MICROBIAL CONTROL IN THE MEAT INDUSTRY

FLAIR-FLOW EUROPE TECHNICAL MANUAL
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IN THE MEAT INDUSTRY
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Microbial Control in the Meat Industry

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PREFACE

The acronym 'RE-TU-ER' was coined by the FLAIR-FLOW dissemination team to denote 'ready-to-use European research' and resulted in a series of RE-TU-ER workshops across Europe. The RE-TU-ER workshops are aimed at food SMEs, and especially at the small and very small companies. The goal is to bring results from EU-supported food research projects to food SMEs Europe-wide, in an easily understood form, thereby facilitating application and use of the results both in the short and long term. Each workshop carries a series of handouts and these have been collated into five technical manuals with the following titles:

1. Ready-to-use fruit and vegetables
   [ISBN 1 84170 106 8]

2. Food processing equipment design and cleanability
   [ISBN 1 84170 107 6]

3. Managing the cold chain for quality and safety
   [ISBN 1 84170 108 4]

4. Microbial control in the meat industry
   [ISBN 1 84170 109 2]

5. Freshness, quality and safety in seafoods
   [ISBN 1 84170 110 6]

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Introduction

Meat is an important element in the diet of most people and its safety depends upon the application of effective control measures at all stages of the production chain, literally from 'farm to fork'. In order to achieve this important objective there has to be co-operation between farmers, feed manufacturers, livestock market operators, livestock hauliers, abattoirs operatives and those working in food processing plants, on the one hand, and on the other, those employed in the meat inspection services and by other regulatory authorities, veterinarians, food technologists and the professionals specialising in occupational medicine, public health and the epidemiology of feed borne disease.

Elimination of meat from carcasses with visible lesions of disease from the food chain can been achieved by traditional meat inspection procedures. It is tempting to assume that this is sufficient to ensure that the carcasses that pass inspection are safe, and that is the end of the matter. This is not the case, however, since important hazards to human health originate with the carriage of pathogenic microbial agents, such as campylobacters and salmonellas, by clinically healthy animals. These 'unseen hazards' can only be controlled by a fully integrated approach to food safety during all stages of production, processing and distribution; this embraces HACCP and similar safety plans. It is essential that all those involved with the meat industry are aware of this since it is only when there is co-operation that progress can be made in ensuring that all meat and meat products sold to the general public are both safe and wholesome.

This article, which is concerned principally with the control of infectious agents hazardous to human health, is divided into eight main parts. The first two cover the management of red meat animals and poultry before and after harvest. These are followed by sections on decontamination of meat, meat spoilage and its control, cleaning and disinfection, further processing and bacterial pathogens on raw meat. The final part deals with quality and safety assurance systems.

No specific reference is made to legislation. It is assumed, however, that within the EU, that all meat and meat products will be produced to the requirements of the meat hygiene directives and other directives relevant to meat and poultry production.

1. Management in red meat production before and after harvest

1.1 Prevention and control of infectious agents on the farm

Contamination problems in the slaughterhouse can result from animal husbandry and farm management practices that fail to recognise the requirements for safe meat production. Personnel working with food animals must, therefore, be adequately trained and kept up to date with developments in food safety, including, where appropriate, improved stockmanship and the correct use of medicinal products

Under ideal conditions herds should be self-sufficient in breeding terms and the purchase of additional animals should be kept to a minimum. When selecting stock for purchase, the farm of origin must be ascertained and, where possible, guarantees of its health status obtained. This means that it is inadvisable to purchase animals in auction markets. Ideally, animals, and in particular breeding stock, should be kept in quarantine for up to three weeks after purchase and, where appropriate, undergo serological or other tests before being introduced into the herd or flock.

With respect to housed animals attention should be directed to: (1) the control of rodents, birds and other wildlife by adequate design and construction of buildings, (2) preventing people, including farm workers, unnecessary access to the stock, (3) providing all farm workers and visitors with clean boots and overalls, (4) ensuring the hygienic quality of the feed and water, (5) operating, where possible, an all-in/all-out policy, (6) segregating clinically ill animals, preferably in a separate building and (7) treating farm manure and slurry in order to minimise the risk of contaminating the environment

In addition to facilitating disease control, the identification of live animals is becoming an increasingly important component of quality assurance (QA) schemes which depend on the ability to trace foods of animal origin back to the production farm. These requirements will need to be incorporated into the standard operating procedures (SOPs) which are a necessary component of QA schemes. There is also a requirement to maintain production records, including information on the prevalence of disease and the administration of medicinal products for treatment and prophylaxis. Within the EU, some of these records must be kept for statutory purposes, for example, the use of medicinal products.

1.2. Transportation and lairage

Animals should be examined by the producer before loading to ensure that they are fit to travel. In addition, only clean animals should be sent for slaughter since it is impossible to produce meat with low levels of microbial contamination if the hide or fleece is heavily contaminated with organic material, particularly faeces.

Loading and transport of food animals should undertaken by trained personnel who are knowledgeable about the effect of stress on meat safety and quality (e.g. PSE and DFD in pork and dark cutting in beef). Ideally animals should be slaughtered as close as possible to the point of production. However, for longer journeys it may be a legal requirement to produce a journey plan, before the journey commences, including details of stops for feeding and watering. Following unloading, the transport vehicle should be thoroughly cleaned and disinfected before being reloaded with another consignment of animals.

