COLOUR OF CHILLED MEAT

Barry Y. Johnson

Meat quality is usually assessed by consumers in terms of colour, tenderness, juiciness, flavour, fat cover and marbling. However, it seems that at retail level, customers are most influenced by meat colour in their decision to buy. Colour is perceived to be a valuable guide to the overall quality of meat, so if a visual appraisal raises any doubts it is unlikely that purchase of that particular item will be considered further.

Although colour is the property of meat which first influences the potential customer, it can also readily affect the judgement of wholesale and institutional purchasers. It is therefore necessary to have an understanding of the variations in the colours of meat, and also the effects of various conditions, and handling practices on meat colour.

1. The Basis of Fresh Chilled-meat Colour

In the absence of oxygen, fresh meat is purplish-red and the colour of freshly sliced meat is purplish-red for this reason. This colour is caused by the presence of a pigment called myoglobin, which, on exposure to air, absorbs oxygen and becomes bright red. This takes only a few minutes, but if colour is being appraised this should be done after a minimum of 30 minutes. The oxygenated form of the pigment is called oxymyoglobin, and causes the bright red meat colour expected by the consumer. Oxymyoglobin only occurs to a depth of about 5 mm at 0°C.

After prolonged exposure to air, the pigment turns grey or brown and this brown pigment is known as metmyoglobin. The rate at which the pigments change from one to another is very dependent upon temperature and the amount of available oxygen. The relationship of the pigments is shown in Figure 1.

