
Chemistry in the kitchen: the chemistry of flesh foods III

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Abstract

When self selecting meat, consumers rank the colour of fresh meat as being the most important criterion in their purchase decision because it indicates freshness, while the most desirable eating quality of meat, after texture, is the cooked flavour. Details the well-understood chemistry in relation to meat colour and reviews the less well-understood chemistry of cooked meat flavour.

In this third article in a series of four, Peter Bayliss examines the meat quality issues relating to colour and cooked meat flavour.

When self selecting meat, consumers rank the colour of fresh meat as being the most important criterion in their purchase decision. Other important quality criteria include levels of fatness, connective tissue, bone, exudate and neatness of trim. The most desirable eating quality of meat after texture is its cooked flavour.

Colour of meat

The attractive bright cherry red colour or "bloom" of freshly cut (or comminuted) meat is used by consumers as an indication of its freshness, while meat which has been stored for prolonged periods develops a drab brown colour. However, it is generally not realized that the brown pigment develops relatively quickly and does not necessarily reflect any reduction in the meat's eating quality.

Haempigment chemistry

In the interior of a piece of meat where enzymes actively utilize diffusing oxygen from the meat's surface, myoglobin remains in the reduced state and appears as a purple-red colour, while at the freshly cut surface, meat develops an attractive bright red colour after about 30 minutes. This is a result of myoglobin being oxygenated to form the relatively stable covalent complex oxymyoglobin, which is not easily oxidized. The red pigment is a result of the oxymyoglobin molecule absorbing the green and blue wavelengths of light and reflecting the red (see Figure 1).

Just below the meat surface where oxygen levels are low (1-2 per cent oxygen at 7mm), oxymyoglobin slowly oxidizes to form the undesirable brown pigment metmyoglobin. Metmyoglobin cannot bind oxygen, however; the residual enzymic activity present in the meat tissue reduces the metmyoglobin to myoglobin which is subsequently oxygenated to form oxymyoglobin. Hence the process of oxygenation/oxidations/reduction of myoglobin is cyclic and can be seen in Figure 2 to proceed in an anti-clockwise direction.

Eventually a band of brown metmyoglobin forms and thickens to appear ultimately at the

Figure 1 The relationships of oxygen partial pressure in the atmosphere to pigment chemical states and colours

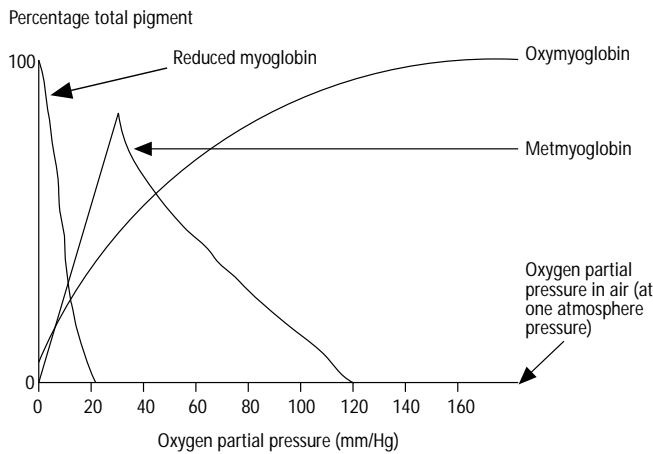


Figure 2 The interrelationship of the pigments in fresh meat

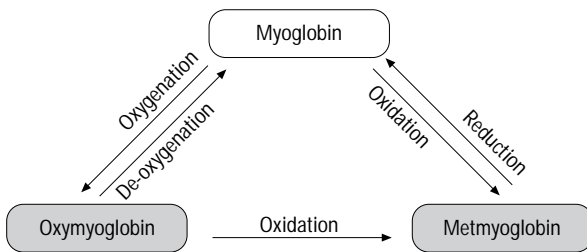
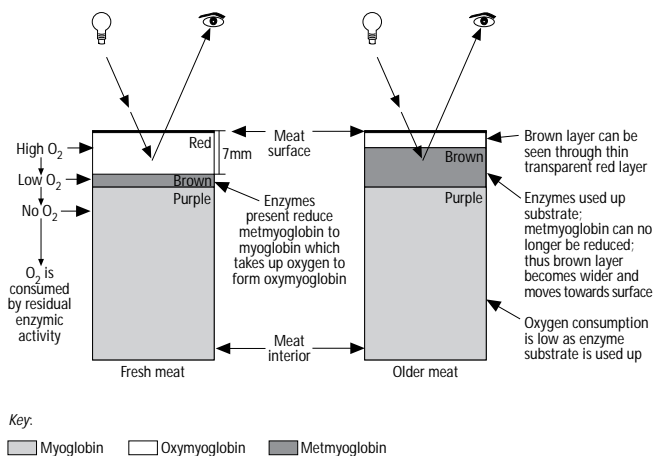