The principal function of the lairage is to provide a reservoir of animals for the slaughter line. For the purposes of food safety, and on animal welfare grounds, facilities must be available for the isolation and removal of any animals showing signs of illness. A separate slaughter unit may be used for such cases, if required by the Official Veterinarian. It is legally permissible to keep animals in the lairage for up to 72 hours although it is preferable to slaughter animals on the day of arrival since this reduces the risk of spreading pathogens, and ensures better carcass yields. An exception may be made for sheep with wet fleeces, since placing them in a pen with a deep, clean, straw bed overnight will allow them to dry out before slaughter the next day.

1.3. Casualty and emergency slaughter

When medicinal products are administered to sick animals the withdrawal period must elapse before the animal is sent for slaughter; otherwise unacceptable levels of residues may remain in the meat and organs. Casualty animals represent a special problem since they may have received medication and unless an appropriate withdrawal period has been observed, the meat may be unfit for human consumption on this account alone.

The admission to an abattoir of either casualty animals or the carcasses of those animals slaughtered in emergency on the farm is contingent upon

veterinary certification of fitness for human consumption based on an ante-mortem inspection. Casualty and emergency slaughter should never compromise the integrity of the food safety programme and thus the animal, or its carcass, must be always: (1) clearly identifiable at all stages of the slaughter process, (2) transported separately from other animals, (3) subjected to a veterinary ante-mortem examination and provided it passes, (4) slaughtered in a manner which minimises the risk of cross contamination to other carcasses and the environment. This must be followed by an extended post-mortem examination, supported by ancillary tests, as appropriate.

1.4. Slaughter, dressing and chilling procedures

The slaughter and dressing operation provides many opportunities for contamination of the carcass with pathogenic bacteria which are not detectable at post-mortem inspection. Good manufacturing practices (GMP) can be focused on limiting this spread and, likewise, the establishment of control points at specific stages during slaughter and dressing.

All staff must be adequately trained in good hygienic practice (GHP) and be provided with proper working instructions. Appropriate protective clothing must be worn and replaced at least every day. Hands and arms should be washed, and knives and equipment pasteurised frequently, or whenever contaminated. Personnel should not move from ‘dirty’ to ‘clean’ areas under any circumstances.

During dressing the oesophagus of cattle and sheep should be sealed to prevent leakage of ruminal contents. In sheep this can be achieved by tying the oesophagus in a knot while in cattle a technique termed ‘rodding’ may be used to free the oesophagus from the trachea and diaphragm and to position a rubber ring or plastic clip on the oesophagus close to the diaphragm. Similarly, it is recommended that a plastic bag is used to seal off the rectum after loosening; this is sometimes referred to as ‘bagging’. Removal of hides or fleece should be carried out so that contact between the outside of the skin and the carcass is avoided while hands and equipment that touch the outside of the skin should not come into contact with the underlying carcass meat. Under no circumstances should carcasses and offal come into contact with floors, walls or work stands while visible soiling of the carcass surface should be removed by washing, excision or the surface decontaminated, for example by flaming. Over-wetting is to be avoided because it favours the subsequent growth of cold-tolerant spoilage bacteria and thus reduces shelf-life.

During post-mortem meat inspection, palpation and incision of lymph nodes, infected tissues or tissues with abnormalities can give rise to cross contamination. Incision should be avoided where possible, and palpation of organs should be minimal.

With respect to pigs it is recommended that feed be withdrawn 12 hours before slaughter to empty the stomach and thus reduce the likelihood of carcass contamination. Scalding should be carried out at a water temperature of at least 60°C. The process, in general, results in a reduction in bacterial numbers on the carcass. The temperature of the water used in the dehairing process should be equivalent to that of scalding. In this way re-contamination can be kept as low as possible. Singeing or flaming of all parts of the carcass, including the head and legs, until a light brown surface colour develops also helps reduce bacterial numbers on the carcass surface.

2. Management in poultry processing before and after harvest

In contrast to the red meat industry, most poultry rearing and processing within the EU is undertaken by a relatively small number of highly integrated companies responsible for the whole chain of production, and sometimes beyond. Thus it should be possible to: (1) introduce co-ordinated training programmes on food safety matters for all employees and (2) monitor strategic control measures which can be applied at appropriate points in the production chain to reduce the risks from food borne pathogens to a minimum. However, the enormous numbers of birds involved presents considerable practical problems and there is much room for improvement.

Some contamination problems in the processing plant, where control of cross-contamination is difficult, if not impossible, have their origin on the farm. Therefore, attempts must be made on the farm to reduce the prevalence of infection with food borne pathogens. This objective can be facilitated by, for example, producing specific-pathogen-free birds, the use of controlled-climate houses and the development of appropriate biosecurity measures.

2.1. Transportation from farm to processing plant

The loading and transport of the birds should be carried out by trained personnel who handle the birds carefully and do not cause them distress. Only apparently healthy birds that are fit to travel should be transported. Ideally, the birds should be reared as closely as possible to the processing plant to avoid any

unduly long journeys. The systems used for transportation are principally of two kinds, with either loose crates or containers that are fixed to the vehicle. Fixed equipment is more difficult to clean and disinfect, but it is important that the birds are loaded into clean containers to avoid any flock-to-flock transmission of pathogens at this stage. Any equipment used in collecting live birds on the farm must also be cleaned and disinfected before re-use.

Before loading, feed should be withheld from the birds for several hours to reduce the amount of subsequent defaecation. Nevertheless, some defaecation does occur in transit and the birds become further contaminated on the feathers and skin. On arrival at the processing plant, the crated birds are usually rested before unloading them onto the processing line. A holding area that is sheltered and quiet is required, with provision for cooling the birds in hot weather. If this is not available, it may be necessary to provide ventilation by continuing to transport the birds until they can be processed.