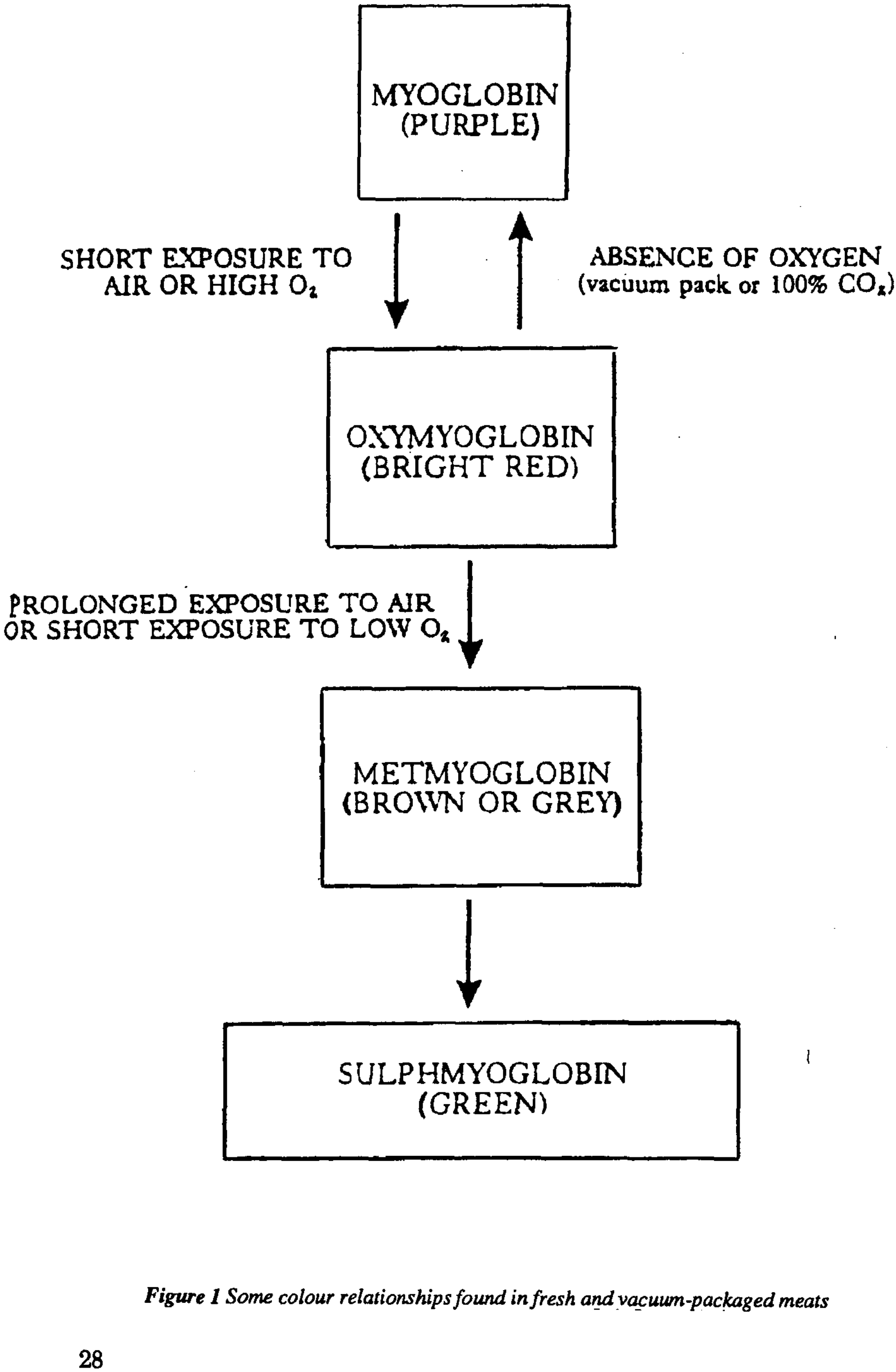

***Figure 1** Some colour relationships found in fresh and vacuum-packaged meats*

General Points

- Low temperatures slow the rate of the chemical reaction leading to brown metmyoglobin pigment formation.
- The red colour of meat is brighter and deeper at low storage temperatures because oxygen is able to penetrate the meat more easily. At 0°C the layer of oxymyoglobin at the surface of the meat is thicker than at 15°C.
- At extremely low concentrations of oxygen (such as in vacuum packs), the development of the brown pigment is prevented. However, at medium to low oxygen levels (about 1%, such as in poorly prepared vacuum packs), metmyoglobin development is greatest. There can be increased browning when unwrapped cuts are stacked in contact with each other and this browning occurs because of the low oxygen levels at the points of contact.
- Differences in the enzyme activities of different muscles cause colour stability variations from cut to cut and also within a cut. It is not uncommon to see in one cut, part of it red and the rest brown. Some cuts, such as rumps and tenderloins, are more susceptible to browning than are others.
- The rate of metmyoglobin formation is related to the balance between enzymes which promote metmyoglobin formation and those which slow it, as well as the oxygen content of the atmosphere around the meat.
- pH (acidity) has an influence on retail display life in air. High pH meat (dark cutting) discolours at a slower rate than does low pH meat. Meat discolours at a slower rate as its pH increases above normal pH (5.5).
- Exposure of meat to intense light, as in display cases in supermarkets, also increases the discolouration rate. It does this mainly by increasing the surface temperature of the meat.
- Contamination of meat with multivalent ions such as copper, iron and aluminium, oxidising agents such as peroxide and hypochlorite and curing agents such as nitrite and common salt (NaCl) also greatly accelerates the rate at which meat discolours.

2. Other Aspects of Fresh Chilled-meat Colour

Pigment Concentration

The greater the concentration of myoglobin, the darker the colour of the meat. Its concentration varies from species to species and beef contains about nine times as much myoglobin as pork and this in part explains why beef is red and pork is much paler. Meat colour is also affected by the sex and age of the animal, with older animals having a higher concentration of pigment. Within a carcass, different muscles contain varying concentrations of myoglobin, and so vary in darkness of colour.

Drying Out

Drying of the meat surface affects the way that light is reflected and absorbed, so reducing the amount of light reflected from the surface of the meat. During drying, the concentration of meat pigment increases at the surface and produces a darkening effect. Drying out also leads to increased brown pigment formation. This darkening due to dehydration can always be seen on the cut surface of the topside on sides of chilled beef.

"Dark Cutting" Meat

Stress prior to slaughtering also plays a significant role as it affects meat pH which in turn affects colour. High pH meat is dark because at low acid levels in the meat there is less oxymyoglobin formation at the surface so that the reduced myoglobin under the surface gives a dark appearance to the meat. Also there is less light reflected from the surface, along with the fact that there is a light scattering effect resulting in the eye perceiving the colour differently.

