mainly Japan. Vacuum packaging technology has been further developed to produce various forms of modified atmosphere packing.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

It has probably been know for millennia that meat can be tenderised by application of enzymes contained in fig juice, pineapple juice and paw paw leaves. In 1907 the first scientific paper about tenderizing meat by ageing i.e. by using the naturally occurring enzymes in the meat, was published. This paper documented an increase in tenderness of up to 30% in meat stored for 8 days above freezing point (Gilbertson, 1985). Of course it was well known before this time that hanging meat improved tenderness. Carcase meat tenderizes through the process of ageing when it is hung at temperatures above -1^{o}C for several days or even weeks. The disadvantages of hanging carcase meat are that it takes up chiller space, the meat is subject to spoilage if the temperatures is not well controlled or the meat is hung for too long and there is weight loss caused by surface dehydration and trimming of spoiled surface tissue.

Meat also tenderises by ageing if it is stored above freezing point in vacuum packs for several days or weeks. The advantages of vacuum packing over ageing meat on a hanging carcase or "ageing on the bone" are that the vacuum packed meat is usually in the form of boneless cuts (although lamb carcases can be vacuum packed) and takes up less room in chillers and refrigerated transport, there is less weight loss and storage life can be reliably extended to more than 80 days for beef without losses due to spoilage. Thus the combination of vacuum packing technology to extend the storage life of chilled meat and the natural process of tenderisation of meat by ageing has resulted in production of high-quality chilled meat with extended storage life for domestic and export distribution.

24.2 Principles of meat storage

Meat is an excellent medium for the growth of bacteria and other microbes and successful storage depends on controlling microbial growth. There are five distinct conditions for microbial growth. They are:

- nutrients
- temperature
- water availability
- ph
- oxygen environment

For each growth condition, microbes have a range they will tolerate and an optimum. The range and optimum conditions for growth vary between the different types of bacteria and by manipulating the conditions it is possible to stop or limit the growth of particular microbes. For example, if meat is stored in air at ambient temperature (e.g. 25^{o}C) the conditions will be such that many different types of bacteria can grow quickly, including pathogenic bacteria such as *Salmonella spp*. The meat will spoil within a few hours.

If the meat is chilled to below 5^{o}C, the types of microbes that can grow are greatly reduced. The bacteria that can grow on chilled meat are psychrophiles (cold loving) and psychrotrophs (cold tolerant) organisms. Table 24.1 shows the growth range and optimum growth temperature of bacteria.

Table 24.1 Temperature growth range and optimum growth temperature of bacteria. Source: Grau, (1978).

Type of bacteria	Typical growth range	Optimum growth temperature
Psychrophiles	-8 to 20^{o}C	12 to 15^{o}C
Psychrotrophs	0 to 30^{o}C	20 to 30^{o}C
Mesophiles	7 to 45^{o}C	25 to 37^{o}C
Thermophiles	45 to 75^{o}C	50 to 65^{o}C

From Table 24.1 it can be seen that only psychrophiles and psychrotrophs can grow on chilled meat at 5^{o}C. The mesophiles (which include most of the pathogens such as *Salmonella spp.*) and thermophiles cannot grow. The conditions on chilled meat therefore select the type of bacteria that will grow. In particular, the organisms that grow most quickly are psychrotrophic aerobes i.e. cold tolerant organisms that require oxygen for growth. An example of this type of organism is

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Pseudomonas spp. This type of organism dominates the microbial flora on chilled meat stored in air. Pseudomonads spoil meat when they reaches a population of about $10^7/cm^2$. At this population off odours are detectable and at a population of $10^8/cm^2$ slime is seen on the surface of the meat. The slime or stickiness is due the gelatinous capsule of Pseudomonads.

Pseudomonads preferentially use glucose as an energy source. There is not much glucose in meat but as it is consumed at the surface of meat some will diffuse to the surface from the deeper tissues. When the population of *Pseudomonas spp*. is about 10^7-$10^8/cm^2$, the rate of diffusion is too low to meet the demands of the bacteria. *Pseudomonas spp*. will then utilise amino acids as an energy source. This results in production of ammonia and off odours and flavours. There is less glucose in high pH meat (>pH5.9) than in normal pH meat and off odours and flavours occur when the cell density of *Pseudomonas spp.* reaches about $10^6/cm^2$.

The time it takes for *Pseudomonas spp*. to spoil meat depends the initial level of contamination and the storage temperature. Table 24.2 shows the time it takes for Pseudomonas to make meat slimy at different temperatures assuming the initial level of contamination is 100 cells per cm^2.