2. 2. Processing and portioning of poultry

The microbiological condition of carcasses is a reflection of the microbial load associated with the live bird and the care taken to control the spread of microorganisms during the slaughter process. Birds arriving for slaughter are frequently heavily contaminated with microorganisms carried in the intestines, on the skin and among the feathers. These include both enteric bacteria and organisms derived from the rearing environment. However, some carcass contamination, with *Staphylococcus aureus* and *Listeria monocytogenes* for example, is mainly acquired from the environment of the processing plant.

Primary processing is divided into four phases, each physically separated from the others: (1) unloading and shackling of live birds which causes a degree of wing flapping and aerial dispersion of microorganisms, (2) stunning, killing, scalding and plucking, (3) evisceration and carcass cleaning, and (4) chilling and subsequent stages such as grading and packaging. Portioning is also a separate activity.

During scalding many bacteria are washed from the carcasses and contaminate the scald water. Bacterial survival is related to scald temperature, which is largely determined by the type of bird and end product. The low temperatures (50-52°C) used for carcasses that will be air-chilled favour bacterial survival, especially for Enterobacteriaceae, and thus provide a significant opportunity for salmonella cross-contamination. Salmonellas and other vegetative bacteria are destroyed much more rapidly at temperatures of

58°C and above, which are normally used for carcasses intended for water chilling followed by freezing. Defeathering with automatic machinery causes scattering of microorganisms and cross-contamination of carcasses. Conditions inside these machines are favourable for microbial growth and colonisation, especially *Staph. aureus*. High levels of carcass contamination with this organism may indicate poor hygiene in the plucking process. During carcass evisceration, levels of enteric bacteria can increase on the skin and surface of the body cavity. Faecal contamination can be exacerbated by failure to set the evisceration machines properly.

The use of inside-outside carcass washers removes visible faecal contamination, but does not eliminate bacteria attached to the carcass surface (See section 3). Since attachment is a time-dependent process, it is beneficial to wash the carcasses several times during processing after defeathering and not just prior to chilling. In this way, contaminants can be removed before they become attached.

Three types of chilling process are used within the EU; air-blast, water immersion and spray chilling, the latter involving a combination of air and water chilling. All three methods may lead to cross contamination of carcasses, but the problem is greater in systems that use water. Water immersion chilling can reduce overall levels of carcass contamination, when operated according to EU requirements. Furthermore, the risk of cross-contamination may be reduced with the use of chlorinated water. Chilling must be carried out promptly to prevent microbial growth. In the primary process, the deep muscle temperature of the carcass should be reduced to 8°C while secondary chilling (or freezing) is necessary to achieve a final temperature of <4°C.

The portioning process involves both automatic and semi-automatic lines, while portioning of turkeys is often largely manual. It is essential that the environmental temperature is kept as low as possible (usually ca. 12°C) and that the portioning area and the equipment (surfaces, knives, conveyor belts, containers etc.) remains dry. In particular, condensation must be avoided. These conditions limit the growth of cold tolerant pathogens and spoilage bacteria. The degree of microbial contamination on cut portions reflects their degree and duration of exposure to the processing environment.

3. Decontamination of meat

Almost all contamination is on the outside of the meat since in the healthy animal the muscle, fat and edible organs contain very few if any microbial

contaminants. When microorganisms come into contact with surfaces, they invariably become attached and ultimately are difficult to remove. In its simplest form, attachment involves two main stages: (1) a loose association between the organism and the surface, through electrical forces, followed by (2) time-dependent, irreversible attachment, involving the formation of viscous polymers that 'anchor' the organism to the surface. Attachment to meat is influenced by the nature of the surface and changes induced by wetting, as well as by surface structures on the bacteria, such as flagella and fimbriae.

From the practical viewpoint attached bacteria are difficult to remove from carcass meat by normal washing procedures and, in the attached state, are more resistant to antimicrobial agents, and hence less readily inactivated. Since bacterial attachment increases with time it is advisable to minimise the period of contact between meat surfaces and contaminating microbes. In poultry processing this has been achieved by washing carcasses at intermediate points during processing, thus removing contaminants before attachment can occur. When washing is delayed until the end of evisceration, as frequently occurs with the larger carcasses of red meat animals, a much smaller proportion of the organisms present can be removed.

Some methods of decontaminating carcasses are available for commercial application while others are still at the development stage. The ideal method will: (1) have no effect on the appearance, smell, taste or nutritional properties of the meat, (2) leave no residues following treatment and (3) be cheap and convenient to apply. A likely bonus is improvement of product shelf-life by inactivating spoilage microorganisms as well as pathogens. Decontamination is a valuable tool in the production of safe food and should not compromise good hygiene practices (GHP) because, on its own, decontamination is unable to solve the microbiological problems which develop during the rearing and slaughtering of meat animals.

3.1. Chemical methods of decontamination

3.1.1. Organic acids

The most widely studied acids are acetic and lactic. Acetic is less pleasant to use because of its smell and it sometimes causes off flavours. Studies have not revealed any clear superiority of lactic or acetic acid, but in combination they seem to be more effective than either used alone at equivalent concentration. Both are cheap, traditional food components, widely used in the food industry and well-accepted by consumers. Lactic acid is a major natural constituent of raw meat. There are some commercially available preparations containing these two acids in combination with other acids such as citric and ascorbic, designed to improve colour stability. 'Buffered' lactic acid (obtained by adding sodium hydroxide until pH 3.0 is achieved) has been reported to be very effective at 10% lactic acid content. No adverse effects on appearance or flavour were observed.