Meat colour gradually darkens with increase in ultimate pH right through the pH range 5.4 to 7.0. If beef has a pH of 6.0 or more it is usually classified as "dark cutting" or "high pH" beef. However meat with an ultimate pH of 5.8 may be regarded as dark by some consumers, although it would not be classed technically as "dark cutting" meat. Any stimulus which causes rapid use of muscle energy whilst the animal is still alive - stress, cold weather, disease or strenuous muscle contractions are examples - can cause animals to produce dark cutting meat.

Two-toned (Pale and "Dark") Meat

In two-toned meat there are undesirable gradations in meat colour within a cut, with the deep meat tissue being paler than the normal red meat closer to the surface. Pale coloured meat will discolour more quickly in the presence of oxygen, than will the normal coloured meat because its enzyme system is affected and the metmyoglobin reaction progresses faster.

The two-tone effect is sometimes evident in beef (particularly heavy carcasses), but is not seen in small stock carcasses to any extent because of their faster chilling rate. The paleness causes a ring effect, sometimes called a "heat ring".

The undesirable paleness leading to two toning is due to denaturation of meat proteins at relatively high temperatures (30 - 40°C) and acidity due to the natural development of lactic acid during the early stages of rigor mortis (acid production is also faster at higher temperatures).

Electrical Stimulation tends to even up the colour and make it more uniform and lighter.

Fast chilling of hot, heavy beef sides after slaughter gives more evenly coloured meat, gives firmer muscles and also minimises the subsequent unsightly weep (drip) in display or vacuum packs that might bring customer complaint.

There are often considerable variations in the colour of pork, within a carcass and a muscle. Pork is sometimes pale, has a soft texture, and a wet and very weepy surface. The condition is called "pale watery pork", or PSE (*pale, soft and exudative*) pork. The differences from muscle to muscle (often within a cut) are due to a pH effect as not all muscles are affected equally. The problem is partly of genetic origin, and an increased incidence indicates that breeding programmes could be improved. As well as breed, the incidence of PSE pork depends mainly on husbandry, preslaughter and stunning treatment.

3. Normal Colour of Vacuum Bagged, or 100% CO_2 Flushed (no Oxygen) and Bagged, Chilled Meat

The removal of oxygen during vacuum packing leads to changes in the colour of meat. Inside a vacuum-package residual oxygen is consumed and carbon dioxide is produced as a result of metabolism by the muscle tissue and microbial growth. The atmosphere that usually results contains less than 0.5 per cent oxygen, some 20-40 per cent carbon dioxide with the remainder being nitrogen.

The bright red (oxymyoglobin) colour of fresh meat disappears in the vacuum or CO_2 flushed pack as the pigment reverts to its purplish-red form. This is the normal and desirable colour of vacuum packed meat. Within minutes of opening the pack the surface purple myoglobin changes to bright red oxymyoglobin - it "blooms" to a bright red colour, but aged meat does not hold its colour in air as well as non-aged.

4. Abnormal Colour of Vacuum Bagged, or 100% CO_2 Flushed and Bagged, Chilled Meat

Storage life of meat in the pack is generally limited by adverse brown or green colour changes. (It is not possible for the brown pigment once formed to revert to the red or purplish- red pigment forms under normal conditions.) These are mainly due to too much oxygen in the pack, the pH of the meat, or too high a temperature (or a combination of the three).

Browning

Browning indicates that there is too much oxygen in the pack and this occurs fastest at moderate (1%) levels. If there are poor seals, punctures, or poor evacuation at the time of packing and sealing, the meat will turn brown during storage.

The oxygen permeability of the films used for vacuum packing is also very important, and is a matter to which the intending packer should pay close attention. Care is needed to ensure that the appropriate degree of impermeability is chosen to prevent oxygen gaining access to the meat surface. If the permeability is a little too high, a small amount of oxygen will gain access to the meat surface and its concentration could very easily reach the critical, albeit low, level at which metmyoglobin formation is most rapid.

It is impossible to evacuate all the air from a vacuum pack but residual oxygen should be used up by respiration of the meat and microbial activity. However, if the meat is not fresh at the time of packing, insufficient meat respiration to consume the residual oxygen could cause a problem.