Table 24.2: Time for meat to spoil due to Pseudomonas growth at different temperatures assuming initial contamination of 100/cm^2 Source: Grau, (1978).

Storage temperature (^oC)	Time taken for development of slime (days)
0	10
2	5-6
4	4
6	3-4

The key points about the storage of chilled meat are that:

1. Pathogenic mesophiles do grow on meat at temperatures below 7^oC
2. Storage life is limited by spoilage by psychrotrophic aerobes; the time taken for meat to spoil is temperature dependent.

Non-microbial spoilage of chilled meat

While the storage life of chilled meat is mainly determined by microbial growth, there are non-microbial changes to meat quality during storage. The main change is to meat colour.

The colour of meat is determined by the state of the pigment myoglobin.

Myoglobin transports oxygen within muscle and like haemoglobin it has the ability to absorb and desorb oxygen. The myoglobin molecule comprises a haematin nucleus attached to a globular protein. The haematin portion of the molecule contains one atom of iron. When the iron is in the reduced i.e. ferrous state, it can combine with oxygen. The iron can be oxidised to the ferric form and in this form it does not combine with oxygen. The colour of the pigment depends on the oxidation state of the iron and the oxygenation or absorption of oxygen by the iron.

In fresh meat (as opposed to cooked or cured meat) the myoglobin can have three colours. They are

1. Purple; this is the colour of the reduced myoglobin;
2. Bright red: this is the colour of oxygenated myoglobin. Oxygenated myoglobin is called oxymyoglobin.
3. Brown: this is the colour of oxidised myoglobin. Oxidised myoglobin is called metmyoglobin

Reduced myoglobin absorbs oxygen and changes to oxymyoglobin when meat is exposed to oxygen. It can also change to metmyoglobin without going through the oxygenated stage. Oxygenated myoglobin can be oxidized to metmyoglobin and can be changed back to reduced myoglobin if oxygen is not available at the surface of the meat. Metmyoglobin cannot be oxygenated but it can be converted back to reduced myoglobin if the ferric ion is reduced.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Myoglobin is oxidized to metmyoglobin by oxygen. Other factors can promote oxidation such as salt and low pH but these factors are not usually important in unprocessed meat. Metmyoglobin is reduced back to myoglobin by naturally occurring reducing enzymes in the meat. Other chemicals can reduce metmyoglobin, e.g. sulphur dioxide but this is not relevant in unprocessed meat.
The enzymes that reduce metmyoglobin are only active if oxygen is available.

The usual situation in meat is that there are three colour zones.

In the deeper tissues of meat there is no oxygen. The pigment cannot be oxygenated or oxidized and remains as the purple coloured myoglobin.

At the surface of meat exposed to air, the pigment is oxygenated to bright red oxymyoglobin. In this zone, the reducing enzymes are active because oxygen is present and they prevent the formation of metmyoglobin by reducing any oxidized pigment.

The third zone is between oxygenated layer and the deeper un-oxygenated meat. In this layer there is enough oxygen to oxidize myoglobin to metmyoglobin but not enough to activate the reducing enzymes. This zone may be brown is colour. However, in unaged meat this zone is very small because the reducing enzymes are highly active. Also, the ratio of metmyoglobin to myoglobin must be more than 1:1 before a brown colour can be seen and the amount of metmyoglobin formed in unaged meat is not enough to produce a brown colour. As the meat remains exposed, the metmyoglobin zone expands because the activity of the reducing enzymes weakens. After a several days the brown colour of metmyoglobin is visible at the surface of the meat.

Brown metmyoglobin may form at the surface of a piece of meat, for example where two pieces of meat are in contact. At this point there is a limited supply of oxygen and when the oxygen is used up by microbial activity or meat respiration, the situation is reached where there is not enough oxygen to activate the reducing enzymes and the pigment will oxidize to brown metmyoglobin.

In some circumstances brown discolouration can be reversed. If the reducing enzymes are still active but are short of oxygen, re-oxygenation of the surface may allow the enzymes to reduce the metmyoglobin back to myoglobin which is then oxygenated to oxymyoglobin.

Bearing in mind the above, the factors that affect the rate of browning of meat are:

Amount of oxygen

Metmyoglobin forms very rapidly at low levels of oxygen. The maximum rate of browning occurs at about 0.5 - 1% oxygen at atmospheric pressure. The partial pressure of oxygen or oxygen tension determines the extent to which meat will absorb or desorb oxygen. Formation of metmyoglobin at the surface of meat is most rapid at about 4 mm partial pressure of oxygen. At this level there is enough oxygen to oxidize myoglobin but not enough to activate the reducing enzymes.