3.1.2. Trisodium phosphate (TSP)

This compound, which is highly alkaline at its in-use concentration, has been used to treat raw poultry to reduce the numbers of salmonellas and campylobacters, and for treatment of beef to remove *E. coli* 0157:H7. It is also active against Gram-negative spoilage bacteria such as pseudomonads, thus extending shelf-life. TSP can be applied either by dipping or spraying. Red meat primal cuts can be dipped immediately prior to packaging while TSP can be applied to poultry either before air chilling after evisceration, or after water chilling. Several minutes should elapse before TSP is rinsed off in order to allow the product to act.

3.1.3. Chlorine and chlorine dioxide

Chlorine is effective for controlling cross-contamination during water chilling of poultry carcasses and reducing contamination on equipment but shows little activity when applied directly to carcasses, since chlorine is rapidly inactivated by contact with organic material. The situation with chlorine dioxide is similar. It is more effective than chlorine but it can only be used at relatively low concentrations because of unpleasant effects on operatives.

3.2. Physical methods of decontamination

Physical methods of carcass decontamination have the advantage that they avoid the possible problem of chemical residues in the meat and, by definition, do not require any disposal of spent material.

3.2.1. Washing procedures

Washing of carcasses eliminates visible soiling and may reduce microbial contamination, but the efficiency of the process depends partly on the degree of microbial attachment to carcass surfaces and partly on the manner of water application. The key factors include spray pressure and flow rate, nozzle type and configuration and angle of spray. Washing using high pressure may appear to reduce contamination to low levels, but can also force bacteria into the tissues. Red meat carcasses are often washed with water from a single, hand-held nozzle. This is relatively inefficient because areas of the carcass can be missed, while a single stream of water can simply spread foreign material from one part of the carcass to another, without actually removing it. Realisation of this limitation has resulted in the development of different types of washer that permit more uniform and controlled cleaning of carcasses. The effectiveness of carcass washing in reducing microbial contamination is increased by the use of hot water. However, the water temperature must not be so high that carcass 'bloom' is adversely affected.

3.2.2. Steam

Although effective, steam at atmospheric pressure produces unacceptable changes in the surface appearance of the carcass. Possible future alternatives are to use steam at sub-atmospheric pressure or to use super-heated steam at high pressure for very short times, and repeating treatments. A steam-vacuum system used in conjunction with a hot water wash might result in a reduction of up to 10000-fold in carcass contamination.

4. Meat spoilage and its control

Many factors affect the storage life of fresh meat but it is temperature which is by far the most important since a shift of even a few degrees can have a profound effect on the keeping quality of the product due to the multiplication of cold-tolerant spoilage bacteria.

Microorganisms contaminating meat are derived from soil, gastrointestinal contents, hide, skin, or feathers, processing equipment, personnel and water. Those associated with the spoilage of chill-stored meat are, however, mainly cold-tolerant microbes that are derived from the environment and not the intestinal tract. With so many potential sources it is inevitable that contamination cannot be prevented, but only minimised, by GMP and hygiene measures. This is important, since fresh meat is a suitable substrate for bacterial multiplication since it has a high water activity and provides a range of readily utilisable low molecular weight sources of carbon and energy (e.g. glucose, lactic acid, amino acids, creatine) and other nutrients such as metal ions and soluble phosphorus compounds.

Bacterial contaminants will be distributed on all surfaces of the carcass and, following butchery, uncut and cut muscle surfaces. In general, the deep tissues will contain few, if any, microorganisms. Despite differences in the source of the microbial contaminants and the muscle tissue of different species, the characteristics of microbial spoilage are remarkably similar. Particular combinations (associations) of cold-tolerant organisms commonly develop during storage, depending on the conditions imposed (e.g. temperature, gaseous atmosphere) and the type and properties of the meat (e.g. pH value and ratio of fat to lean). Differences in the composition of the bacterial associations at spoilage can be explained by the influence of: (1) temperature on the multiplication rate, (2) oxygen requirements and (3) carbon dioxide sensitivity. *Pseudomonas* spp. can multiply with oxygen levels of 1% (v/v), low carbon dioxide concentrations (<20%, v/v) and low temperatures. In contrast, lactic acid bacteria multiply independently of oxygen levels in concentrations of carbon dioxide up to 100% (v/v), and at low temperatures. Multiplication of the Enterobacteriaceae and *B thermosphacta*, on the other hand, is favoured less by decreasing temperatures than that of either *Pseudomonas* spp. or lactic acid bacteria, since they are more resistant to carbon dioxide than *Pseudomonas* spp. but far less resistant than that of the lactic acid bacteria. Although multiplication of both groups can occur in the presence or absence of oxygen, neither multiplies effectively without oxygen when the pH values are below 6.0.

4.1. Methods of extending storage life

The principal method of extending storage life is the maintenance of the chill chain and this is temperature dependent. Chilling is not generally a bactericidal process and hence it is essential to start with the meat having as low a level of microbial contamination prior to storage as possible. It is essential to keep the temperature of meat products below 4°C and preferably 2°C. However, this may not be possible in practice and hence refrigeration is commonly combined with other systems (hurdles), the most common being modification of the gaseous atmosphere surrounding the meat when packed in transparent film

which is relatively impermeable to gases. The gaseous composition within the pack will change with time. The main gases used in gas packaging are carbon dioxide, as a microbial inhibitor; oxygen, which maintains the red colour of meat; and nitrogen, which, because of its low solubility in water, is incorporated as a ‘filler’ to prevent collapse of the package.

The advantages of modified atmosphere packaging (MAP) include (1) a sealed pack which prevents further contamination of the product, (2) increased shelf-life allowing less frequent loading of retail display shelves, (3) improved presentation providing a clear view of the product and (4) centralised automated packaging with dedicated quality assurance. The disadvantages of MAP include: (1) the costs of gas packaging equipment, gases, packaging materials, analytical equipment to ensure correct gas mixtures and systems to identify and eliminate ‘leakers’ and (2) larger packs which require more space during transport and retail display.

