Meat technology update

5/06 – October 2006

Colour defects in meat
Part 1: Browning of fresh meat

Fresh meat eventually turns brown (sometimes interpreted as grey-brown); its acceptability to customers usually determined by loss of red colour ('bloom') rather than onset of bacterial spoilage. Display life is reduced by several factors that hasten discolouration. This article gives some realistic expectations for display life, discusses the basis for meat colour, and some reasons for premature loss of bloom.

Retail display life

It is the colour of meat that first influences the potential retail customer and also affects the decisions made by wholesale and institutional customers. There is a strong preference for meat that has the bright red colour that consumers associate with freshness and quality.

Because the bright red colour is enhanced by high concentrations of oxygen, most displayed meat is either open to air (in which case there is a risk of drying of the meat surface), packed in an oxygen-permeable wrap, or sealed in a modified atmosphere high in oxygen—normally around 80%. Meat displayed in these ways usually becomes discoloured through browning before bacteria have grown sufficiently to cause spoilage.

Incorrect storage or handling at any stage of the distribution chain will reduce retail storage life. The principal factor affecting the shelf life of meat on display is temperature. 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. As well as keeping microbial growth to a minimum, it will prolong retention of the bright red colour. As it is impossible to maintain a steady 0°C in open meat display cabinets, a realistic optimum temperature range is 0–5°C. Meat should be cooled to below 5°C before it is prepared for retail display, and it is best cut just prior to packaging for display.

The basis of meat colour

In the absence of oxygen (O_2), fresh meat is purplish-red. This is the colour of the pigment myoglobin. On exposure to air, myoglobin absorbs oxygen. The oxygenated form of the pigment is called oxymyoglobin. It is bright red and produces the 'bloom' expected by the consumer. Since the oxygenation

Figure 1: Loss of bloom (oxymyoglobin) and development of brown discolouration (metmyoglobin) after 3 days on retail display.

occurs progressively, blooming takes up to 30 minutes; it is for this reason that colour appraisal of meat should not be carried out until after it has been exposed to air for 30 minutes. The oxygenated layer is only 3–4 mm at 0 °C, even less at higher temperatures.

After prolonged exposure to air (up to several days, but the rate is influenced by factors described below), the meat turns grey-brown or brown. The brown pigment is known as metmyoglobin. Browning starts under the surface at the interface between the oxygenated layer of oxymyoglobin and the deoxygenated myoglobin. The layer of metmyoglobin gradually expands and, when it is visible at the surface, the meat is brown.

Enzyme systems in the meat and environmental factors both influence the rate at which the pigments change from one state to another. Generally speaking, pigment changes are

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caused by factors that reduce the oxygen available at the meat surface or cause dissociation of the oxygen from oxymyoglobin. With this in mind, conditions of primary importance to meat colour are temperature, pH, the age of the meat and the amount of available oxygen.

Retail storage after ageing

Some enzymes can convert metmyoglobin back to myoglobin and hence oxymyoglobin. The enzyme system in meat becomes less active with ageing, and discolouration is faster. When these enzymes lose activity, the concentration of metmyoglobin increases. After three weeks in vacuum packs, meat that is then exposed to air or a high-oxygen atmosphere discolours faster than fresh meat. The longer meat is aged, the faster it will discolour after being exposed to air. The longer the period of storage in the vacuum pack the shorter the display life of the consumer portions, because of more rapid conversion of oxymyoglobin to the brown metmyoglobin.

Storage time in the vacuum pack (weeks at 0 °C)	**0**	**2**	**4**	**6**	**8**
Retail display life (days)					
*Overwrapped trays	3	3	2	2	1
High-O_2 MAP	7-10	5-6	4	3	2

This table indicates the retail display life of consumer cuts of beef (stored at about 5°C) in conventionally over-wrapped and oxygen-enriched modified atmosphere packs (MAP) as a function of the meat storage time in the vacuum pack at 0°C.

Beef and lamb stored in high levels of carbon dioxide (CO_2) appear to retain their retail display life better than vacuum-packed beef and lamb. For example, products prepared from lamb primals or carcases that have been stored at 0°C in a CO_2 atmosphere for 12 weeks have a retail display life in over-wrapped packs of about 2–3 days.

Dark cutting meat

Stress prior to slaughtering can play a significant role in meat colour since it affects meat pH, which in turn affects colour. Meat colour gradually darkens with an increase in ultimate pH 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-coloured by some customers.