Figure 3 The oxygenated and oxidized states of myoglobin in sectioned meat



surface (see Figure 3). This browning of the meat's surface coincides with a decline in the reduction capacity of enzymes as their substrate is used up. Meat held at 5°C will have this brown band reach its surface within 48 hours, appearing patchy at first due to differing diffusion rates at the muscle surface.

Some influences on the colour of meat

Species

The myoglobin content and hence colour intensity of muscles vary considerably according to species (Table I).

Stress in the live animal

Short-term stress

This type of stress tends to be confined to certain breeds of stress susceptible (SS) pig, e.g. the Pietrain, which has been extensively used in breeding because of its meatiness. The actual process of humanely slaughtering SS pigs predisposes a release of catecholamines which invokes a rapid glycolysis and hence a concomitant drop in pH, while the carcass is still hot. The meat derived from animals with short-term stress produces meat which is pale, soft and exudative (PSE). The ultimate pH (pHu) of normal and PSE pork are identical; however, the combination of pH and temperature denatures protein within the muscle fibres (see Table II).

During short-term stress the glycolytic rate of the muscles accelerates rapidly because of the large demand for adenosine triphosphate (ATP) as muscle cells try to maintain homeostasis (see Figure 4).

Muscles which reach a pH value of 6 while the carcass temperature is higher than 30°C will become PSE. Only certain muscles present in a particular retail cut may be affected, giving rise to the term "two toning". The paleness is caused by sarcoplasmic proteins coming out into the solution that surrounds the shrunken muscle fibre and also between neighbour muscle fibres (see Figure 5).

Table I Myoglobin content of differing species and ages

Meat type	Description	Myoglobin (%)
Beef	Bright cherry red	0.6
Lamb	Light to brick red	0.25
Pork	Greyish pink	0.06
Veal	Brownish pink	0.2
Rabbit	Brownish pink	0.2

Table II Glycolytic rate of normal and PSE pork

	Rigor times
Normal pork	5 to 8 hours
PSE pork	5 to 10 mins (when the carcass is hot)

Figure 4 Comparison of rates of pH decline in stress-susceptible and stress-resistant pigs

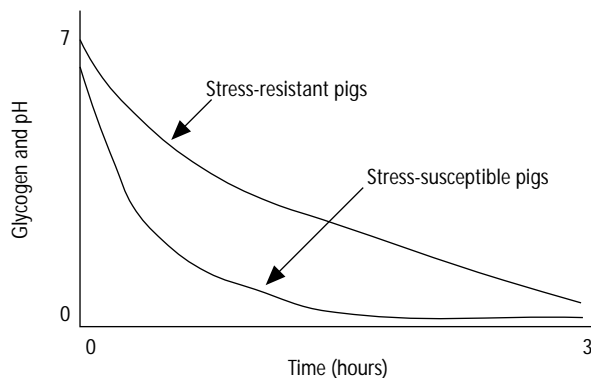
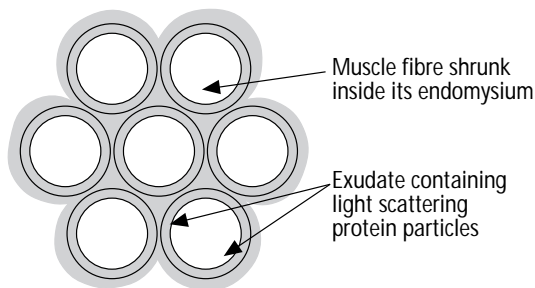


Figure 5 Accumulation of exudate as a result of muscle fibre shrinkage



When touched PSE meat may feel comparatively soft. This is due to shrinkage of the muscle fibre within the endomysium and the excess exudate acting as a lubricant, making the whole “muscle system” flexible. When normal pork is cut up into retail cuts, the ends of the muscle fibres are severed and excess quantity of fluid is exuded at the cut surface. This is a result of pressure being put on to the free fluid (sarcoplasmic), bathing the filament lattice by the contracting muscle fibre within its endomysium so that fluid is released into the annular sub-endomysial space.