4.2. Safety of chill-stored meat

Microbial spoilage of meat is due primarily to the multiplication of non-pathogenic bacteria, although some bacterial pathogens may grow on chill stored meat and hence extending shelf-life may allow cold-tolerant pathogens, for example, those belonging to the genera *Aeromonas*, *Listeria* and *Yersinia*, to reach dangerous levels in the absence of detectable spoilage. However, overall the risks to human health from meat packaged in modified atmospheres is less than for fresh meat stored in air since all bacterial multiplication will be retarded or inhibited.

Clostridia, particularly *Cl. botulinum*, can grow on meat stored under modified atmospheres with low levels of oxygen. However, although this represents a potential hazard, the risk to consumers from this source would appear to be extremely low since packaged meat stored under refrigeration has an excellent safety record with respect to botulism. Cold-tolerant pathogens may grow on meat, particularly that with a high pH value, stored for an extended period under modified atmospheres. High concentrations of carbon dioxide are inhibitory for these pathogens and hence vacuum packaged meat, or meat stored in 100% nitrogen, represents an increased risk.

5. Cleaning and disinfection of equipment and premises

Cleaning and disinfection is one of the cornerstones of current GMP and GHP and is a prerequisite for the production of high quality, wholesome meat. Plant management must be permanently committed to good hygiene and must ensure that effective cleaning systems are developed and their performance is effectively monitored. Standard operating procedures, which also comply with health and safety at work legislation, are required for each department or production area and their development in modern high throughput plants may involve a considerable amount of staff time, and require assistance from professional advisors.

Cleaning and disinfection are technically distinct but both reduce the numbers of contaminating microorganisms, including pathogens and those that cause spoilage. Both procedures require the application of: (1) mechanical energy (e.g. scraping, brushing, water pressure), (2) chemical energy which breaks down soil and may kill microorganisms, (3) heat or thermal energy which melts fat and oil, and sometimes kills microorganisms and (4) time. For disinfection, mechanical action improves the contact between microorganisms and the treatment solution.

Cleaning programmes are frequently combined with disinfection and involve several stages. These include: (1) preparation, involving dismantling of equipment, (2) dry removal of gross soil (small pieces of meat, bone, feathers) using, for example, brushes, 'squeegees' water pressure or compressed air, (3) pre-rinse with potable water, (4) cleaning with chemical detergent. This comprises three principal phases: (i) wetting and penetration of soil and surfaces by the cleaning solution, (ii) reaction of the cleaning solution with soil to facilitate peptidisation of organic material, dissolution of soluble compounds and emulsification of fats and (iii) prevention of redeposition of dispersed soil, (5) rinse with potable water at 40-50°C, (6) disinfection and (7) final rinse with potable water. The last rinse is essential in order to prevent contamination of the product with chemical residues. The period of contact between the surface and the disinfectant must be sufficient for microbial inactivation but not so long as to allow drying out. Where possible, the cleaned and disinfected surfaces should be dried quickly since this inhibits the growth of residual microorganisms.

Only approved licensed cleaning agents and disinfectants should be used, according to the manufacturer's instructions, since these will be non-corrosive, non-toxic and not taint the meat. Protective clothing must be worn if required

and care must be taken that the chemicals used do not cause environmental problems when discharged into the sewage system. All surfaces should be cleaned at least once a day. However, items which come into close contact with the product (such as knives, gloves, cutting boards) should be cleaned and disinfected more frequently. Cleaning may be undertaken without disinfection but disinfection should never be applied without cleaning since any soil present is likely to reduce the effectiveness of the disinfectant. Cleaning and disinfection of polishing equipment, including the lashes, preferably by a cleaning-in-place (CIP) system, is particularly important. If this is not done properly, bacteria will grow overnight and these will spread to the carcasses during the next working day.

Responsibility for the day to day supervision of cleaning lies with the meat producer or the contract cleaning company while the standard of cleaning is best monitored routinely by QA personnel who have no direct involvement with cleaning. The result should be recorded as either a pass or a fail and any action taken noted. The records should be evaluated regularly and any weak points in the SOP (standard operating procedure) improved where appropriate. Clearly, a programme of thorough visual inspection must be in place before a system of bacteriological tests is introduced.

6. Further processing of meat

There is a long tradition of processing all edible parts of the carcass including muscle, with and without bone, heart, liver, kidney, fat and blood. The initial objective of traditional methods such as cooking, curing, drying, fermentation and smoking was to extend keeping quality so that meat was available during times of shortage and these methods have evolved empirically over hundreds or even thousands of years. More recently, other processes have been introduced in order to increase the value of the final product and meet the demand for a greater variety of products, particularly those which require a minimum of preparation prior to consumption. In the case of poultry, many of these products mimic those traditionally produced from red meats, but often without the same level of preservation.

It is essential that all meat used in meat products will be of the highest microbial quality. Water is an important ingredient in some processed meat products and ice may also be used. In all cases water must be of potable quality. There is now an adequate basis for control of microorganims through the implementation of GMP and the application of the principles embodied in the

Hazard Analysis Critical Control Point (HACCP) concept and these should be adopted as far as possible in modern meat processing premises which have a high throughput. The meat processing industry as a whole continues to provide a challenge to the regulatory authorities, since there are many small producers preparing traditional products. These manufacturers often employ old established methods with little, if any, monitoring of ingredients, process conditions and the quality of the final product. In addition, the small size of many premises makes it difficult, sometimes, to introduce even the basic requirements of GMP, for example the adequate separation of areas in which raw and cooked products are handled.

