Review

Microbiological conditions of meats from large game animals and birds

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Abstract

Large game animals and birds used for the commercial production of meat include deer of various species, wild boar and feral pigs, ostriches, emus and rheas, crocodiles and alligators, bison, and kangaroos. Meat from feral pigs and kangaroos is obtained from wild animals only, but much or most meat from the other game animals or birds is obtained from farmed animals. The microbiological conditions of meats from hunted animals can be compromised by poor placement of shots, the usual evisceration and sometimes further dressing of carcass in the field, and ageing of carcasses at ambient temperatures. However, the general microbiological conditions of carcasses from farmed game animals or birds slaughtered and dressed at suitable abattoirs can be comparable with or better than the microbiological conditions of carcasses from domestic animals or birds. The incidences of enteric pathogens on meat from wild or farmed game animals or birds can be less than those for meat from intensively reared domestic animals, but infection of some game meats with *Trichinella* or other foodborne parasites may occur.

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1. Introduction

The microbiological conditions of meat obtained from large game animals and birds will depend upon the types of microorganisms carried by each species, on the hide, in the gastro-intestinal tract, or in the muscle tissue itself; the circumstances in which the creature is killed; and the conditions under which the carcass is dressed and butchered. The microflora that develops during storage will depend upon the storage conditions and intrinsic biochemical qualities of the meat.

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Most game animals from which meat is obtained are killed in the field. The animal may be trapped, or cornered or brought down by hunting dogs, and be dispatched with a knife or other blade instrument. However, most hunted large game would now be shot with a rifle bullet or, far less frequently, with an arrow or a bolt from a bow. Generally, when an animal is killed in the field the carcass is eviscerated, and damaged or visibly contaminated tissue is trimmed from it while it is at or near to the kill site; but skinning and butchering may be delayed for up to several days and be carried out at a more or less distant location. Before further dressing, carcasses eviscerated in the field are preferably hung by the hind legs with the body cavity propped open to facilitate drying of the internal surfaces exposed by evisceration. Commercial hunters may, however, transport uneviscerated carcasses to a game meat packing facility. In such circumstances a common requirement is that the carcass be delivered to a plant for evisceration within 2 h of the animal being killed.

Game animals used for meat may be under some form of human control. Such control may involve management of physically unrestricted populations in generally extensive geographical areas, herding of migratory populations, management of populations restricted to parks, ranches or estates, or farming of animals. The carcasses of animals under human control that are killed in the field would usually be dressed at temporary or permanent processing facilities or plants. Animals that are herded or farmed may be slaughtered and their carcasses processed at temporary or permanent facilities designed for the processing of specific species, or at small abattoirs where a variety of animal species are slaughtered.

Meat from carcasses dressed by occasional hunters would generally be preserved by freezing, if not consumed within 1 or 2 weeks of a kill. For some species, substantial fractions of the meat from carcasses dressed and processed at packing plants are likely to be vacuum packaged for extended storage as chilled product.

2. Venison

Indigenous and/or introduced species of deer are hunted in most regions of the world, with the animals being from uncontrolled or controlled populations. During the past 30 years farming of deer has been initiated in many countries. The world population of farmed deer is estimated to be about 5 millions, with about half that population being in New Zealand (Mackintosh, de Lisle, Collins, & Griffin, 2004). Deer farming in other countries has not developed in the same extent as in New Zealand, and in some countries farming may be in decline while the numbers of deer held in parks increase (Fletcher, 2004). Although various species of deer are farmed in different parts of the world, the most numerous species or subspecies of farmed deer are red deer (Cervus elaphus scoticus), elk (Cervus elaphus nelsoni), and fallow deer (Dama dama) (Hoffman & Wiklund, 2006). In addition, in Nordic countries, herding of reindeer (Rangifer tarandus tarandus) is a traditional practice. The population of reindeer in Eurasia is estimated to be about three million, of which about two million are subject to herding with some degree of taming (Malmfords & Wiklund, 1996).

It is generally recommended that wild deer be killed when the animal is standing broadside on to the hunter, with a shot to the chest that passes through the heart and both lungs (Winkelmayer, Malleczek, Paulsen, & Vodnansky, 2005). However, professional hunters involved in deer culling may prefer shooting animals in the head or neck, to minimize the damage to carcasses (Urquhart & McKendrick, 2006); while poor marksmanship, bad weather, difficult terrain, etc. may result in animals being wounded rather than being killed outright, and/or damage to the gut, with consequent contamination of the body cavity with gut contents.