High-pH meat is dark-coloured because, with low acid levels in the meat, there is less oxymyoglobin formation at the surface. The reduced myoglobin under the surface gives a dark appearance to the meat. There is less light reflected from the surface. This, coupled with the fact that there is a light-scattering effect, causes the eye to perceive the colour differently.

Browning of dark cutting meat occurs more slowly than in meat of 'normal' pH; however bacterial spoilage occurs sooner at high pH, and the meat may be spoiled by microbial activity rather than by discolouration.

Two-toned (pale and dark) meat

Two-toning usually refers to meat in which there are undesirable gradations in meat colour within a cut, usually with the deep meat tissue being paler than the normal red meat closer to the surface. Pale-coloured meat will discolour more quickly than normal-coloured meat in the presence of oxygen because its enzyme system has been affected, leading to faster progression of the metmyoglobin reaction.

The paleness leading to two-toning is caused by denaturation of meat proteins at relatively high temperatures (30–40 °C) when the pH is low due to the acidity that results from the accumulation of lactic acid during the early stages of rigor mortis. The paleness normally occurs in the deep muscle (e.g. topsides) of heavy carcases where chilling is slow. It is not seen in smallstock carcases to any extent because there is a more even chilling rate throughout the carcase.

Fast chilling of heavy beef sides after slaughter gives more evenly coloured meat, and firmer muscles. It also minimises the subsequent unsightly weep (drip) in display or vacuum packs; however, where rapid chilling is applied and no electrical stimulation is utilised, the rate of pH decline can be quite slow and carcases may be incorrectly assessed as dark cutting.

Effective electrical stimulation (ES) will overcome the two-toning effect in many carcases by accelerating the rate of pH decline. ES tends to even up the colour, making it more uniform and lighter; however, in heavy carcases, ES may aggravate two-toning. It is important not to overstimulate. The way in which slaughter floor electrical inputs influence meat quality was discussed in some detail in previous Meat Technology Updates 3/04 and 1/06. As a guide, if the pH is at, or below, 6.0 while the temperature is still at or above 35 °C, then the electrical inputs have been excessive, and there may be undesirable paleness of the slow-cooling muscles.

Two-toning can also refer to browning of some parts of the cut surface of a piece of meat. Different muscles have different biochemical activities, so the rate of discolouration differs between muscles, and this can lead to different colours in a single cut (Figure 2).

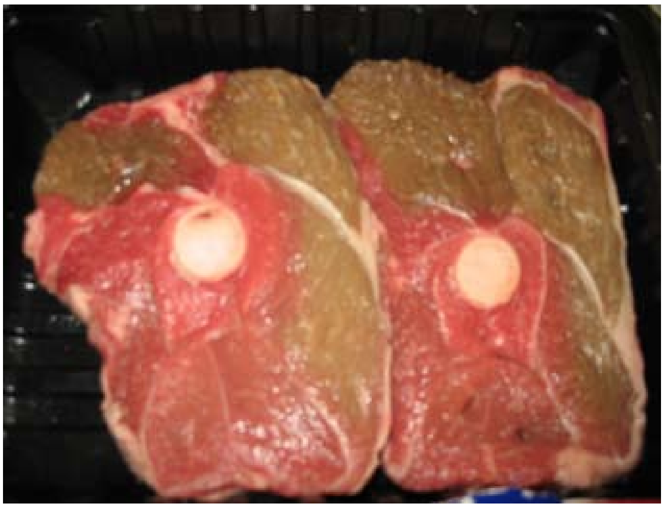

Figure 2: Evidence in lamb leg steaks of a muscle-to-muscle difference in colour stability.

Colour of vacuum-packaged and (100% CO_2 or N_2) MAP meat

From a colour point of view, the aim of vacuum-packaging or packing in CO_2 is to prevent the production of undesirable brown metmyoglobin during storage, by reducing the concentration of oxygen in the pack to below 0.2%. To achieve this, the meat should be packed and sealed as quickly as possible after boning or cutting the carcase. Inside a vacuum package, residual oxygen is consumed and carbon dioxide (CO_2) is produced as a result of metabolism by the muscle tissue. The bright red oxymyoglobin colour of fresh meat disappears in vacuum packs and in CO_2 flushed packs as the pigment reverts to its purplish-red form. This is the normal and desirable colour of vacuum-packed meat. Within a short time of the pack being opened, the purple myoglobin at the meat surface changes to oxymyoglobin and the meat blooms again to a bright red colour, in response to the oxygen present in air.