Many meat products contain comminuted meat, either coarsely or finely chopped or minced. Mechanically recovered meat may also be used. The process of comminution re-distributes microorganisms present on meat surfaces throughout the product. It also destroys the structural integrity of the muscle and releases substances from the cells that are readily available for microbial growth. This clearly represents a microbial hazard that may be compounded by the addition of herbs and spices and other ingredients that may be contaminated with microorganisms. The resulting product is, therefore, susceptible to microbial spoilage and must be held under refrigeration, i.e. at 0-2°C or frozen until required for further processing.

The microbial stability and safety of many traditional and novel meat products involve the use of a combination of different methods of preservation, for example curing and smoking. This has a particular advantage for products with an intermediate to high water content, since a combination of several preservation principles, sometimes called 'hurdles', will reduce further the opportunity of microorganisms growing in, or on meat. In general, preserved meat products have a good safety record although food manufacturers must assess all novel methods of food processing, for example 'sous vide', in order to ensure that the product is safe and that the risk of botulism is eliminated.

7. Bacterial pathogens on raw meat

Meat is recognised as a source of several bacterial pathogens that cause food poisoning in humans although the source of infection is not determined in the majority of outbreaks of food borne infectious disease investigated. There are several reasons for this, an important one being that the food responsible for the problem has usually been consumed completely, or has been disposed of, before microbiological investigations are instituted.

Currently the most important pathogens associated with raw meat are *Campylobacter* spp., *Clostridium perfringens*, pathogenic serotypes of *Escherichia coli,* for example *E. coli* O157:H7, the salmonellas and certain serotypes of *Yersinia enterocolitica*. *Listeria monocytogenes* is also a common contaminant of meat, but the public health significance of the strains present on raw meat is unclear. Many of these bacteria are confined to the intestinal tract of the animal, while others occur, for example, in the nasopharynx or on the skin. All of them may contaminate carcasses during dressing and further handling. Usually, the organisms are capable of prolonged survival on meat surfaces, although *C. jejuni* is sensitive to drying and considerable reductions in contamination levels can be achieved by forced air chilling. With the exception of spores of clostridia and aerobic bacilli, food borne pathogenic bacteria are heat sensitive and should be killed by proper cooking, especially when present as surface contaminants.

Inevitably, pathogenic bacteria are sometimes introduced into the interior of meat products, as with comminuted foods such as sausages and beef burgers; thus, the potential for food borne disease is increased in such products. In addition to undercooking, contributory factors in food poisoning outbreaks include inadequate thawing or cooling after cooking, preparing food too far in advance and cross-contamination. Some pathogens, including campylobacters, salmonellas and *Yersinia* spp. are amenable to on-farm control measures. It is clear, however, that control should also be exercised in the abattoir and during the preparation of meat products and food in the kitchen.

7.1 Occupational bacterial diseases among abattoir workers

Most bacteria causing clinical disease in farm animals do not affect man, although animals sent for slaughter may be 'symptomless' carriers of pathogens such as *Brucella abortus*, campylobacters, *Chlamydia psittaci*, the cause of psittacosis and ornithosis in birds and enzootic abortion in sheep, *Coxiella burneti*, the cause of Q fever, *Erysipelothrix rhusiopathia*e, leptospires, *Mycobacterium bovis*, salmonellas and *Y. enterocolitica*.

Increased prevalence of clinical illness caused by campylobacters and salmonellas has been observed among workers in poultry plants presumably due to airborne or oral infection via the hands. Chlamydial infections are common in poultry, particularly ducks, and chlamydiosis has been reported in people working in poultry processing plants. Workers in pig slaughterhouses may have levels of antibodies to *E. rhusiopathiae* that are higher than the normal population while severe cases of *Y. enterocolitica* infection have been reported among newly employed meat inspectors in pig slaughterhouses probably due to handling tonsils.

The ultimate control measure of the zoonotic infections is eradication from farm animals. This has been achieved for *Br. abortus* and *M. bovis* in many countries while the prevalence of other infections, such as *Leptospira hardjo*, can be reduced by the use of vaccines.

Modification of dressing procedures in which organs such as the bladder, udder and uterus are not incised will reduce the risk of spread of *Br. abortus, C. burneti, L. hardjo* and *M. bovis* while covering the anus with a plastic bag will reduce contamination with enteric pathogens such as *Y. enterocolitica*. Incision of the submaxillary lymph nodes may result in *Y. enterocolitica* and other pathogens being transported from the tonsillar region to other parts of the carcass by the knives and hands. Prevention of psittacosis among poultry plant workers can be achieved by installation of forced ventilation. Strict personal hygiene, such as avoiding any touching of the mouth with contaminated fingers and applying strict hygiene in rest rooms, are important factors.

Abattoir workers sometimes suffer pyogenic infections including boils on the fingers caused by streptococci and staphylococci of human origin. The source of infection is not the animals or carcasses on the slaughterline, rather the spread of bacteria between workers, which is favoured by the humid atmosphere, poor personal hygiene and dirty resting facilities. Workers suffering from boils, or similar infections, should be excluded from slaughter premises. To prevent the spread of infection the wound should be covered with adhesive tape or similar material.

7.2. Control of pathogenic microorganisms on meat

The control of pathogenic microorganisms on meat must start on the farm. The principal routes of transmission include: (1) vertical spread of infection from mother to offspring and, (2) more commonly, horizontal spread from animals of the same, or different species, including rodents and other wild animals, and man.

