SESSION 2. MICROBIOLOGY AND HYGIENE

REVIEW: MICROBIOLOGY AND HYGIENE OF RED MEATS

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SUMMARY

Reviews of the microbiology of red meat carcasses and of fresh meat are listed. Emerging microbiological problems are identified and prospects for their solution considered.

INTRODUCTION

Red meats are important sources of Salmonella and Clostridium perfringens, both of which are frequent causes of food-borne illness. They may also be a source of Staphylococcus aureus, Campylobacter spp, Yersinia enterocolitica, a range of Enterobacteriaeceae (ICMSF, 1980), Listeria monocytogenes and Aeromonas hydrophila.

Muscle contains c. 75% water and a variety of substrates for microbial growth including carbohydrates, amino acids and lactic acid (Dainty, 1982; Dainty et al., 1983; Lawrie, 1985). Meat has a high water activity (a_w) c. 0.99, which is suitable for growth of most microbes. Only by removing a large proportion of that water (e.g. by drying) will the a_w be reduced sufficiently to affect microbial growth.

Within the pH range of meat, from c. 7.0 to c. 5.4, values approaching 5.4 are less favourable for growth of many of the bacteria of concern. Lower pH values are particularly important in maintaining the stability and safety of products containing preservatives such as sodium nitrite and sorbate.

The redox potential of red meat is believed to be important in determining the nature of microbial spoilage, but its exact role is not clear. Tissue respiration of oxygen continues after death but, because oxygen supply via the blood ceases, the oxygen content and redox potential of muscle fall, leading to anaerobic conditions even a few millimetres below the muscle surface within a few hours post mortem. However, microbial growth in deep musculature is rare except where refrigeration is inadequate (Gill, 1979; Roberts & Mead, 1985).

Meat microbiology has concerned itself with the number and types of microbes found initially on the carcass, and identifying the sources of that contamination. It has identified many of the factors that determine the nature and extent of microbial growth on or in the product under different conditions of storage and packaging, and possible hazards associated with consumption of meat carrying microbes associated with food-borne illness. More recent research has characterised some of the chemical consequences of microbial growth in red meat, including evaluation by taste-panel of the odour of the raw meat and the acceptability of cooked meat in an attempt to relate the observed microbiological changes to the chemicals associated with spoilage and identify their microbial origins (Ayres, 1955; Mossel & Ingram, 1955; Ayres, 1960; Ingram, 1962; Linton et al., 1977; ICMSF, 1980; Eustace, 1981; Gill, 1982; Nottingham, 1982; Dainty et al., 1983; Mossel et al., 1985; Sebranek, 1985; Dainty, 1985; Grau, 1986; Gill, 1986; Shaw et al., 1986; Egan & Roberts, 1987).

THE PRIMARY CONTAMINATION

The microbiology of carcass meat is determined by the conditions under which the animals are reared, slaughtered and processed. Programmes to improve animal health and inspection under veterinary control have eradicated, or largely controlled, diseases which were once common in livestock and frequently transmitted to man (e.g. anthrax, brucellosis, cysticercosis, trichinosis and tuberculosis) (Acha & Szyfres, 1980). Animals exhibiting symptoms of e.g. salmonellosis are also readily excluded from slaughter by ante-mortem inspection. However, some animal infections, and other conditions which are a potential hazard to human health, cannot be detected by ante-mortem inspection. These apparently healthy stock still present a real problem in meat hygiene since the proportion varies with circumstances and no simple means are available to improve our understanding of the numbers of animals involved. Animals "carrying" Salmonella do not necessarily excrete them. Stress during transport and lairage may cause a breakdown of the "carrier state" causing greatly increased excretion of Salmonella, the transfer of which from one animal to another is facilitated by the close contact in transport and lairage. This problem is poorly defined and there is debate whether the precautionary measures currently taken, which include condemnation of carcasses, are excessive. There are no known means by which the contamination of meat by bacteria able to cause food-borne illness can be prevented.

