water. Higher scald water temperatures will eliminate most vegetative bacteria but cause an unacceptable loosening of the skin cuticle.

After scalding, birds are mechanically defeathered by a system of rotating rubber fingers. A number of studies have demonstrated how these can pass organisms, for example *Salmonella*, from one carcass to others following it and when the fingers become worn or damaged they are liable to microbial colonization. As the poultry carcass is not skinned, skin-associated organisms will not be removed.

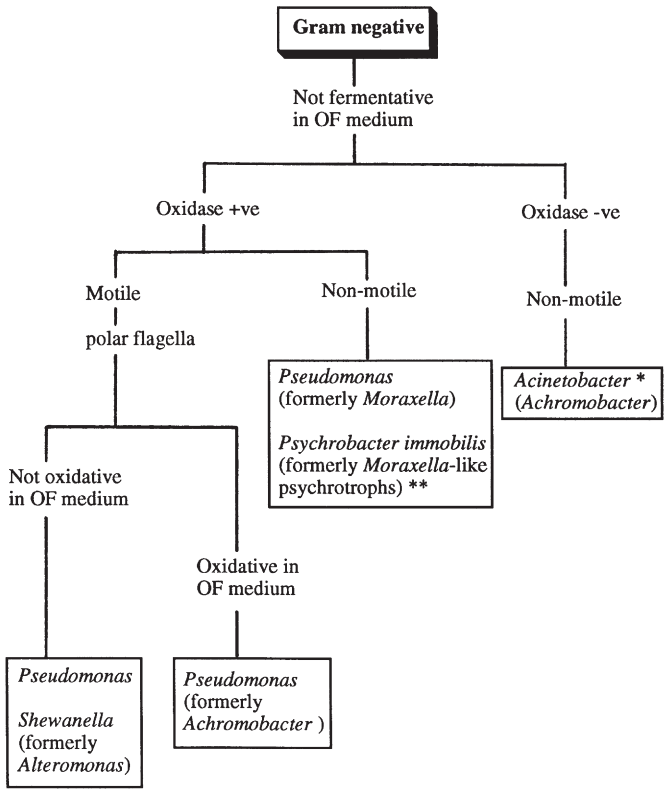
The intestinal tract of poultry will contain high numbers of organisms including pathogens such as *Salmonella* and *Campylobacter*. Poultry evisceration therefore poses similar microbiological hazards to those with other animals but the size and structure of the carcass make it a much more difficult operation to execute hygienically. To allow high processing rates, poultry evisceration is usually automated but this too leads to a high incidence of carcass contamination with gut contents. Since the carcasses are not split like those of sheep and cattle, effective washing of the gut cavity after evisceration is more difficult.

Poultry to be frozen is usually chilled in water and this offers a further opportunity for cross contamination. This is controlled by chlorination of the cooling water, use of a counter-current flow as in scalding, and a sufficient flow rate of water to avoid the build up of contamination.

5.3.3 Spoilage of Fresh Meat

Aerobic storage of chilled red meats, either unwrapped or covered with an oxygen permeable film, produces a high redox potential at the meat surface suitable for the growth of psychrotrophic aerobes. Non-fermentative Gram-negative rods grow most rapidly under these conditions and come to dominate the spoilage microflora that develops. Taxonomic description of these organisms has been somewhat unsettled over the years with some being described as *Moraxella* and *Moraxella*-like. Such terms have now been largely abandoned in favour of a concensus that has emerged from numerical taxonomy studies. In this, the principal genera are described as *Pseudomonas, Acinetobacter* and *Psychrobacter* with *Pseudomonas* species such as *P. fragi, P. lundensis* and *P. fluorescens* generally predominating. A dichotomous key describing the differential characteristics of these organisms and some of the names used previously to describe them is presented as Figure 5.4. Other organisms are usually only a minor component of the spoilage microflora, but include psychrotrophic Enterobacteriaceae such as *Serratia liquefaciens* and *Enterobacter agglomerans*, lactic acid bacteria and the Gram-positive *Brochothrix thermosphacta*.

The first indication of spoilage in fresh meat is the production of off odours which become apparent when microbial numbers reach around



* see Bouvet, P.J.M. & Grimont, P.A.D. (1986). Taxonomy of the genus *Acinetobacter*. *International Journal of Systematic Bacteriology* **36**, 228-240.
see Juni, E. & Heym, G.A. (1986). *Psychrobacter immobilis* gen. nov., sp. nov. Genospecies composed of Gram-negative, aerobic, oxidase-positive coccobacilli. *International Journal of Systematic Bacteriology* **36, 388-391.

Figure 5.4 *Characteristics of some Gram-negatives associated with meat*

10^7 cfu cm^{-2}. At this point it is believed that the micro-organisms switch from the diminishing levels of glucose in the meat to amino acids as a substrate for growth. In meat with lower levels of residual glucose this stage is reached earlier (10^6 cfu cm^{-2}) and this accounts for the earlier onset of spoilage in high pH meat.

