Understanding the preservation of meat and meat products

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Meat is a highly nutritious and 'dense' form of food, derived from animal musculature post mortem and post rigor mortis, primarily from 'red meat' mammals, but also from certain avian species, such as poultry (for example chicken, turkey, duck).

Other internal organs are also often referred to as meat, such as the liver, heart, kidneys, but the definition of what constitutes 'meat' differs from country to country; in Western countries these internal organs are often referred to as 'offal'.

On slaughter of the animal, the blood supply ceases to circulate oxygen and glucose to muscles and other tissues which then begin to metabolise anaerobically, producing lactic acid until the pH and redox potential or chilling of the carcase fall sufficiently to inhibit further metabolism, but which may continue slowly for a few days post mortem, even in chill conditions.

The rate of diffusion of oxygen into the surface of meat is only sufficient to maintain the outer few millimetres in an oxidised red state (oxy-myoglobin and -haemoglobin); the interior becomes anaerobic (low redox potential, or Eh).

The chemical composition and neutral pH of meats also provide a highly nutritious substrate for microbial growth; many microbiological media include meat digests or extracts.

Many different types of micro-organisms may gain access to meat during slaughter, skinning (or de-feathering of poultry), removal of the intestinal tract and internal organs and further butchering operations.

The lowered internal pH and Eh of post rigor muscle, inhibits the growth of aerobic organisms, for example pseudomonads, but permits the growth of facultative and anaerobic micro-organisms, for example Enterobacteriaceae, lactic acid bacteria, and clostridia, the metabolism of which further reduces the pH and redox potential.

Spoilage of meat occurs largely at the surface by Gram-negative aerobic organisms (pseudomonads), unless during chilling the surface is dried sufficiently to present a low water activity (aW), which then becomes inhibitory to pseudomonads.

Meat with such a dried surface then spoils with the growth of yeasts and fungi (for example 'whiskery beef'). Deep spoilage especially near joints (bone taint) can occur from growth of lactic bacteria, for example streptococci, and occasionally clostridia, when chilling is slow. Meat is a particularly notable vehicle of foodborne infectious microbes (food poisoning), mainly derived from the animal's gut contents, but also from skin and feathers.

Equipment used in abattoirs also readily becomes contaminated with such organisms, resulting in cross-contamination of meat in-process unless rigorously and frequently sanitised.

Preservation of meat

The main means of preserving fresh meat is by prompt chilling with some drying of the surface. Since surface spoilage is by aerobic organisms, vacuum- or gas-packaging of primal or retail joints is a very effective method of extending the shelf-life of meats, from approximately 10-14 days to four weeks or more in chill conditions (ca. 2°C).

The developing microbial flora changes from pseudomonads to lactic acid bacteria, resulting in a slightly 'cheesy' or acidic odour which is quickly dispersed on exposure to air; additionally the rather brown/purple colour of packaged meat, 'blooms' quickly to the bright red colour of fresh meat.

Various methods have been tested to reduce surface contamination of carcases, in particular to reduce or eliminate contamination with meat-borne pathogens, for example salmonellae, E. coli O157:H7.

These methods include high pressure washing, washing with hot water or solutions of dilute acids (for example lactic acid), which have achieved some success and been installed in some abattoirs.

There is a wide variety of meat products, primarily associated with the Northern European industry, but many countries have developed their own indigenous varieties of cured, smoked, dried, meat products, such as sausages, hams, patés, etc.

In general, methods of preservation of meats are based on a lowering of pH, usually via fermentation of added sugars, and water content (lower water activity, aW), by drying and/or smoking, or added salt, together with some chemical preservatives, for example curing salts, nitrite and nitrate.

Salt

Salt (NaCl) is a basic ingredient in many meat products, either alone or in combination with nitrite (NO_2^{-1}), nitrate (NO_3^{-1}), polyphosphates, sulphites, ascorbates (vitamin C), or lactates.

In meats, different concentrations of salt, solubilise some meat proteins and precipitate others, leading to binding of meat parti-

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cles and formation of meat structures and different products.

Microbiologically, salt also acts as a humectant, reducing water activity (aW) and thus limiting the growth of the Gram-negative spoilage bacteria. Pseudomonads and most Enterobacteriaceae, are inhibited at ca. 2% salt-on-water (s/w) NaCl, (aW ca. 0.987), but growth of lactic acid bacteria (LAB) continues.

Additionally, several strains of LAB produce antimicrobial peptides that have been demonstrated to actively inhibit Gram-positive pathogens, for example L. monocytogenes, and in some cases are lethal for this pathogen.

At 3.5% s/w NaCl, the psychrotrophic strains of Clostridium botulinum (non-proteolytic types B and E) are inhibited at chill temperatures, but levels of ca. 10% s/w NaCl are needed to inhibit the mesophilic strains of Cl. botulinum (proteolytic types A and B).

Whilst Staphylococcus aureus can grow at a minimum aW level of 0.86 (ca. 18% s/w NaCl), enterotoxin production generally has not been reported in foods below aW ca. 0.93, although in broth systems under ideal conditions enterotoxin has been demonstrated at aW 0.87.

Thus, this pathogen is of considerable concern in salted cured meats of aW ≥0.93 that may be stored above ca. 12°C (for example ham sandwiches).

Whilst micro-organisms need a balance of cations (Na^+, K^+, Ca^{+2}, Mg^{+2}, etc) for their metabolic activities, an imbalance of these ions, particularly of Na^+ and K^+, inhibits many enzymes, and organisms utilise energy in order to export excess Na^+ ions.