Carcasses of wild deer would generally be eviscerated soon after slaughter, but evisceration may be delayed for several hours, with swelling of the intestines increasing the probability of the gut being damaged during its removal (Deutz, Fuchs, Pless, Deutz-Pieber, & Koffer, 2000). The likelihood of the gut being damaged during evisceration in the field would obviously vary with the skill of the person performing that task (Sumner, Perry, & Reay, 1977a). There will inevitably be some delay between the completion of evisceration in the field and placing of the carcass in a refrigerated facility. During the time at ambient temperatures, the flora deposited on the body cavity and cut tissue surfaces of the eviscerated carcass will tend to increase, with growth of the flora in any given time increasing with increasing temperature (Paulsen & Winkelmayer, 2004). Further growth of the flora on meat and body cavity surfaces may occur during holding of carcasses at chiller temperatures before they are skinned and butchered, although in some instances growth of the flora may be contained by drying of the contaminated surfaces (Paulsen & Winkelmayer, 2004). Unskinned carcasses of wild deer may be held for extended times, of up to three weeks at near-freezing temperatures, to allow the meat to develop the gamy flavours desired by some (Stranssky, 1984). Carcasses of farmed deer are not usually held for long before skinning, as meat with a mild flavour that appeals to a wide range of consumers is required.

As the initial microbiological condition of the carcass is affected by several highly variable factors, and its condition at the time of skinning after ageing is affected by additional factors that are also highly variable, it would be expected that the microbiological conditions of wild deer carcasses and the meat obtained from them would vary greatly. Published data on the microbiological conditions of wild deer carcasses soon after evisceration are largely lacking; and some microbiological data obtained for wild deer carcasses at later times, or for meat from such carcasses, were compromised by slow freezing of samples for storage, which might have reduced the numbers of bacteria that were subsequently recovered. However, ranges of several orders of
magnitude in the numbers of total aerobic bacteria recovered from carcasses before chilling (Paulsen et al., 2003; Paulsen & Winkelmayr, 2004), and at US and New Zealand plants from deer carcasses at the time of carcass breaking (Smith, Field, & Adams, 1974; Sumner et al., 1977a) indicate that the expected large differences in the microbiological conditions of wild deer carcasses processed at any plant often occur. The maximum numbers of aerobic bacteria recovered from carcasses in those studies were >10^8 cfu/cm^2 or g, while the mean numbers of total aerobic bacteria on carcasses of wild deer at the time of skinning are likely to be >10^4 cfu/cm^2 (Paulsen, 2005).

It is generally accepted that the deep tissues of meat from healthy animals will be sterile. However, contamination of the deep tissues of intact muscle is possible if large numbers of bacteria are introduced into the brain or blood stream when animals are killed (Mackey & Derrick, 1979). While contamination of deep tissues is very unlikely when animals are slaughtered under controlled conditions, it might occur when animals are shot in the field, as some animals may be wounded, with damage to internal organs, rather than being killed outright. In one study of the contamination of the deep tissue of muscles of wild deer carcasses, bacteria at numbers near the level of detection of 10^2 g^-1 were recovered from about half the carcasses that were examined (Riemer & Reuter, 1979). In other studies, bacteria were recovered in low numbers from within the muscle tissues of only a few or a single carcass from wild deer shot by hunters (Paulsen et al., 2003; Ring, Häusle, & Stoppler, 1988). Methods used for obtaining samples of deep muscle tissue have not always prevented samples being contaminated with extraneous organisms (Gill, 1979). In none of the studies of the contamination of the deep tissues of deer carcasses was any sampling of muscle tissue that could be expected to be sterile carried out, to establish that the method used could reliably recover tissue without extraneous contaminants. It therefore seems likely that the finding of a high incidence of deep tissue contamination of wild deer carcasses was due to ineffective exclusion of extraneous contaminants during the sampling of muscle tissue. The findings of low incidences of deep tissue contamination might also be due to occasional failures of sampling techniques, but in the absence of further information on the matter it could be assumed that occasionally the deep tissues of wild animals shot in the field might be contaminated.