Age of meat

Reducing enzymes loose their activity as the meat ages and aged meat has less resistance to browning compared with fresh meat.

Temperature

Meat temperature affects colour in several ways. The activity of reducing enzymes is prolonged at low temperatures and meat stored at low temperature is more resistant to browning. At higher temperatures, enzymes are more active but they are quickly exhausted, in addition the rate of oxidation of myoglobin doubles for every 5^{o}C increase in temperature. Higher temperatures also promote other oxygen consuming reactions such as respiration. They also promote the rate of microbial growth. These effects consume oxygen and reduce the amount of oxygen available to activate reducing enzymes.

The solubility of oxygen is affected by temperature. Oxygen in more soluble in colder meat and will penetrate to a greater depth in colder meat. This pushes the metmyoglobin layer deeper into the meat.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Type of meat

Different muscles have different enzyme activity and this affects how deeply oxygen penetrates into the meat. In muscles with a high rate of respiration, oxygen is consumed quickly. Oxygen penetrates less deeply into meat from these muscles and the meat is less resistant to browning. The major muscle in striploin and cube roll is the most resistant to browning, topside is intermediate, and the major muscles in rump and tenderloin are the least resistant.

Other intrinsic factors such as pH, breed, age of animal, sex and diet are reported to affect the rate of browning of meat but these factors are less important than the extrinsic factors such as temperature and oxygen availability. Low pH meat is more susceptible to browning because enzymes are less active at low pH.

Microbial activity

A high rate of microbial growth promotes browning of meat because the microbes consume oxygen and reduce the amount of oxygen available to activate reducing enzymes.

24.3 Packaging systems to prolong shelf life

If meat is stored in an anaerobic environment (i.e. no oxygen) the aerobic bacteria (e.g. *Pseudomonas spp*.) that spoil meat cannot grow. In addition meat will not discolour due to the formation of metmyoglobin. The objective of vacuum packing is to create an anaerobic environment around the meat. This achieved by sealing meat in an evacuated flexible packaging film that has very low oxygen permeability.

After meat is vacuum packed in a low oxygen permeability film, any residual oxygen dissolved in the meat or remaining in the pack due to an incomplete evacuation is consumed by tissue respiration. During storage, a small amount oxygen will diffuse through the packaging film but providing the film permeability is low enough, oxygen that passes through the film will be consumed by meat tissue respiration or microbial respiration. Thus the environment in the pack is maintained in a virtually anaerobic condition.

In these conditions, the psychrotrophic aerobic bacteria cannot grow and will not spoil the meat. Other bacteria will grow on the meat. Under typical conditions the microbial flora will be dominated by lactic acid bacteria. These bacteria can grow at $0^{o}C$ in an anaerobic environment. Lactic acid bacteria can grow to populations of about 10^{7} to $10^{8}/cm^{2}$ on vacuum-packed meat. Depending on conditions it could take from 3 to 10 weeks or more for lactic acid bacteria to reach these numbers. When the population of lactic acid reaches $10^{7}/cm^{2}$, the meat is not necessarily spoiled. Lactic acid bacteria produce short chain fatty acids such as lactic and butyric acids and the meat is usually considered to be spoiled when the accumulated by-products the metabolism of lactic acid bacteria give the meat a permanent cheesy or sour milk odour (Grau, 1978).

For vacuum packed beef stored at $0^{o}C$ the storage life is up to 80 days. Even longer storage life has been reported as meat hygiene, packaging film reliability and temperature control improves.

For vacuum packed lamb, the typical storage life at $0^{o}C$ is about 60 days and for pork the typical storage life is about 45 days.

In the anaerobic conditions of the vacuum pack, oxymyoglobin quickly reverts to the purple coloured myoglobin and this colour is maintained during storage. When the package is opened and meat exposed to oxygen the meat will be oxygenated and the colour will bloom to a bright red. However, if the meat is several weeks old at this stage the activity of the reducing enzymes is weak there is little resistance to brown discolouration. The display life of aged vacuum packed meat could be less than a day due to rapid onset of brown discolouration after the vacuum pack is opened.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Factors affecting the storage life of vacuum packed meat

Successful vacuum packing depends on creating the conditions that allow the slow growth of lactic acid bacteria but which prevent or inhibit the growth of other organisms. These conditions are packaging to maintain an anaerobic environment, low storage temperature and pH below 5.9. It is also important that the initial level of microbial contamination on the meat is low.