The basis for our understanding of the origins of the primary contamination of the carcass and the factors which control the rate of growth of that contamination flora is based on far-sighted studies in Australia in the 1930's. Empey & Scott (1983) & Scott & Vickery (1939) identified soil, hide, hair and the contents of the gastro-intestinal tract as major sources of contamination of the carcass, and aerial contamination as relatively trivial, but varying with the season and with operations in progress. Means of reducing contamination were studied and the numerically dominant bacteria, yeast and moulds identified. The investigation extended into chillers, and documented the effects of temperature and relative humidity on weight loss and the rates of multiplication of the relevant spoilage microbes.

Attempts to control the hygiene of slaughter have mainly been by visual assessment of the premises, the operatives and the carcasses, to the extent of not accepting for slaughter animals which are "visibly unacceptably dirty". This subjective control, with inevitable differences in interpretation of imprecisely worded guidelines and Codes of Hygienic Practice (e.g. Codex, 1976; FAO, 1984), has frequently resulted in disagreement between meat producers and regulatory authorities, particularly when the latter have insisted upon costly changes to the structure of abattoirs and chill-rooms in the name of improved hygiene which, from previous experiences, seemed unlikely to be effective, and which the producers consider a poor return for the financial outlay involved.

Although the microbiology of the carcass is determined to some extent by the conditions under which the animals are reared, more critical control points are procedures during slaughter, particularly removal of the heavily contaminated hooves, hide or fleece, and the skill exercised during evisceration to ensure that gut contents are prevented from contaminating the carcass surface.

In one of the few reviews of quantitative aspects of the bacteriology of red meat carcasses and the abattoir (Ingram & Roberts, 1976) there was insufficient systematic data in the literature to conclude other than that the bacteriological status of carcasses had not improved as a consequence of modifications to premises and slaughter lines. Attempted comparisons were confounded by a poor appreciation of the distribution of bacteria over the carcass surface, of differences in bacterial numbers between carcasses, between abattoirs and between visits to the same abattoir. Comparisons that were possible were complicated by differences in sampling methods.

In a subsequent review of the effect of slaughter practices on the bacteriology of red meat carcasses, no evidence could be found that contamination of carcasses by pathogens or the overall levels of contamination had decreased, while large and costly "improvements" continued to be undertaken on the basis of preconceived ideas (Roberts, 1980).

Subsequently, extended surveys of commercial carcasses have improved our understanding of the distribution of bacteria (Roberts et al., 1980), compared numbers of bacteria on beef carcasses at representative abattoirs in seven Member States of the EC (Roberts et al., 1984), and shown that a simple bacteriological counting method gives results indistinguishable from those obtained using the ISO reference method (Hudson et al., 1983). The same method has been applied successfully by others (Johanson et al., 1983) and in evaluating the bacteriological consequences of automation of a slaughterline (Whelehan et al., 1986).

These, and other, surveys offer a clearer indication of what can be achieved under commercial conditions of slaughter, applying good manufacturing practices. In broad terms 10^3-10^4/cm is common, and 10^2-10^3/cm achievable with care. Taking a broad view, there are differences in the levels of bacterial contamination of carcasses at production of c. x 10^2-10^3 in all the countries where data have been published.

CONTAMINATION OF THE DEEP MUSCULATURE

From time to time concern is expressed over the microbial contamination of the deep musculature. Some believe the musculature of healthy, rested animals is essentially sterile and remains so after slaughter, others believe that at slaughter defence mechanisms active in the live animal cease to function allowing microbes to enter the musculature and to remain viable. Contamination of the musculature can take place by several routes (e.g. from the captive bolt, stick-knife), but the extent of contamination via those routes under commercial conditions has not been established. Some unexpected observations in the early literature seem best explained by faulty aseptic technique, but there have been many instances of spoilage of the deep muscle in bovines ("bone-taint") and cured pork products, both claimed at different times to be of bacterial origin. The incidence of "bone-taint" has fallen greatly with improved refrigeration, to the point where it is uncommon except when the carcass pH is high and the chilling inadequate. During "hygienic slaughter" much attention is paid to prompt evisceration, but there is evidence that this requirement may be too rigid. When slaughter is interrupted, e.g. for mechanical faults on the line lasting perhaps one hour, there is concern that continued, rigid implementation of "immediate evisceration" can result in the needless condemnation of perfectly acceptable carcasses. The literature has been thoroughly reviewed (Gill, 1979; Roberts & Mead, 1985).