Not all the air will be evacuated from a vacuum pack, but any residual oxygen should be used up by respiration of the meat tissue. How well this residual oxygen is used up is dependent on the age of the meat when packed because its respiration ability declines with time. The rate of decline varies between muscles. The tenderloin, for example, loses the ability to respire quite quickly. If the meat is older than around 48 hours post-slaughter at the time of packing, there may be insufficient meat respiration to consume the residual oxygen. If there is residual oxygen in the pack, metmyoglobin will form, and this browning problem will be exacerbated by high storage temperatures.

Browning of meat while stored in a vacuum package indicates that there is too much oxygen in the pack. Browning occurs fastest at about 1% oxygen. If the packaging film allows too much oxygen to permeate through, or if there are poor seals, pinhole punctures, or poor air evacuation at the time of packing and sealing, the meat will turn brown during storage. The oxygen transmission rate of the films used for vacuum packaging is very important.

Colour problems will also occur with beef and lamb stored in high concentrations of carbon dioxide, unless oxygen is excluded from the pack. As with vacuum packs, if a critical 0.5 to 1 per cent of oxygen is present, the rate of browning will be higher than in air. In addition to discolouration of the lean surface, problems with the appearance of fat surfaces may occur (grey-brown discolouration). With lamb, a brownish discolouration of the fascia (connective tissue) surfaces may develop after several weeks' storage at 0°C if there is too much oxygen present.

Note that this type of browning should not be confused with cooked meat browning which can be caused by excessive heat during shrinkage of the packaging film.

There is documented evidence of what is termed 'transient discolouration', where metmyoglobin increases during the first 3 days or so of storage under low-oxygen conditions, and then decreases. It then may or may not increase again to an unacceptable level. This has been observed with striploins and particularly in trays of tenderloin beef in low-oxygen master packs. The use of oxygen scavengers as part of the packaging system can prevent the transient discolouration. In a Canadian study, beef tenderloins were aged in vacuum packs for 2 to 3 weeks. Steaks were then prepared in N_2 master packs and stored for a further week, after which the individual trays were removed from the master packs and placed on retail display. Unless oxygen scavengers were in the trays when they were prepared in the master packs, the steaks discoloured rapidly. Meat in trays with sufficient scavengers had retail lives in excess of 4 days after being removed from the master packs.

Bone-in retail cuts

Bone-in cuts that are packed in high-O_2 gas mixtures are prone to rapid discolouration. Modified atmosphere packaging (MAP) with high levels of oxygen predisposes bone marrow to discolouration. There is evidence that high oxygen is detrimental to bone marrow colour stability because the haemoglobin that accumulates on cut bone surfaces after cutting is oxidized in the presence of oxygen to dark brown methaemoglobin, resulting in significant discolouration within 24 hours after packaging. There is also evidence that packaging in atmospheres devoid of oxygen (e.g. CO_2/N_2 mixtures) will limit marrow discolouration during storage and display.

Tunnel-boned legs

It is likely that two factors contributed to the discolouration of the tunnel-boned lamb legs seen in Figure 3: residual air in the cavity after vacuum-packaging; and diminished enzyme activity in legs boned 3 to 4 days after slaughter of the lambs.