Animal feed which has not been heat treated is a potential source of some pathogens including salmonellas, while it is rarely, if ever, contaminated with others such as campylobacters. Silage is a possible source of *L. monocytogenes*, when contaminated with soil and of poor quality, with a high pH value (>4.5). Water from rivers and ponds may be a primary source of infection for

Aeromonas spp. and *Campylobacter* spp. and it is advisable to give animals potable water to drink although this may subsequently become contaminated in the water trough. The farm environment, including the buildings, may remain contaminated with pathogens, such as salmonellas, despite careful cleaning and disinfection. Clearly buildings should be designed and built in such a way that they can be easily cleaned and maintained in good structural repair.

Animals may become infected with pathogens during the journey from the farm to the abattoir. The stress of the journey itself may induce excretion of salmonellas while the crowding of animals on vehicles, particularly pigs, poultry and sheep, facilitates cross-contamination. The flesh of animals is usually regarded as sterile while their surfaces and intestinal tracts are heavily contaminated with bacteria of many different genera. Most of these are unlikely to be harmful although it is essential to minimise contamination with spoilage bacteria from the environment, since this will reduce the keeping quality of the meat.

It is impossible to produce carcass meat and raw meat products which are free of bacteria. This means that the control of microbial contamination depends heavily on the application of GMP and HACCP systems (see Section 8). Good management practice involves not only the techniques used by the slaughtermen and other personnel, but also the construction of the building, and the design of the equipment, which will facilitate the separation of clean and dirty procedures, and abattoir cleaning and disinfection.

As outlined in Section 3, washing of the carcass will remove a proportion of the organisms present while surface contamination can be further reduced, but not eliminated, by the judicious use of antibacterial sprays or dips. Chilling is an effective critical control point (CCP) and hence it is essential to reduce the temperature of carcasses as quickly as possible to 7°C for red meat and 4°C for poultry. With the latter, a final temperature of 0-2°C is necessary to maintain an adequate shelf-life. Clearly, it is essential to chill cooked foods rapidly after cooking, to prevent recontamination from raw foods and to maintain cold conditions throughout the chain of distribution.

In general, bacterial pathogens cannot be eliminated from meat by any of the measures presently available. However, much can be done to minimise their occurrence by ensuring high standards of hygiene in the abattoir. This will involve the application of GMP and HACCP principles, effective cleaning and disinfection of buildings and equipment, and rigorous attention to temperature control throughout the food chain.

8. Quality and safety assurance schemes

Food must satisfy the needs and expectations of the consumer and there are two principal approaches to assuring the quality of food from a safety and sensory point of view. These comprise quality control (QC) and quality assurance (QA) programmes, with the latter including HACCP systems. Both these approaches have the same objective, that is management of risks associated with food by the selection and implementation of appropriate measures. An effective QA scheme will, however, provide greater confidence in food safety than is available from other approaches including QC. For the industry, an effective QA programme will reduce operating expenses, thus giving better use of resources and a quicker response to, or prevention of, problems. It will also facilitate inspection by food control authorities of those aspects of production that are critical to food safety. One of the advantages of using HACCP systems as the basis for QA schemes is that controls are based on clear principles and concentrate on identified hazards.

8.1. Procedures for assuring safety and quality

Quality control is in essence retrospective since it usually involves end-product testing; this is relatively inefficient. However, since it is only a small proportion of a batch of food that is sampled and this may not be representative of the whole. An example of QC is the traditional inspection of carcasses and offals, a procedure that is carried out by relatively few people in the slaughterhouse, usually employed by the authorities responsible for the implementation and enforcement of meat hygiene legislation. These individuals may have little interaction with the company employees and do not necessarily act to minimise hygiene problems. Little can be done when problems are discovered by a QC inspection since they cannot be rectified. If serious, product recall may be necessary; an expensive procedure which does not solve the problem and can have serious effects on consumer confidence and the financial well-being of the production company concerned.

On the other hand, QA, which includes HACCP systems, involves a proactive rather than a reactive approach. For maximum effect QA programmes need to cover the whole production chain from raising of the animals to the final consumer. Successful implementation must involve all people working in the production chain, including managers and food handlers, and not just a few specialists such as meat inspectors. Quality assurance programmes aim to control, prevent or eliminate problems, and should ideally start with the

eradication of microbial pathogens from farm animals. Continuous monitoring of the whole production process ensures that control measures can be introduced promptly and effectively in response to either new hazards or altered risks, so that their impact can be eliminated or minimised before product safety and quality are compromised.

Quality assurance and QC systems should not be seen as independent of each other, however, since they can operate simultaneously in the same production situation, with QA providing control and QC providing inspection or test data which can be used to monitor the effectiveness of this control. Hence, planned inspection and testing can be used to demonstrate the quality of process management to both regulatory authorities and customers.

8.2. Pre-requisites for quality control and quality assurance

First and foremost, animals selected for slaughter must be in good health and in a clean condition. During transport and handling, stress must be minimised as this may result in the excretion of pathogens and their spread from animal to animal. Because the microorganisms associated with spoilage of meat are derived both from the environment and the gastrointestinal tract, contamination during slaughter and dressing of the carcass, and further processing of the product, is inevitable and the resulting risks can only be minimised by GMP and GHP.

The underlying requirements for the effective implementation of quality and safety assurance systems are often included in GMP and GHP documents and in some countries, for example the USA, they may be called ‘pre-requisite programmes’. An important requirement is that agreed hygiene procedures must have a sound and justifiable technical basis. In addition, they must be supported by managers and employees, all of whom must be trained and equipped to fulfil all the tasks involved in producing a safe and wholesome product.