ACHIEVEMENTS, PROBLEMS AND PROSPECTS

Tremendous advances have been made in the prevention of transmission of diseases from animals to man, with a resultant reduction in food-borne illness.

The outstanding, seemingly insoluble, problem worldwide is the symptomless carriage of Salmonella associated with food-borne illness (Meara, 1973; Nottingham, 1982; Roberts, 1982). The most obvious improvement is to provide Salmonella-free feeds, but this is rarely attained.

INTENSIVE SLAUGHTER

Rarely has the equipment used to mechanise processes been designed with hygiene and ease of cleaning/ disinfection in mind. As a consequence no improvement in the microbiological status of carcasses has resulted subsequent to mechanisation of the slaughterline. The opposite is sometimes the case: e.g. scrapers and polishers on pig slaughterlines are particularly difficult to clean and sanitize.

CRITICAL CONTROL POINTS

One substantial advance in recent years has been the confirmation of the points on slaughterlines where significant microbial contamination takes place. On beef and lamb slaughterlines removal of the hide/fleece is an important source of contamination, as is removal of the head and hooves. On beef, lamb and pig slaughterlines evisceration is an operation which can cause significant microbial contamination of the carcass if improperly performed. Hence evisceration is a critical control point. On pig slaughterlines the temperature of the scalding tank is critical, as is the subsequent scraping and "polishing" of the carcass. In all species the conditions of chilling the carcasses are critical: i.e. the temperature, humidity and velocity of the air, and ensuring adequate space between carcasses to allow air circulation and drying of the carcass surface.

SUBSEQUENT STORAGE

Storage conditions evolved to achieve maximum shelf-life and safety have been investigated microbiologically in great detail. Spoilage of red meats stored "aerobically" under chill conditions (below 8-10°C) is due primarily to the growth of Pseudomonas spp. The shelf-life of all meat species can be extended significantly by vacuum or gas-packaging using oxygen-impermeable films. Gas mixtures containing at least 20% carbon dioxide are particularly appropriate, oxygen being included to enhance meat colour.

Under anaerobic storage conditions growth of Pseudomonas is limited by reduced oxygen concentration and increasing concentrations of carbon dioxide so that lactic acid bacteria dominate numerically the final flora. The metabolites produced by lactic acid bacteria tend to be associated with "cheesy" "dairy" odours/flavours and are less objectionable than the more putrid odours produced by Pseudomonas spp.

In exceptional circumstances (e.g. high pH) spoilage is caused by different bacteria e.g. beef of high pH (>6.0 has been spoiled by Altermonas putrefaciens or by particular lactic acid bacteria. In both instances spoilage was the consequence of hydrogen sulphide production. Brochothrix thermosphacta causes spoilage of red meats at relatively low numbers (c. 10^4/g). Spoilage microbiology and chemistry has been thoroughly reviewed (Dainty et al., 1979, 1983; Newton & Gill, 1981; McMeekin, 1982; Dainty, 1982, 1985; Gardner, 1983; Lowry & Gill, 1985; Shaw et al., 1986; Tompkin, 1986; Egan & Roberts, 1987).

AUTOMATION

There is little evidence that automation of slaughterlines has improved the microbiological hygiene of carcass meat. In some circumstances there is even suspicion that automation has worsened the hygiene. The hope is that "robotic" slaughter will effect a considerable improvement in the hygienic status of the carcass, but the costs of such automated lines must be reasonable.

Spray washing is commonly an ineffective commercial process which uses unnecessarily large amounts of water. For maximum shelf-life it is important that the carcass surface dries during the early stages of chilling, as will occur after using a correctly designed spray washing system (Bailey & Roberts, 1976).

ELECTRICAL STIMULATION

There is no substantial evidence that electrical stimulation of red meat carcasses affects the bacteriological condition of the carcass or that of the stored meat.

HOT DEBONING

Provided that hot deboning is carried out under hygienic conditions and subsequent refrigeration is controlled, no bacteriological problems have resulted (Smith, 1985).

GAS PACKING

Modified atmosphere packaging is widely practised. The hazards appear no more serious than with traditional methods of aerobic and anaerobic packaging (Shaw et al., 1986; Shaw, 1987).