When deer farming is a relatively undeveloped industry, the animals are likely to be killed on the farm by shooting in the head or neck while they are feeding. Selected animals in a group can be killed in this manner without frightening the other animals with them (FAWC, 2003). If the carcasses are then eviscerated on the farm and transported to a packing plant where they are treated as are the carcasses of wild deer, the microbiological conditions of the farmed deer carcasses may be only little better than those of wild deer (Sumner, Perry, & Reay, 1977b). However, when carcasses of farmed deer were placed in a refrigerated facility immediately after evisceration in the field, the mean numbers of aerobes on dressed carcasses were found to be about 10^3 cm^-2 (MacDougall, Shaw, Nute, & Rhodes, 1979). In countries where deer farming is well developed, farmed deer are slaughtered mainly at plants designed or adaptable for processing of the animals. At such plants, pens and runways are designed to minimize animal distress, and animals are restrained in a knocking box for stunning with a captive bolt (Bastiaansen, 2004). When deer are processed at such facilities, the mean numbers of aerobes on carcasses and cuts can be about 10^2 cfu/cm^2 (Gill, Jones, Bryant, & Brereton, 2000; Seman, Drew, Clarken, & Littlejohn, 1988).

Reindeer are slaughtered during late autumn and winter months, in field facilities that are open to the environment or at packing plants. For individual facilities of either type, the mean numbers of aerobes recovered from dressed carcasses ranged from <10^2 to >10^3 cfu/cm^2, with control of the microbiological contamination of carcasses at field facilities apparently being generally somewhat better than at packing plants (Vaarala & Korkeala, 1994; Vaarala & Korkeala, 1999). It was suggested that a better hygienic performance of the carcass dressing process at field facilities could be due to the carcasses being exposed to cold, dry conditions during dressing (Vaarala & Korkeala, 1999). Whether or not that is the case, the findings of the studies show that dressed reindeer carcasses as well as those of other deer can be of a microbiological condition comparable to that of beef carcasses dressed with good control of microbiological contamination (Gill, 2005a).

Although venison may often be frozen for storage, much prime meat from managed, farmed or herded animals is distributed as vacuum packaged, chilled product. The storage life of vacuum packed, chilled meat depends upon not only the extent to which it is contaminated with spoilage organisms at the time of packaging, but also on the pH of the meat. Bacteria of high spoilage potential can grow on muscle tissue of pH >5.8 or on fat tissue that is not bathed in exudates of pH <5.8, to cause early spoilage of vacuum packaged product (Gill & Gill, 2005). Venison is free of covering fat, and although stresses imposed on animals in the pre-slaughter period can result in the production of carcasses of high pH (Wiklund, Rehbinder, Malmfors, Hansson, & Danielsson-Tham, 2001), usual pre-slaughter stresses apparently have little effect on the ultimate pH of muscles in carcasses of red deer or reindeer (Pollard et al., 2002; Wiklund, Andersson, Malmfors, & Lundström, 1996). Consequently, vacuum packaged venison can remain acceptable for times up to 18 weeks when stored and distributed at temperatures about −1°C (Seman, Drew, & Littlejohn, 1989). Such storage stability has allowed the development of a substantial trade in chilled venison transported by sea from New Zealand to Europe (DINZ, 2003).

Even so, early “blown pack” spoilage of vacuum packed venison can occur. This sporadic spoilage condition
of vacuum packaged meats is characterized by gross swelling of vacuum packs as a result of large volumes of gas being produced by psychrophilic clostridia growing on the products (Dainty, Edwards, & Hibbard, 1989). The spores of the spoilage organisms have been found in soil particles on deer hides and in deer faeces, so it seems likely that the spores are transferred to the meat during carcass dressing (Broda, Bell, Borema, & Musgrave, 2002). Heating of spores during the heat shrinking of vacuum packs after they are sealed may accelerate spore germination and reduce the time required for pack swelling to become apparent (Bell, Moorhead, & Broda, 2001). Otherwise, the circumstances under which blown pack spoilage of vacuum packaged venison develops are poorly understood.

Contamination of venison with *Salmonella* appears to be uncommon. No *Salmonella* were detected in eight studies in which *Salmonella* were sought in samples of meat and/or faeces from the carcasses of wild deer shot by hunters in Europe, North America and New Zealand (Deutz et al., 2000; Paulsen & Winkelmayer, 2004; Paulsen et al., 2003; Riemen & Reuter, 1979; Ring et al., 1988; Smith et al., 1974; Sumner et al., 1977a; Wahlström et al., 2003), nor were any recovered during an extensive survey of faeces from wild deer in New Zealand (Henderson & Hemmingsen, 1983). It has been suggested that the evident rarity of *Salmonella* in deer may be due to the absence of a gall bladder in these animals (Mackintosh, Haigh, & Griffin, 2002); but that seems unlikely given that the organism is usually found in the guts of infected animals, and that it can localize in various tissue and organs other than the gall bladder (ICMSF, 1996).