The quantity of fluid in PSE meat increases quite considerably and recent research indicates that it is due to the myosin heads being subjected to PSE-inducing conditions (pH 6.0, 35°C). As a consequence they shrink from 19nm in length to 17nm. This has the effect of pulling together the filament lattice which is locked in rigor in a vertical direction, applying pressure and increasing drip loss.

The cost of PSE meat to the industry is considerable, as surveys reveal that consumers positively discriminate against

purchasing “two-toned pork” and pork with excess drip in retail packs. Meat processors also have reduced yields.

Long-term stress

Animals that suffer stress because of long hauls, being mixed with unfamiliar social groups, starvation, etc. will have low levels of glycogen at the time of slaughter and will produce meat which appears dark, firm and dry (DFD). The physical changes that occur in DFD meat are the opposite to those occurring in PSE meat. The DFD condition is usually associated with young bulls (4 per cent) and pigs. The pH of DFD meat is > 7.0 which results in little protein denaturation and hence, low light scatter. As a consequence, light penetrates and is reflected from deep within the translucent muscle. The colour of dark myoglobin pigment is reflected giving the high pH meat a characteristic dark appearance.

The high pH results in a lower concentration of anions (positives) in the sarcoplasm and hence fewer are donated to the thick and thin filaments of the myofibrils. The electrostatic repulsion is maintained and the muscle fibres do not shrink away from their surrounding endomysia. As there is no sub-endomysial space the whole “meat system” is less flexible than normal and has a tactile firmness as a consequence of tightly packed fibres.

The most significant loss with DFD meat to the industry is when it is vacuum packed. The normal shelf life of vac-packed meat at 5°C is about 8 weeks while DFD meat starts to show signs of spoilage after 2 to 3 weeks.

Meat packaging

Vacuum packing

Wholesale cuts of meat are vacuum packed in oxygen impermeable films and, prior to retailing, are removed, butchered and allowed to reoxygenate.

Modified atmosphere packing (MAP)

The trend for meat which is retailed is to place it into MAPs which contain about 60 per cent oxygen, which maintains the oxymyoglobin for 5 to 6 days and about 40 per cent carbon dioxide which inhibits microbial growth.

Meat flavour

It is estimated that the human olfactory bulb situated at the back of the nose is responsible for about 85 per cent of the food flavour

sensation, while the lingual taste buds provide the sensation of sweet, salt, etc. only.

Some foods, especially vegetables and fruits, have characteristic aromas that can be attributed to single or a very small number of compounds, e.g. pineapple (citral), boiled mushrooms (1-octen-3-one), etc. However, most foods contain a complex mixture of volatiles that all contribute to some degree to the aroma. It can be seen from Table III that the flavour of beef consists of several hundred compounds ranging from the simple hydrocarbons right through all the groups.

Fat and the water soluble non-protein components of meat given in Table IV are the major source of cooked meat flavour. The water-soluble non-protein fraction contains nitrogenous compounds (amino acids, peptides, creatine, nucleotides), carbohydrates (sugars, lactic acid, glycogen) and inorganic salts. The fat in meat is predominantly triglyceride lipid and structural lipids (phospholipids). Triglyceride lipid is found in adipose tissue located in the various fat deposits of the carcass and as it contains connective tissue it will also have traces of water-soluble nitrogenous compounds and carbohydrate. Phos-

Table IV Flavour precursors in meat

Water soluble	Lipid derived
Peptides	Triglyceride lipids
Amino acids	Phospholipids
Nucleotides	Extraneous substances dissolved in fat
Thiamine	
Sugars	
Sugar phosphates	

pholipids are structural components of all cell membranes. As well as contributing to the taste and mouthfeel attributes of meat, the fat and water-soluble fractions are also the precursors of volatile flavour compounds.

Unless meat is cooked there is little aroma and flavour; raw meat has a weak salty and blood-like taste with very little odour. Heat processing is essential for development of the organoleptically desirable flavour and odour of meat prior to its consumption.