Packaging material

A range of packaging films that give suitably low oxygen permeability can be used to vacuum pack meat. Permeability depends on the type of plastic. Films with low oxygen permeability usually include either ethyl vinyl alcohol (EVOH) or nylon to provide the oxygen barrier. The thickness of the film also plays a role in permeability. The oxygen permeability of the film is measured in terms of the

volume of oxygen the can diffuse through a specified area of the film in a specified time and under specified conditions of pressure, temperature and relative humidity. The typical oxygen permeability of films used for vacuum packing is about 25 ml O_2 per m^2 per 24 hours at 760 mm Hg, 25^{o}C and 75% RH. In practice the oxygen permeability is less than 5 ml O_2 per m^2 per 24 hours because the films are used at about 0^{o}C, not 25^{o}C.

Longer storage life can be achieved by using extremely low permeability films such as metallised or metal laminate films which have permeabilities less than 1 ml $O_2/m^2/24$ hours. However, these films are expensive and the extra storage life does not justify the extra cost. Higher permeability films may also be used. For example less expensive films with permeabilities up to 150 ml $O_2/m^2/24$ hours can provide storage life for beef up to about 35 days. With these types of films sufficient oxygen may permeate the film to provide the optimum oxygen tension within the pack for formation of metmyoglobin and the meat may become brown.

Temperature

The long-term storage temperature is the most important factor in determining the practical storage life of vacuum-packed meat. This is because the lower the temperature, the slower the growth and metabolism of microbes on the meat and the longer it takes for off odours to accumulate. Meat starts to freeze at -1 to -1.5^{o}C and the storage temperature should not be below -1.5^{o}C. At a storage temperature of -1 to -1.5^{o}C the storage life of vacuum packed beef can exceed 90 days. Table 24.3 indicates the effect of temperature on storage life

Table 24.3: Effect of storage temperature on the effective storage life of vacuum packed meat. Source: Spooncer, (2006).

Species	Approximate storage life (days)			
	-1^{o}C	0^{o}C	2^{o}C	4^{o}C
Beef	>90	80	55	40
Lamb	70	60	45	30
Pork	50	45	30	25

pH

The pH of vacuum-packed meat affects the type of microbes that can grow on the meat. *Altermonas putrefaciens* can produce hydrogen sulphide on vacuum packed meat if the pH is above 6.0 (Grau, 1978). Hydrogen sulphide combines with myoglobin to produce the green coloured pigment sulphmyoglobin. Greening of high pH meat can occur within 20 to 35 days of packing although greening has become less frequent with improvements in packaging films and temperature control. Greening is accompanied by a rotten eggs gas smell of H_2S and the meat is not fit for consumption.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Species

The expected storage life of vacuum-packed beef, lamb and pork is different as shown in table 24.3. There is no clear reason for the different storage life of the meat from different species. Some researchers have pointed to a relatively high incidence of high pH meat in pork for the short shelf life (Shay, 1986). But normal pH meat from both lamb and pork has a shorter storage life than beef. Another theory is that the initial level of contamination on lamb and pork is higher than on beef. It is also possible that non-microbial proteolysis of meat, particularly pork, may contribute off odours and flavours that limit the storage life of the meat.

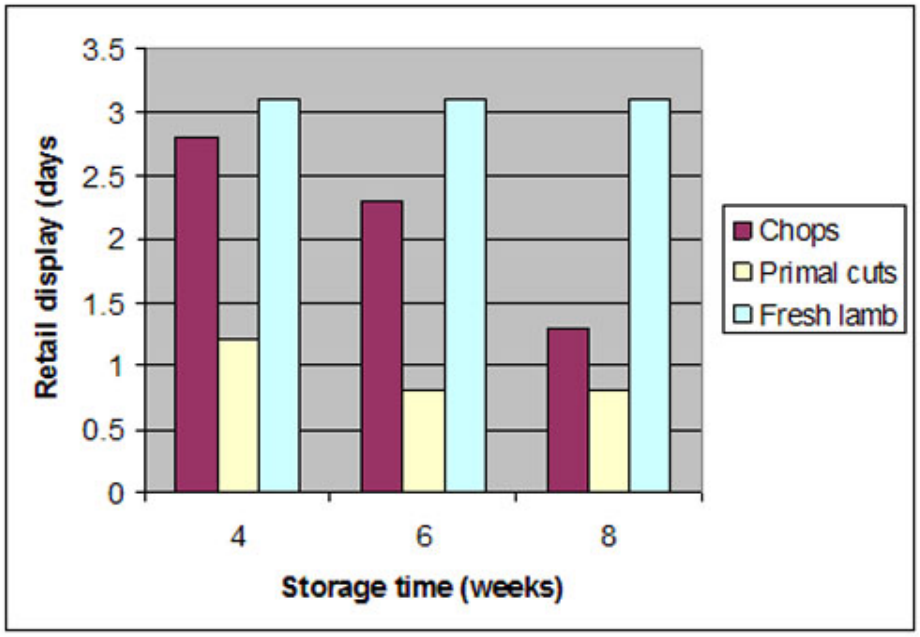
Characteristics and defects of vacuum packed meat