8.3. Hazards and hazard identification

QA systems and end-product sampling cannot ensure the absence of pathogens from raw meat. This means that the objective of these systems must be to ensure that their numbers remain within specified limits, such that utilisation according to any instructions of ‘reasonable’ usage results in a product that is safe to consume.

Two approaches to consumer safety are in common use depending on whether a product is either sold ready-to-eat or contains raw meat and is intended for cooking. Ready-to-eat products must be free of pathogens at the completion of the manufacturing and packaging processes. On the other hand, products intended for cooking rely on a combination of manufacturing practices and consumer cooking to ensure safety when the food is consumed. This highlights the importance of minimising the risks of raw meat carrying pathogens and providing validated cooking instructions for packaged raw products. Although cooking will eliminate the direct hazards, it will not control the chance of cross-contamination in the home.

8.4. Implementation, control and monitoring

HACCP systems are not in general use on farms and other sites of primary production although there is no reason why they should not be introduced to control the spread of pathogens associated with food poisoning. At present, therefore, QA systems implemented by the meat industry are generally restricted to the non-agricultural parts of the supply chain, including transport, slaughter, butchery, packaging, distribution etc. CCPs will include the cleanliness of animals entering the slaughterhouse and their management in the lairage or unloading bay, the plant layout, its operation and maintenance. This is closely linked with the personal hygiene of operatives, the quality of their protective clothing and equipment, production discipline and training, as well as the control of temperature during production, storage and transportation. Although these may not all be specifically identified as CCPs in a HACCP plan, they should be covered by GMP or GHP procedures. If the product is packaged under vacuum or within a modified atmosphere, there may be additional CCPs specific to these operations, including, for example, the maximum pH value of the meat and the integrity of the pack seal.

It is normally the responsibility of the QA staff to monitor the effectiveness of a HACCP system on a day-to-day basis, usually by either auditing, or inspection of the process and hygiene records, especially those referring to CCPs. Although not always possible, monitoring should provide information in time for corrective action to be taken to regain control of the process before the need to halt production and segregate or reject the product. Accurate records are needed for both trend analysis and verification and these should be accumulated during a planned sequence of observations or

measurements. It must then be possible to use this information to demonstrate whether or not there is adequate control.

Sampling plans, sampling sites and microbiological techniques are crucial considerations in setting product specifications and may often be specific to a type of animal or product. Irrespective of the technique used, sampling plans should be statistically based and their type and stringency should be determined by the severity of the hazard or the information required. Failure to detect pathogens may only be a reflection of shortcomings in the isolation method used and hence not a measure of their absence. In situations in which storage conditions may injure microorganisms, it is important that analytical methods suitable for their recovery are used or underestimation of numbers may result. If there is temperature or time abuse during transport, microbial numbers may increase and agreed levels may be exceeded and responsibility for failure may have to be determined by inspection of records.

9. Conclusions

1. The safety of foods of animal origin depends on the application of effective control measures at all stages of production including feed manufacture. This is particularly important for ‘unseen hazards’ such as campylobacters and can only be controlled by a fully integrated approach to food safety.

2. Certain farm animal species, for example, poultry are a major reservoir of salmonellas and campylobacters, but these are usually carried asymptomatically by the animal. Conditions of intensive rearing are not necessarily responsible for the increased prevalence of these infections; however, such conditions may lead to extensive spread of infection, should any foodborne pathogens gain access to the birds.

3. On the farm, strict control of husbandry hygiene (biosecurity) is the key to reducing the risk of herd and flock infection. Although the hygiene requirements are well established, their application needs to be more stringently enforced in many cases, especially in relation to broiler flocks.

4. The spread of pathogens in the slaughterhouse and poultry processing plant is presently unavoidable, particularly because of high carcass production rates in the larger establishments and the nature of the processing operation. The modern slaughter process, particularly when

automated, does not include any means of eliminating pathogens from the end product. Terminal carcass decontamination can be used to provide a CCP.

5. Cleaning and disinfection are of critical importance at all stages of production, transport and processing.

6. In order to extend shelf-life it is essential to maintain the cold chain at all times. Chilling does not generally kill bacteria and hence meat should be prepared with only minor levels of microbial contamination.

7. Storage in MAP does not improve microbial quality; it only delays the time to spoilage. Thus, keeping-quality is improved and the risks to human health from pathogens on meat is reduced because the generation time is increased .

8. The processing of meat has a long tradition and involves typically either cooking, curing, drying, fermentation or smoking. For many products two or more of these processes are combined and, in general, such products have a good safety record. More recently, other methods have been developed to increase the shelf-life of meat products and food manufacturers must assess critically all food processing procedures so that the risk of foodborne infections and botulism are eliminated.

9. Quality assurance plans, including HACCP systems, can only be implemented effectively if GMP and GHP programmes are already in place and fully operational, and when all the people employed in the production chain know their responsibilities, and that they are adequately trained and equipped.

10. QA programmes, which are proactive in nature, are more likely to be effective than QC programmes that rely on retrospective end-product testing. However, QA and QC should not be seen to be mutually exclusive, indeed QC testing can be used effectively as part of the validation of QA programmes.

11. Separate QA programmes must be developed for safety and quality issues and these programmes must ultimately cover the whole chain of meat production from 'farm to 'fork'. It is essential that the protocols are kept under review since the risks may need to be re-assessed to take account of changes in production processes and the prevalence of foodborne pathogens.

12. Product safety is the responsibility of many individuals, including farmers, feed manufacturers, livestock market operators, livestock hauliers, the people working in meat processing plants and the regulatory authorities. It is essential, therefore, that everybody working with food animals, meat or meat products is adequately trained and kept up to date with developments in food safety so that they can then play their full part in the production and preparation of safe and wholesome meat and meat products.

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