Excessive energy utilisation is one of the mechanisms of the antimicrobial activity of salt. Although additions of Na^+ to meat and other food products, can be partially replaced by K^+ salts (for example for health reasons), above ca. 50% replacement, the metallic taste of potassium salts becomes noticeable.

Nitrites and nitrates

Nitrite, in combination with salt, is an essential ingredient in cured meats, producing the classical pink colouration by combining with the iron-containing globin pigments (myoglobin, haemoglobin).

The levels of nitrite necessary to produce this pink colour are only ca. 10ppm, but levels of ca. 150-200ppm are required to inhibit clostridia in cured meats stored at chill temperatures.

Nitrate (NO_3^{-1}) was used in curing salt mixtures or brines (but is generally now replaced by the required level of nitrite), and is slowly converted to nitrite by the action of particular micro-organisms (mainly streptococci) in the brines or in meat joints at low temperatures.

If there is a rapid production of nitrite, there may be production of NO_2 gas (for example a brown atmosphere above brine tanks). If ascorbic acid is also incorporated into a brining mixture, such a rapid reduction of nitrate can occur. The addition of ascorbate or erythorbate enhances the activity of nitrite.

There is an additive effect of salt on the inhibitory activity of nitrite for clostridia. The anti-botulinal effects of nitrite in cured meat systems, has been studied extensively.

This propensity of nitrite as nitric oxide (NO) to combine with iron (Fe)-containing pigments in meat, also accounts for its action of inhibiting the pathogenic clostridia in cured meats.

Nitrite combines with the electron-carrying ferredoxins (the anaerobic equivalent of cytochromes in aerobic organisms) in clostridia, disrupting the iron-sulphur rings at the core of these molecules, thus denying their ability to transport electrons and thereby generate energy (ATP).

Thus nitrite limits the energy supply whilst the presence of salt requires extra energy in order to export excess Na+ ions. Nitrite-inhibited clostridia rapidly export pyruvate as an end-product of carbohydrate metabolism; pyruvate is toxic to anaerobic cells.

Polyphosphates

The addition of polyphosphates to meat increases the water-binding capacity of the muscle fibres, increasing the 'juiciness' and reducing weight loss during storage and cooking.

Polyphosphates also have metal-chelating properties, especially for multivalent cations such as Ca^{+2}, Mg^{+2}, $Fe^{+}2$ and Fe^{+3}, and have antimicrobial activities.

Since iron is essential to many microbes, especially clostridia for their electron-carrying proteins, ferredoxins, polyphosphates inhibit growth of several micro-organisms.

For clostridia, it has been found that the longer the chain length of polyphosphates (for example up to P_{20}), the greater are the inhibitory effects.

In general, polyphosphates are added to cured meats at 0.3-0.5% w/w; at the lower concentrations, there is little additive inhibitory effect with nitrite and salt, but at 0.5% w/w, an additive effect has been demonstrated.

Sulphites and SO_2

The use of sulphur dioxide for preservation of wines and fruit has been practised since the time of the ancient Greek and Roman Empires.

The low pH of wines and fruits favours the formation of the $SO_2.H_2O$ moiety which is the most active of all the SO_2 entities dissolved in water.

$$SO_2.H_2O \leftrightarrow HSO_3^- + H^+ \leftrightarrow SO_3^{2-} + H^+$$

As with weak organic acids, it is the un-dissociated form of sulphur dioxide in water, that more readily penetrates the cell membrane; thus the effective pH range is pH <4.0.

The use of sulphites for meat preservation, as in British fresh sausages (generally added as metabisulphite salts), is much more recent. Addition of sulphite inactivates or strongly inhibits the Gram-negative spoilage and food-poisoning organisms (pseudomonads, enterobacteria including Salmonella spp.) during chill storage.

The eventual spoilage flora of such sulphite-preserved chill-stored fresh sausages, are lactic acid bacteria, in particular Brochothrix thermosphacta, with production of acidic end products. Sulphite-resistant yeasts may also form a significant part of the spoilage flora.

Organic acids

Lactic acid is a natural end-product of glucose metabolism in muscle, which is normally processed by the liver in a living animal to CO_2 and water and some glucose.

However, in the absence of both an active blood supply and oxygen, lactic acid accumulates in the meat, lowering the pH.

The lowered pH has a preservative effect, limiting the growth of many organisms including meat spoilage aerobes, but also is antagonistic for aerobic Bacillus spp., Staph. aureus and Enterobacteriaceae, and at higher concentrations (2.5-5.0% w/w) inhibits Clostridium botulinum and Listeria monocytogenes, as well as many spoilage bacteria.

Addition of lactic acid, for example in some meat products, lowers the pH marginally, but has the effect of increasing the level of the un-dissociated acid that enters the microbial cell more readily.

Once inside a cell at the higher intracellular pH value, lactic acid dissociates to increase the H+ level.

The cells then have to expend energy to expel the protons, or in synthesising pH neutralising compounds, thus reducing growth rates.

Increasing the concentration of lactic acid or lactate salts, will increase the concentration of the un-dissociated acid at a given pH value, thus increasing the preservative effects.

Even though acetic acid has a higher acid disassociation constant (pKa) value than lactic acid (pH value at which 50% of the acid is dissociated), it has a much stronger acid taste and is naturally present in meat only at very low levels, and in meat products is less effective than lactic acid.

Citric acid is also a weak acid and less effective than either lactic or acetic acids, and is present in meat only at very low levels. ■

References are available from the author on request