Colour

Vacuum packed meat should have a dark purple colour. This indicates that the pack is intact and the meat has not been oxygenated. To achieve this film permeability must be sufficiently low and the seals must be intact.

After the pack is open the colour should quickly bloom to bright red due to oxygenation of the myoglobin. In aged meat, oxygen penetrates more deeply than in fresh meat because enzymes that consume oxygen are less active. However the colour stability is poor because reducing enzymes are less active and the rate of reduction of metmyoglobin is slow. There is a relatively rapid appearance of brown discolouration at the surface of meat. This is illustrated in Figure 24.1 which shows the retail display life of lamb removed from vacuum packs. Figure 24.1 includes vacuum-packed lamb stored for 8 weeks although this product had an off odour in comparison with fresh meat.

Figure 24.1: Retail display life of aged vacuum packed lamb. Source: Bill et al., (1988).



Odour

When a vacuum pack is opened there may be a milky or cheesy odour. The odour comes from the by-products of microbial activity. The odour should dissipate within a few minutes of opening the pack. The smell of vacuum-packed meat is called "confinement odour" and is taken to be a sign that the meat is in good condition because it is characteristic of lactic acid microflora.

If the meat has a putrid odour it has probably been spoiled by aerobic bacteria. This can happen if the seal of the vacuum pack is not intact or the film is punctured. Putrid odours could also be caused by temperature abuse.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Another odour that occurs on vacuum packed meat is that of rotten egg gas (hydrogen sulphide). The gas is produced by bacteria that grow on the meat at high pH. A slight odour of H_2S may also occur if the film permeability is high (>50ml $O_2/m^2/24hr$) (Johnson, 1991). Hydrogen sulphide is soluble in meat tissue and the odour usually does not dissipate. If there is a small amount of production H_2S the odour may dissipate in about 30 minutes. If the odour persists the meat is not fit to eat because the flavour will be tainted.

If any type of odour persists on the meat (other than typical meaty odours) for more than 30 minutes after opening the pack, the meat is not suitable for consumption.

Weep

Weep is the fluid that is exuded from chilled meat. It is viscous and sticky because it contains soluble proteins including myoglobin. It is red or purple depending on the state of the myoglobin but does not contain haemoglobin and should not be confused with blood.

Weep occurs because the water holding capacity of muscle tissue is reduced during post-mortem changes. These changes include fall in pH, shortening of sarcomeres and partial denaturation of some protein. As the pH of muscle falls most of the proteins approach their isoelectric point (this is the pH at which the protein has no net electrical charge) and this reduces the ability of the proteins to attract water. Denatured protein also has reduced or no electrical charge and has reduced capacity to hold water.

Physical damage to muscle cells caused by cutting and slicing meat also allows water to leak out of the tissue. Weep from chilled meat occurs whether or not the meat is vacuum packed but it is particularly noticeable in a vacuum pack because it accumulates around the meat. The normal amount of weep is about 1-2% of the weight of the meat. Some cuts of meat produce virtually no weep while 4% is an excessive amount.

The amount of weep in a vacuum pack is affected by the rate of initial carcase chilling and the type of cut. Slow carcase chilling increases the amount of protein denaturation, particularly in the deep muscle tissue where the temperature may be more then 30^oC when the pH has dropped below 6.0. This type of denaturation may produce noticeably pale and exudative meat. Even if there are no visible signs of denaturation meat that has been chilled slowly is likely to produce more weep in a vacuum pack. If chilling is too rapid the meat will cold shorten and this will also produce excessive weep.

The type of cut affects the amount of weep in a vacuum pack because the more cut surfaces there are due to boning slicing and trimming of the meat, the more weep is produced in the vacuum pack. Cuts of meat in which the muscles are intact because they are seam boned produce very little weep.

Physical abuse such as squashing packed meat and temperature abuse of stored meat also produces weep.
It is common practice to put soaker pads into vacuum packs to absorb the weep and avoid the unattractive appearance of fluid slopping around in the pack.