HIGH pH PRODUCT

Selective breeding for leanness has resulted in pig carcasses with high pH muscles, particularly in the shoulder (collar). This meat is considerably less stable bacteriologically, with respect to shelf-life, than meat of lower pH, but has not resulted in any hazard with respect to food poisoning organisms. Similarly beef of high pH is less stable than that of normal pH.

FOOD-BORNE ILLNESS

In the last 5-10 years the traditional patterns of food-borne illness have changed, evidenced by the frequent implication of Campylobacter spp. in food-borne illness. Campylobacter is rarely present on beef and lamb carcasses, but can be isolated from freshly slaughtered pig carcasses. It appears not to survive commercial refrigeration, but can be recovered from meats at retail sale. There is some uncertainty whether strains isolated from meats are identical to those responsible for enteritis.

Escherichia coli can be isolated from red meats, usually in low numbers. The association of E. coli strain 0157:H7 with beef is poorly understood and cause for concern because of the severity of the illness (Riley et al., 1983).

Yersinia spp. are frequently isolated from pig carcasses, but seem less commonly associated with beef or lamb (Lee et al., 1981). Listeria spp. have been demonstrated on beef carcasses but the association of meat-borne Listeria with human illness is not established. Both these organisms are of concern because the trend in the meat industry is towards extending chilled shelf-life, under which temperature regime both are able to grow. Their ability to compete with the spoilage flora under a broad range of conditions is poorly understood.

AVOIDANCE OF FOOD-BORNE ILLNESS

There is still no means known to guarantee the absence of the above vegetative pathogens from meat. Decontaminating carcasses with acids is favoured by some workers but is not accepted by all regulatory agencies. They are all relatively sensitive to heating. Consequently, even if they are present on carcasses, illness can be avoided by appropriate handling procedures to prevent their transfer to other foods in the domestic situation, and by appropriate cooking of meats before consumption. This is a more cost-effective control measure than attempting to prevent their occasional occurrence on the carcass.

CRITERIA

The use of microbiological criteria is considered separately (Roberts, 1987). The extreme variability of distribution in meats of pathogens such as Salmonella prevents practical sampling plans being established. Although meat is traded internationally and is implicated in food-borne illness, there is no evidence to suggest that applying microbiological criteria will reduce the health risk. Microbiological monitoring at the slaughterhouse at identified critical control points can be used to assess effectiveness of sanitation, and there is some value in limited monitoring of the carcasses at production (NRC, 1985; ICMSF, 1986).

MODELLING

Food microbiologists are slowly appreciating that the growth response of microbes are governed by the factors such as temperature, water activity, pH, substrates available for growth, preservatives acting in combination. The microbiological needs of a changing meat industry, with an ever-increasing range of product formulations and storage conditions, will never be met by ad hoc examination of representative products. Models which predict the probability of growth, or the rate or extent of growth, of microbes of concern in safety and spoilage are urgently needed. Few laboratories are committed to the effort needed to generate the type of data that will enable those models to be developed. The literature contains examples which illustrate clearly that mathematical modelling of microbial growth responses is relevant to the needs of the food industry (Mackey et al., 1980; Ratkowsky et al., 1982, 1983; Robinson et al., 1982; Gill, 1984; Smith, 1985; Stannard et al., 1985; Roberts & Gibson, 1986).

CONCEPTUAL PROGRESS

Increasingly it has been recognized that the continued use of and reliance upon imprecisely worded codes of practice or imposition of microbiological specifications affords little prospect of improving hygiene (NRC, 1985; ICMSF, 1986), and that the most cost-effective means are the Hazard Analysis Critical Control Point (HACCP) concept. This implies identifying the "hazard" (i.e. the microbes of concern) and, in the case of the raw product, either preventing their reaching the carcass, or accepting that their occasional presence is inevitable, and ensuring that other measures (e.g. temperature control) are taken to prevent their multiplication. The philosophy of the HACCP concept, with particular reference to Salmonella, is introduced in WHO/ICMSF (1987). This document is an excellent introduction to those unfamiliar with the concept. It is elaborated more broadly, with reference to a wide range of circumstances in food production, handling and processing in ICMSF (1988).

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