The range of heating conditions used in normal cooking of meat is very wide and can account for wide differences in flavour of the end product. During grilling or roasting the outside of the meat may attain high temperatures for comparatively long periods. Meat that is stewed (wet cooking) may remain at these high temperatures for several hours. Even when steak is grilled to produce a "rare" interior (i.e. bloody and uncooked) the surface browning reactions produces flavour metabolites which diffuse throughout the steak during heating. This distribution of flavour from the meat surface is assisted by fluxing which is brought about by the effects of heating and cooling that always accompany grilling. When raw meat is heated a series of physical and chemical changes takes place. During cooking the fat melts; thus it becomes more susceptible to chemical reactions such as autoxidation and degradation.

The contractile proteins of the lean contract as they are denatured during heating (40–50°C) and squeeze out meat juices (sarcolemmic fluid). As the temperature rises, the collagen in the endomysia undergoes denaturation and shrinks (60–70°C) resulting in contraction and further drip loss. Heat labile cross links in collagen (especially in meat derived from young animals) break down allowing the connective tissue to soften as it is converted to gelatin. In stews where the meat is "wet cooked" for protracted periods (>80°C) collagen becomes completely hydrolysed as any "mature cross links" are broken

Table III Volatile components of cooked beef aroma

Type	Numbers identified
Aliphatic hydrocarbons	63
Alicyclic hydrocarbons	4
Terpenoids	7
Aliphatic alcohols	34
Aliphatic aldehydes	43
Aliphatic ketones	6
Aliphatic carboxylic acids	20
Lactones	5
Aliphatic esters	10
Aliphatic ethers	3
Aliphatic amines	2
Chlorinated compounds	6
Benzenoid compounds	69
S-compounds (non-heterocyclic)	62
Furans and derivatives	33
Thiophenes and derivatives	35
Pyrroles and derivatives	12
Pyridines and derivatives	10
Pyrazines and derivatives	49
Oxazoles and oxazolines	7
Thiazoles and thiazolines	15
Other S-heterocyclics	12
Miscellaneous	7

down. Browning reactions commence at about 90°C. When meat is dry roasted water is driven off, the outer surface of the joint becomes dry and pyrolytic reactions occur.

Main chemical reactions involved in flavour development

Chemical reactions within and between components of lean, fat and atmospheric oxygen produce a multitude of identifiable organic compounds during cooking; however, very few have a meat-like character when tested in isolation. The easily recognizable aroma of cooked meat would seem to result from a large number of substances being smelt at the same time.

A number of reactions can occur with the major classes of flavour precursors (see Figure 6).

Amino acids

The concentration of amino acids tends to increase with cooking due to protein hydrolysis. Deamination and decarboxylation of amino acids generally requires high temperatures in excess of normal cooking temperatures although some pyrolytic reactions may occur at roasting temperatures, providing some odour compounds.

Carbohydrates

Small quantities of sugars (glucose and ribose) are present in meat. Heating sugars at high temperatures results in caramelization, giving highly odorous substances which include carbonyls, aromatic hydrocarbons and furan derivatives. Concentrations of sugar decrease during cooking.

Amino acid-carbohydrate interaction

This reaction is probably the most important in leading to the development of meat flavour. This reaction of sugars with amino acids is known as the Maillard reaction or non-enzymatic browning reaction. The reactions are extremely complex and yield a variety of odorous compounds including aldehydes, ketones, pyrazines, furans, thiazoles and pyrroles. The sulphur-containing amino acids, cystine, cysteine and methionine give rise to important sulphur-containing compounds.

During cooking the oxidative decomposition of fatty acids is the most important, especially of the unsaturated acids which yields various carbonyl compounds and alcohols. These compounds are odorous and can also undergo reaction with products from the sugar amino-acid reactions (see Figure 7).

Nucleotides

In living muscle ATP is the major nucleotide; however, during rigor mortis it is converted as shown in Figure 8.

In meat the major nucleotide is inosine-5-mono phosphate (IMP) and

Figure 6 Overview of flavour-forming reactions of some water-soluble components in meat