Gas In packs

Gas bubbles may appear vacuum packs during storage. It is unlikely that the gas is produced by microbial activity because gases such as carbon dioxide and hydrogen sulphide produced by bacteria are soluble and will dissolve in the meat tissue rather than appear as bubbles. Gas bubbles are predominantly nitrogen. The source of the bubbles is nitrogen dissolved in the fatty tissue of the meat. At body temperature triglycerides in the fatty tissue are mostly liquid and may contain dissolved nitrogen. As carcases are chilled after slaughter, triglycerides crystallise and nitrogen is forced out of solution and may be trapped within the fat tissue. In a vacuum pack nitrogen may released from the fat and form bubbles. Bubbles are most noticeable in product that has subcutaneous fat cover that is trimmed shortly before packing.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Other forms of packing

The storage life of meat can be extended by packing in gas atmospheres. An alternative to vacuum packing is to pack meat in an atmosphere of 100%

carbon dioxide. Packing in CO_2 creates an anaerobic environment and thus has a similar effect to vacuum packing in extending storage life. However, CO_2 has additional inhibitory effects on the growth of lactic acid bacteria and *Brochothrix thermosphacta* and can provide a longer storage life than conventional vacuum packing.

Gas packing of lamb and pork in CO_2 is useful because these meats may not have a suitably long storage life in vacuum packs. Storage life up to 9 weeks for pork and 15 weeks for lamb at -1^{o}C is achievable in CO_2 atmospheres.

As with vacuum-packed meat, storage life is dependent of storage temperature and film permeability. In addition the storage life of CO_2 packed meat depends on the volume of gas and the residual oxygen content in the pack. When packing in CO_2, the ratio of gas to meat must be at least 2:1 and preferably 3:1.

Carbon dioxide is soluble and if there insufficient gas, the gas will dissolve in the meat tissue and create a vacuum pack. The residual oxygen content in the pack at the time of packing must be less than 0.1%.

Packing of meat in mixtures of oxygen and carbon dioxide is used for retail display. Mixtures containing 70 to 80% oxygen and 20 to 30% carbon dioxide are used in retail packs. In this gas atmosphere the storage life of steaks and chops is about 10 days at 2^{o}C. The storage life of minced diced meat is about 6 days. The purpose of the high oxygen content is to maintain the colour of the meat by achieving a deep layer of oxygenated meat at the surface of the meat. The carbon dioxide in the atmosphere provides limited inhibition of microbial activity and provides a few extra days storage life compared to packing in air.

24.4 Ageing and meat quality

If meat is held at above freezing point it will tenderize due to the ageing process. Ageing progresses in the same way if the meat is vacuum packed, gas packed or is held in air. The advantage of vacuum packing and gas packing is that meat can be held for extended periods without spoiling or loosing weight through evaporation.

Immediately after slaughter meat is tender. As rigor progresses meat toughens. This is partly due to contraction of the sarcomeres. Meat is most tough when it is set in rigor about 12 to 24 hours post mortem. Following rigor meat starts to become more tender due to the ageing process. Tenderisation is believed to occur through proteolytic degradation of some of the structural proteins of the sarcomere. In effect proteins are broken down by naturally occurring enzymes in the meat and this weakens the meat structure. It is not clear precisely what proteins are affected by ageing and what enzymes are involved but the following points summarise some of the reported mechanisms of ageing:

- There are three proteolytic enzyme systems in meat that could contribute to tenderisation during ageing (Pearson and Young, 1989). They are the alkaline proteases; the neutral proteases that are activated by calcium, this system is also called calcium activated factor (CAF) or calpains; and the acid proteases also called cathepsins.
- The alkaline proteases probably have little effect on tenderness because after slaughter the pH of muscles quickly drops below 7. However, there is evidence that some tenderisation takes place when the meat temperature is high and the pH near neutral and some authors have suggested that alkaline proteases may be involved.
- The calpains are activated by release of calcium into the sarcoplasm. There are two types of calpains, calpain I and calpain II. Calpain I requires a small (micromolar) concentrations of calcium for activation. Calpain II requires larger amounts of calcium e.g. 1-5 millimolar and it is unlikely that these levels of calcium will be available in normal circumstances. However a portion of calpain II activity may be triggered by the available calcium (Pearson and Young, 1989).