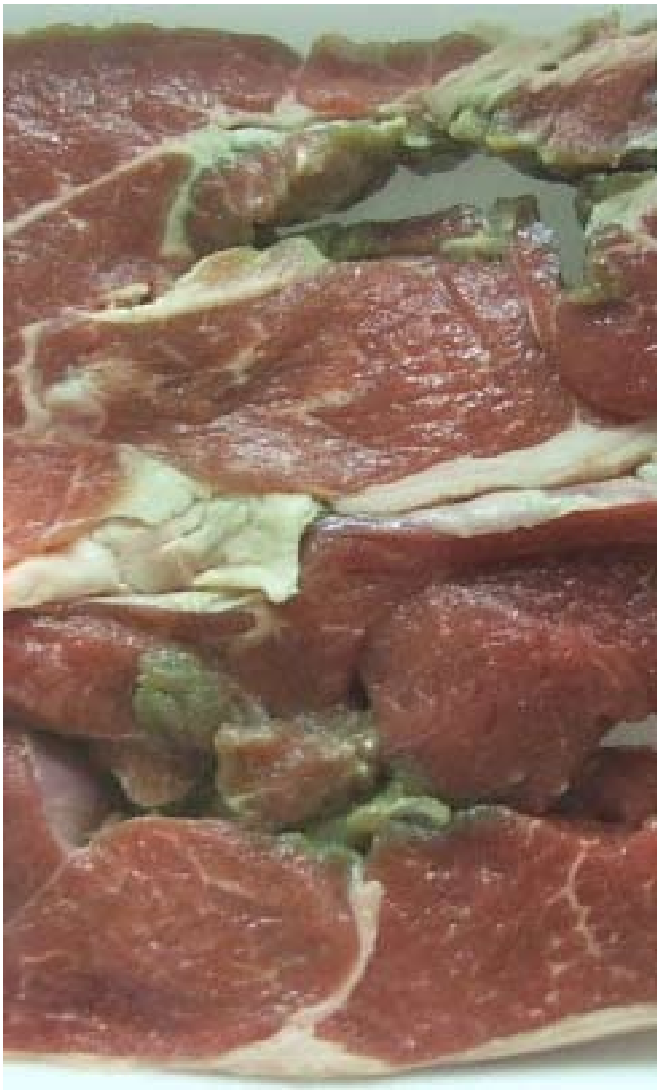

Figure 3: Evidence of browning of lamb surface created when bone was removed.

Discolouration of frozen product

On occasions, discolouration has been observed in frozen beef and lamb. It is unclear, though, whether the discolouration occurred during frozen storage or before the meat was frozen. The main focus of recent studies in this area has been on frozen restructured beef steaks, where mixing and grinding contribute to colour instability; however, the results for intact steaks used in these studies as controls indicated that steaks stored at –23 °C after being vacuum-packaged, developed more metmyoglobin over three months than did steaks that were not vacuum-packaged before being frozen. This suggests that the phenomenon of maximum browning associated with the critical 0.5 to 1% oxygen discussed earlier for chilled meat also applies for frozen meat.

Some points about meat colour

- The greater the concentration of myoglobin, the darker the colour of the meat. Myoglobin concentration varies from species to species: beef contains about nine times as much myoglobin as pork. Also, older animals have a higher concentration, and different muscles contain varying concentrations of myoglobin, and so differ in darkness.
- Aged meat has poor colour stability compared with fresh meat. Enzymes in fresh meat can prevent the formation of brown metmyoglobin, but these enzymes lose their activity as the meat ages.
- The rate and extent of metmyoglobin formation (browning) are related to the oxygen content of the atmosphere around the meat, as well as temperature and the balance between the various biochemical reactions that occur—those that promote metmyoglobin formation and those that slow it. The rates of these reactions are determined by enzyme systems.
- Metmyoglobin formation is slower at low temperatures because the low temperature slows the biochemical reaction and preserves the activity of enzymes in aged meat.
- At extremely low concentrations of oxygen (such as in vacuum packs and modified atmosphere packs containing pure carbon dioxide), 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.
- The red colour of meat is brighter and deeper at low storage temperatures because oxygen is able to penetrate the meat more easily. The layer of oxymyoglobin at the surface of the meat is thicker at 0°C than at 15 °C (3–4 mm compared with 1–2 mm).
- pH (acidity) has an influence on retail display life in air. High-pH (dark cutting) meat discolours at a slower rate than normal pH (5.5) meat.
- Beef from grass-fed cattle contains high levels of natural antioxidants such as vitamin E and beta-carotene, which slow down the browning discolouration. Beef from cattle raised on good-quality pasture has Vitamin E content and lipid stability equivalent to that from grain-fed cattle supplemented with over 2500 international units (I.U.) of Vitamin E per day for four months. Dietary beta-carotene supplementation will extend retail display life.
- Localised areas of discolouration on the surface of fresh meat can be caused by any of: spoilage bacteria; contaminating substances; partial contact with other meat or packaging surfaces; or from by-products of fat oxidation (i.e. rancidity development).
- Differences in biochemical activities in different muscles cause colour stability variations from cut to cut and also within a cut. It is possible to see red and brown parts within one cut. Some cuts, such as rumps and tenderloins, are more susceptible to browning than others such as striploins.
- Various antimicrobial interventions affect meat colour and colour stability – some positively, some negatively. Organic acids sometimes decrease redness and colour stability, probably because they reduce the meat pH where they contact the meat surface.
- Contamination of meat with multivalent ions such as copper, iron and aluminium and oxidising agents such as peroxide, hypochlorite and common salt (NaCl), greatly accelerates the rate at which meat discolours.
- Lighting will influence the colour appearance of meat. Certain types of lighting accelerate colour deterioration e.g. incandescent lights and those fluorescents with a UV component. 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.
- In low-oxygen modified atmosphere packs (carbon dioxide or nitrogen), there can be a condition termed transient discolouration where discolouration becomes evident during the first three days of chilled storage, then disappears.

Contact us for additional information

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