In addition, if there is residual oxygen in the pack due to any of these factors, the browning problem will be exacerbated by high temperatures.

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 higher than in air, and browning occurs more rapidly (under some commercial conditions it may be difficult to exclude all oxygen and colour changes are sometimes 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 if there is too much oxygen present and if this occurs the appearance is inferior to that of fresh primals.

From a colour point of view the aim of vacuum or gas packing is to minimise the production of undesirable brown metmyoglobin by *reducing the concentration of oxygen in the pack to below 0.2%.* The meat should be packed and sealed as quickly as possible after boning or cutting the carcass.

This type of browning should not be confused with cooked meat browning (grey-brown) which may be due to excessive heat during shrinking.

"High pH" Greening

Sometimes the meat surface (and/or weep) turns deep green, and has the unmistakable odour of "rotten eggs" (hydrogen sulphide gas). The bacteria responsible for this smell grow only on vacuum packaged "dark cutting" meat (pH 6.0 and above). The bacteria can grow when only traces of oxygen are present. Hence, "dark cutting" meat should not be vacuum packed.

High pH meat can go green in about four to six weeks, even when stored at 0°C. The rate of greening spoilage increases as muscle pH increases. The greening is generally faster with higher permeability films. This type of green meat (which is also "dark cutting") usually has "off" flavours.

This defect is more noticeable with beef, because the higher concentration of myoglobin means the green colour is more intense.

"Normal pH" Greening

This type of greening occurs on normal acidity meat (less than pH 6.0) and is caused by a different type of bacteria than the high pH greening bacteria. It is only likely to occur after the meat has been stored for greater than eight weeks at 0°C.

The green discolouration is not as intense as that caused by high pH greening.

If only areas of the fat are slightly green, the meat may, on occasions, also exhibit the "rotten egg" smell upon opening the bag. The odour will usually dissipate and, after trimming, the meat may be acceptable to eat. If, however, the smell persists, then there will usually be an "off" flavour.

Both types of greening are aesthetically undesirable and caused by the production of hydrogen sulphide from bacteria growing on the meat. The hydrogen sulphide reacts with metmyoglobin to give green sulphmyoglobin. Whilst the bacteria can grow and produce H_2S in the absence of oxygen, it is thought the green discolouration occurs only when there are traces of oxygen present. The reaction is slowed and/or prevented by low temperatures (which slow the metabolic activity of the bacteria) and low oxygen concentrations (which prevent the formation of metmyoglobin). Careful attention to the use of films of suitably low oxygen transmission rate, proper evacuation, temperature control and to hygiene should be observed. Green meat, drip or fat regains a reddish colour on exposure to air.

Sometimes the "rotten egg" smell may be present without the green colour.

Black Spots

Under certain conditions, some cuts develop black or brownish-black spots on the fat surface after about eight weeks' storage. The spots are caused by the breakdown of blood pigment by yeasts, and are quite harmless. Their presence indicates poor hygiene before packing.

Lighting Effects

With some packing films, under artificial lighting, a green sheen may show on the meat in the intact bag. This is an optical illusion due to the interaction of light passing through the film and being reflected off moisture on meat connective tissues or on the bag.

5. Retail Storage of Chilled Meat in Air or in Air-permeable Film, or in Oxygen

The bright red colour of oxymyoglobin is desirable in meat at the point of sale. The development of the brown colour should therefore be retarded for as long as possible. If meat is left exposed to air for a number of days, without the surface dehydrating, brown patches (metmyoglobin) will appear on the surface and eventually the whole surface will be brown. The meat will have the characteristic stale, or "tired" appearance.

The retention of the attractive, bright red colour for beef and the characteristic colour of lamb and pork is dependent upon the efficient operation (temperature), lighting and location of the refrigerated display unit.

In order to obtain the longest possible shelf life for meat on display, the storage temperature should be as close to 0°C as possible. This will keep microbial growth to a minimum and prolong the retention of the attractive red meat colour. As it is impossible to maintain a steady 0°C in open meat display cabinets, a realistic optimum temperature range is 0-3°C.

Storage in Air or in Air-permeable Film

Because the bright red colour is favoured by high concentrations of oxygen, most displayed meat is either open to air or sealed in an oxygen permeable wrap. The wrap allows passage of oxygen but prevents undesirable drying of the meat surface.