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

- Once calpains are activated they are unstable and become progressively less active during storage. Calpain I is activated while the muscle pH is high and continues until the enzyme activity is exhausted. Calpain II may not contribute much to tenderization in normal circumstances but this enzyme can be activated by addition of calcium ions. Processes for accelerated ageing of meat by addition of calcium have been developed (Koohmarie, 1995).
- Cathepsins are more active at low pH and may be more important in the longer term aging of meat.
- The tenderising effect of aging is mainly due to the disruption of the Z discs (Lawrie, 1985). Thin filaments in the Z disc are attached to actin filaments on either side of the Z disk and provide the mechanism for end-to-end bridging between each sarcomere unit. If the Z disk is disrupted the linkage between sarcomere units is weakened.
- Calpains appear to attack desmin, a protein associated with the Z disks. They also attack troponin T in the thin filaments (actin) of the sarcomere, connectin which provides lateral links between thick filaments (myosin).
- Cathepsins also attack troponin T at pH below 6.0 and may attack actin and myosin at high temperature (above 35^{o}C) or at low pH (less than pH5). However, it is not clear to what extent disruption of these different proteins contribute to tenderisation by ageing.
- Ageing affects the myofibrillar proteins of muscle but it is not clear if connective tissue proteins are affected. There are some reports that cathepsins may break down cross-links between collagen peptides but there is no direct evidence that this contributes to tenderness. The main structure of the connective tissue is not affected by ageing.

Ageing in practice

Although the mechanisms behind the ageing process are not fully explained the practical aspects of tenderisation by ageing are well established. The main factors that affect the ageing process are species, temperature and cold shortening.

Species

Beef, lamb and pork age at different rates. Table 24.4 shows the time taken to age different types of meat at 1^{o}C

Table 24.4: Time to age meat of different species at 1^{o}C,
Source: Dransfield, (1994). Printed with permission from Elsevier.

Type of meat	Time to achieve 50% ageing (days)	Times to achieve 80% ageing
Beef	4.3	10.0
Veal	4.1	9.5
Lamb	3.3	7.7
Pork	1.8	4.2

The rate of ageing is rapid in the first days after slaughter and gradually slows down. In the case of beef, tenderness improves considerably with one week's ageing. The rate of ageing slows in the second and third week of storage and there is very little further improvement beyond three weeks storage. If the storage temperature is 0^{o}C to -1.5^{o}C ageing for more than 3 weeks may be beneficial but for storage temperatures of 0 to 4^{o}C ageing is complete at about 3 weeks. Lamb tenderness improves significantly in the first three days after slaughter and does not benefit much beyond ten days storage. These rates of ageing depend in temperature and the degree of sold shortening of the meat.

Temperature

Rates of ageing are affected by temperature. The higher the storage temperature the faster the meat will age. Models for the rate of ageing have been proposed. For example one model proposes that the rate of ageing increases about 2.5-fold for every 10^{o}C in temperature (Dransfield, 1994). Thus 10 days ageing of beef at 0^{o}C is equivalent to 8 days ageing at 5^{o}C or 4 days ageing at 10^{o}C (ageing at 10^{o}C should not be attempted because of the risk of growth of pathogenic bacteria on the meat).

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

Cold shortening

Meat that has been chilled rapidly in the first 12 hours after slaughter will toughen due to cold shortening. Cold shortened meat does not benefit from ageing to the same extent as non-shortened meat. Meat that has cold shortened remains tough after ageing.

There are degrees of cold shortening and most meat will tenderize to some extent although some cold shortening may have occurred. It is known that meat does not respond consistently to ageing and some of the variation in tenderness after ageing may be explained by cold shortening. If cold shortening is prevented by electrical stimulation, tenderstretch or controlled carcase chilling, a relatively short ageing period will deliver tender meat. Longer ageing periods are required to produce tender meat from cold shortened meat and ageing will not overcome toughness caused by severely cold shortened meat.

Readings

The following readings are available on CD:

1. Anon 1996. Tender Lamb. Meat Technology Update Newsletter 96/5. Australian Meat Technology, Rocklea Qld.
2. Anon 2000. Prevention of fresh meat colour defects. Meat Technology Update Newsletter 00/2. Food Science Australia, Brisbane.
3. Anon 2000. The chilled, vacuum-packed meat cold chain. Meat Technology Update Newsletter 00/5. Food Science Australia, Brisbane.
4. Anon 2001. Gas bubbles in vacuum-packed meat. Meat Technology Update Newsletter 01/3. Food Science Australia, Brisbane.
5. Anon 2001. Modified atmosphere packaging of meat. Meat Technology Update Newsletter 01/4. Food Science Australia, Brisbane.
6. Anon 2002. The causes of drip in meat. Meat Technology Update Newsletter 02/6. Food Science Australia, Brisbane.