Bacterial metabolism produces a complex mixture of volatile esters, alcohols, ketones and sulfur-containing compounds which collectively comprise the off odours detected. Such mixtures can be analysed by a combination of gas chromatography and mass spectrometry and the origin of different compounds can be established by pure culture studies. These have confirmed the predominant role of pseudomonads in spoilage of aerobically stored chilled meat. Usually the different spoilage taints appear in a sequence reflecting the order in which components of the meat are metabolized. The first indication of spoilage is generally the

buttery or cheesy odour associated with production of diacetyl (2,3-butanedione), acetoin (3-hydroxy-2-butanone), 3-methyl-butanol and 2-methylpropanol. These compounds are produced from glucose by members of the Enterobacteriaceae, lactic acid bacteria and *Brochothrix thermosphacta*. Pseudomonads then begin to increase in importance and the meat develops a sweet or fruity odour. This is due to production of a range of esters by *Pseudomonas* and *Moraxella* species degrading glucose and amino acids and by esterification of acids and alcohols produced during the first phase of spoilage. Ester production is particularly associated with *Pseudomonas fragi* which can produce ethyl esters of acetic, butanoic and hexanoic acids from glucose, but other pseudomonads and *Moraxella* species are also capable of producing esters when grown on minced beef. As the glucose becomes exhausted, the meat develops a putrid odour when *Pseudomonas* species and some *Acinetobacter* and *Moraxella* species turn their entire attention to the amino acid pool, producing volatile sulfur compounds such as methane thiol, dimethyl sulfide and dimethyl disulfide.

In the later stages of spoilage an increase in the meat pH is seen as ammonia and a number of amines are elaborated. Some of these have names highly evocative of decay and corruption such as putrescine and cadaverine but in fact do not contribute to off odour. When microbial numbers reach levels of around 10^8 cfu cm^{-2}, a further indication of spoilage becomes apparent in the form of a visible surface slime on the meat.

Vacuum and modified-atmosphere packing of meat (see also Section 4.6) changes the meat microflora and consequently the time-course and character of spoilage. In vacuum packs the accumulation of CO_2 and the absence of oxygen restrict the growth of pseudomonads giving rise to a microflora dominated by Gram-positives, particularly lactic acid bacteria of the genera *Lactobacillus, Carnobacterium* and *Leuconostoc*.

Spoilage of vacuum packed meat is characterized by the development of sour acid odours which are far less objectionable than the odour associated with aerobically stored meat. The micro-organisms reach their maximum population of around 10^7 cfu cm^{-2} after about a week's storage but the souring develops only slowly thereafter. Organic acids may contribute to this odour, although the levels produced are generally well below the levels of endogenous lactate already present. Some work has suggested that methane thiol and dimethyl sulfide may contribute to the sour odour.

The extension of shelf-life produced by vacuum packing is not seen with high pH (>6.0) meat. In this situation *Shewanella putrefaciens*, which cannot grow in normal pH meat, and psychrotrophic Enterobacteriaceae can grow and these produce high levels of hydrogen sulfide giving the meat an objectionable odour.

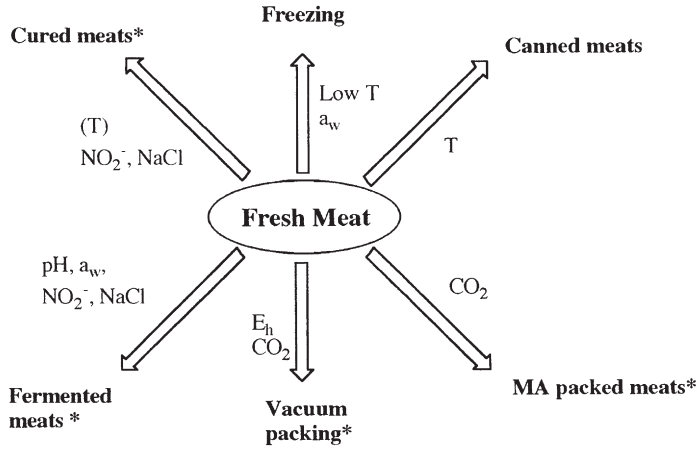


Figure 5.5 *Meat and meat products.* T *indicates elevated temperature;* E_h*, low redox potential; pH, reduced pH;* a_w*, reduced* a_w*; and * stored at chill temperatures*

In modified-atmospheres containing elevated levels of both CO_2 and O_2 growth of pseudomonads is restricted by the CO_2 while the high levels of O_2 maintain the bright red colour of oxygenated myoglobin in the meat. Here the microflora depends on the type of meat, its storage temperature, and whether it was vacuum packed or aerobically stored previously. In general terms though, the microflora and spoilage tend to follow a similar pattern to that of vacuum packed meat. Heterofermentative lactic acid bacteria can be more numerous due to the stimulatory effect of oxygen on their growth and, under some circumstances, *Brochothrix thermosphacta*, Enterobacteriaceae and pseudomonads can be more important.

Meat can be processed in a number of different ways which affect its characteristics, shelf-life and microbiology. The variety of these is illustrated by Figure 5.5; they will not be discussed further here but are treated in greater detail under the generic technologies in Chapters 4 and 9.

5.4 FISH

Here we are mainly concerned with what most people think of as fish; principally the free swimming teleosts and elasmobranchs. The same term can also encompass all seafoods including crustaceans with a chitinous exoskeleton such as lobsters, crabs and shrimp, and molluscs such as mussels, cockles, clams and oysters. Microbiologically these share many common features with free swimming fish but some specific aspects are discussed in Section 5.4.3.

Historically the extreme perishability of fish has restricted its consumption in a reasonably fresh state to the immediate vicinity of where