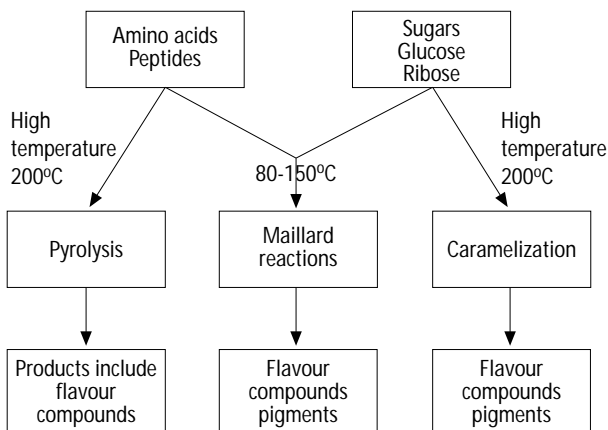


Figure 7 Flavour reactions of lipids in meat

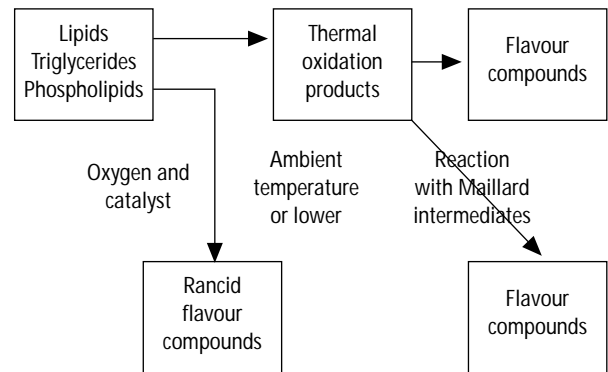


Figure 8 Degradation of Adenosine triphosphate

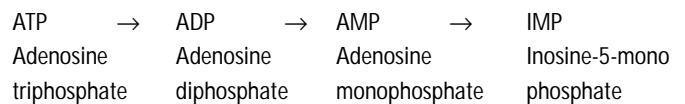


Figure 9 Action and interaction of aroma volatiles that produce flavour

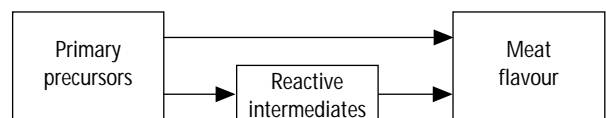
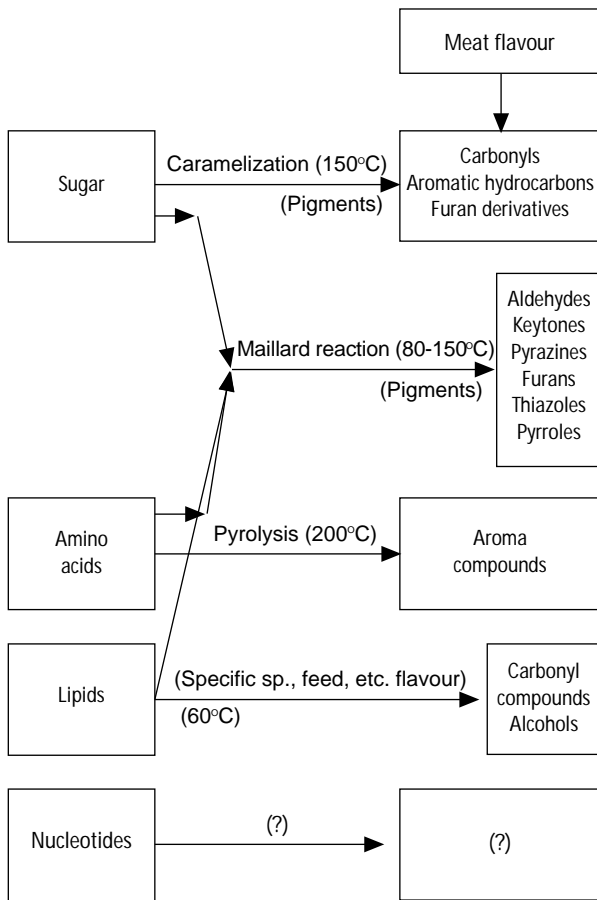


Figure 10 Overview of flavour forming reactions formed in cooked meats



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is probably found in sufficient quantity to influence flavour. IMP is thought to assist in flavour development, first, as a source of reducing sugar and nitrogenous base for Maillard reactions, and second, as a flavour enhancer.

It can be perceived from the above that components found in meat (primary precursors) can react to form meat flavour compounds directly or enter into a reactive pool of secondary intermediates which interact to produce final flavour compounds (see Figures 9 and 10).

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Species flavour

Recent research indicates that there is no cooked meat flavour loss if the triglyceride is removed from meat; however, the removal of the phospholipids does result in flavour loss. Because the active proteins and biochemical mechanisms are similar in all animal muscle the basic flavour precursors of the lean are the same. Hence studies reveal that the adipose tissue is responsible for the characteristic species flavour while the lean provides a basic meaty flavour.