Meat displayed in this fashion usually becomes discoloured due to the development of brown colour (metmyoglobin) before bacteria have grown sufficiently to cause spoilage. Incorrect storage or handling at any stage of the chain will reduce retail cut storage life. Although the attractive colour of fresh retail portions can be maintained for nearly a week if the meat is held constantly at 0°C, temperature fluctuations in most store cabinets make commercial display beyond two days difficult.

The principal factor affecting the shelf life of wrapped meat on display is its temperature. For each 2°C rise in temperature there is a loss of about one day in display life. An increase from 0°C to 5°C in the temperature of a refrigerated display cabinet will halve the display life from a discolouration point of view. This is mainly because the oxidation of myoglobin to metmyoglobin is extremely temperature dependent. However, it is also partly because higher temperatures increase bacterial growth on the meat, and the result is that bacterial metabolites contribute to the increased oxidation rate.

Oxygen-rich Packaged Meat

One way to slow the appearance of browning (metmyoglobin) on meat surfaces is to increase the oxygen concentration of the atmosphere surrounding the meat. At very high levels of oxygen the amount of pigment in the desirable red oxymyoglobin form is highest and the depth of penetration greatest. This occurs best at oxygen concentrations of at least 50%. However, under these conditions carbon dioxide (at least 20%) must be included in the gas mixture otherwise spoilage will occur at the same rate as it does in air. (Air contains about 21% oxygen.)

Packs containing high oxygen and carbon dioxide concentrations are of a type called "modified atmosphere packs" (MAP).

Whilst complete oxygenation slows the deterioration of meat colour, the browning problem is not permanently avoided. Metmyoglobin will tend to form, albeit slowly, even at very high oxygen concentrations.

Storage After Ageing

After three weeks' ageing, aged meat discolours in the retail situation faster than does fresh meat because of a decreased ability to convert any brown pigment which has formed back into the desired red pigment. The longer meat is aged the faster it will discolour after opening to air because the enzyme reducing system becomes less effective with ageing.

Table 1 lists the retail display life of consumer cuts of beef (stored at about 5°C) in conventionally overwrapped and oxygen enriched modified atmosphere 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 due to the more rapid conversion of oxymyoglobin to the brown metmyoglobin. The advantage of longer display life achieved by the use of MAP, decreases 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.

Lamb stored in CO_2 appears to retain its retail display life better than vacuum-packed lamb. Retail shelf life of product prepared from lamb primals or carcasses stored in a CO_2 atmosphere should be three days after 12 weeks chilled storage.

6. Fat Colour

The colour of fat on beef carcasses ranges from white to yellow and varies with feed, breed, animal age and carcass chilling regime. Yellowness is disliked by some segments of the meat trade, and it influences the consumer acceptance of the meat in some markets.

Yellowness of the fat is due (except in certain diseases) to the presence in the fat of ß-carotene, which is a precursor of vitamin A. The greater the concentration of carotene in the fat, the more intense is the yellow colouring. This substance occurs widely in plants, chiefly in association with chlorophyll. Green pasture is a rich source of carotene and this accounts for the greater quantities of the pigment appearing in cows' milk during seasons in which there is abundant green feed. Grains contain little carotene. By feeding cattle on high grain diets, their fat becomes increasingly white.

During storage in the vacuum or gas-flushed bag, fat can become greyish or dull due to interaction with the gases in the bag. This may start to occur about three weeks after packing and is due to changes in the pigments within the fat. By storing the meat with the fat side up, contamination with blood is prevented. Aside from imparting an undesirable appearance, blood in contact with fat will promote undesirable flavour changes.

7. Summary

The delay of adverse colour changes involves efficient refrigeration during chilling, holding, transportation, storage, preparation and display, and proper packaging and selection of meat. In particular, if fresh meat is to be maintained in good condition with minimum colour deterioration for an adequate commercial display period, the temperature of the meat must be kept close to 0°C.

***Table 1** 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	* Overwrapped trays	3	3	2	2	1
	* O_2 enriched (MAP)	>7	5-6	4-5	3-4	2