Activities

@ Available on WebCT

Multi-Choice Questions

@ Submit answers via WebCT

Useful Web Links

@ Available on WebCT

Assignment Questions

@ Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCt

Summary

Summary Slides are available on CD

Vacuum packing can extend the storage life of chilled beef to over 80 days. The extended storage life is achieved by creating an anaerobic (oxygen-free) environment around the meat. In these conditions the microbes that spoil meat by making it sticky, slimy and smelly cannot grow. Other types of bacteria can grow on vacuum-packed chilled meat but they take much longer to produce signs of spoilage.

Vacuum-packed meat is dark in colour, the pack may contain weep, there may be small gas bubbles in the pack and when the pack is opened there may be an odour that dissipates within a few minutes. These characteristics are typical of vacuum-packed meat and should not be taken as an indication that there is anything wrong with the meat.

If meat is aged in a vacuum pack it should bloom to a bright red colour when the pack is opened but the colour may fade to brown within 24 hours. The poor colour stability is a disadvantage of vacuum packed meat.

©2009 The Australian Wool Education Trust licensee for educational activities University of New England

If vacuum-packed meat is not prepared and stored in suitable conditions defects such as brown discolouration, green discolouration, bright red colour, smell of rotten eggs gas, excessive weep (more than 4% of the meat) and persistent odour when the pack is opened may occur.

If meat is stored at -1 to 5^{o}C after the completion of rigor it will tenderise due to the ageing process. During ageing, naturally occurring proteolytic enzymes break and weaken some of the structural proteins of the muscle tissue. The rate of ageing is dependent on temperature and increases as the storage temperature increase. Ageing also progresses at different rates in different species. Pork ages more quickly than lamb which ages more quickly than beef. Cold-shortened meat has a reduced response to ageing and meat that has a high connective tissue content may remain tough after ageing.

Vacuum packing provide a safe and efficient way of ageing meat. Meat can be stored and aged in vacuum packs without loss of yield due to evaporative weight loss or microbiological spoilage.

References

Bill, B.A., Eustace, I.J., and Smith, D.J., 1988. Storage life of chilled primal cuts of lamb. Meat Research Report 3/88. CSIRO Division of Food Research, Cannon Hill Qld.

Dransfield, E., 1994 Optimisation of tenderisation, ageing and tenderness. Meat Science, vol 36 p 105.

Dransfield, E., 1999 Meat tenderness – the μ-calpain hypothesis. 45th ICoMST. Japan Society for Meat Science and Technology. Yokohama, Japan.

Gilberstson, G. 1985 Quality control for vacuum packed meat. In *Proceedings of Meatworks Operation Control Workshop*. CSIRO Meat Research Laboratory, Cannon Hill, Qld.

Grau, F.H. 1978 The spoilage of meat and meat products. Food technology in Australia, vol 30 p 385.

Johnson, B.Y. 1991. Weep and other characteristics of stored and transported chilled meat. In *The Production of Chilled Meat for Export*. CSIRO Division of Food Processing, Cannon Hill Qld.

Koohmaraie, M., Wheeler, T.L. and Shackelford, S.D. 1995. Beef tenderness regulation and prediction. Meat '95, p A4-1. CSIRO Division of Food Science and Technology. Brisbane.

Lawrie, R.A. 1985 The conversion of muscle to meat. In *Meat Science* 4th edition. Pergamon Press

Newton, K.G. 1977 Vacuum packing of fresh meat. MIRINZ 597. Meat Industry Research Institute of New Zealand (Inc). Hamilton, New Zealand.

Pearson, A.M. and Young, R.D. 1989 Some conditions occurring in muscle/meat. In *Muscle and Meat Biochemistry*. Academic Press Inc.

Shay, B.J. and Egan, A.F. 1986 Studies of possible techniques for extending the storage life of chilled pork. Food Technology in Australia, vol 38 p 144.

Glossary of terms

Aerobic	Referring to biological activity that takes place in the presence of oxygen
Anaerobic	Referring to biological activity that takes place in the absence of oxygen
Cold shortening	Contraction of muscles resulting in meat toughness and caused by rapid chilling of meat in the first 12 hours after slaughter
Haematin	A non peptide group with an iron atom at the centre of a planar ring and attached to globular protein to form myoglobin an haemoglobin
Seam boned	Production of primal cuts of meat by separating muscles along the natural seams rather than cutting through muscles
Storage life	The time meat can be stored before changes in appearance of odour makes the meat unacceptable

©2009 The Australian Wool Education Trust licensee for educational activities University of New England