Despite that, salmonellosis in young farmed and recently captured wild red deer in New Zealand and in young white-tailed deer in the USA has been reported (McCallum, Farmton, Brown, & Hemmingsen, 1978; Robinson, Hidalgo, Daniel, Rideout, & Marburger, 1970), while in a study of wild white tailed deer (*Odocoileus virginianus*) and domestic animals grazing the same range land, *Salmonella* were recovered from the faeces of some domestic animals and from the rumen contents but not the faeces of some deer (Branham, Carr, Scott, & Callaway, 2005). The frequent recovery of *Salmonella* of a single serovar from meat prepared from farmed deer at one packing plant, but not at another, was thought to be a result of animals slaughtered at the first plant having been pastured on land contaminated by geckos (*Hoplodactylus pacificus*), which were known to carry the serovar in question (Sumner et al., 1977b). These various reports suggest that when the environment for deer is relatively heavily contaminated with *Salmonella*, from other animals or perhaps occasionally from an infected deer, then the organism may be present in substantial numbers on the hides and in the rumens of deer, and some may be transferred to meat during carcass dressing. The available data indicate that such circumstances may be uncommon with wild deer. It might be expected that those circumstances would arise more frequently with intensively raised farmed deer. However, that expectation cannot be substantiated, as apart from the single report mentioned above, published data on the incidence of *Salmonella* in venison from farmed deer are lacking.

Contamination of venison with *Escherichia coli* O157:H7 may occur in circumstances similar to those in which the meat may be contaminated with *Salmonella*. Contamination of venison with generic *E. coli* is probably frequent (Paulsen et al., 2003; Smith et al., 1974), and verotoxigenic *E. coli* (VTEC) have been recovered at relatively high frequency from both deer faeces and venison (Asakura et al., 1998; Piërd, Van Damme, Moriau, Stevens, & Lauwers, 1997; Thomas, 1999). Moreover, cases of human infection with *E. coli* O157:H7 acquired from venison have been reported (Keene et al., 1997; Rabatsky-Her et al., 2002). However, in various surveys, *E. coli* O157:H7 was rarely recovered from wild deer faeces and was never recovered from venison (Dunn, Keen, Moreland, & Thompson, 2004; Fischer et al., 2001; Piërd et al., 1997; Renter, Sargeant, Hygnstrom, Hoffman, & Gillespie, 2001; Sargeant, Hafer, Gillespie, Oberst, & Flood, 1999; Wahlström et al., 2003). Data on *E. coli* O157:H7 in farmed deer or venison from them are lacking, but evidently carriage of the organism by deer is uncommon and contamination of venison with *E. coli* O157:H7 is probably infrequent.

The extent to which other foodborne pathogenic bacteria may be present on venison is also uncertain. Relatively large numbers of aeromonads were recovered from vacuum packaged venison from wild red deer after the meat had been stored at chiller temperatures for a few days, but whether those organisms included pathogenic strains was not determined (Paulsen, Bauer, Winkelmeyer, Smulders, & Hofbauer, 2005). *Yersinia enterocolitica* were recovered from venison sausages, from venison on retail sale in Japan, and from deer carcasses; but it was not certain that the organisms in sausages originated from venison rather than some other ingredient (Bosi, Madie, Wilks, & Fenwiek, 1995), while the isolates from venison lacked pathogenic properties and the isolates from carcasses were not examined for such properties (Kanai et al., 1997; Paulsen et al., 2003). Campylobacters were recovered from deer faeces, but less frequently than from the faeces of other wild animals (Wahlström et al., 2003), and from three of one hundred deer carcasses (Paulsen et al., 2003), but were not recovered from venison in Japan (Kanai et al., 1997). In addition, an outbreak of *Clostridium botulinum* type F poisoning involving home-prepared venison jerky has been reported (Midura, Nygaard, Wood, & Bodily, 1972). Deer may carry *Toxoplasma gondii*, as the prevalence of animals seropositive for the parasite can be high (Reichel, Timms, Ross, & Penrose, 1999), and infection with the organism as a result of the consumption of venison has been reported (Ross et al., 2001). Despite that, these various reports suggest that contamination of venison with foodborne pathogens may be relatively rare and that, as with *Salmonella* and *E. coli* O157:H7, such organisms on venison may often
be derived from the environments of live animals rather than from infected deer. However, further data on the contamination of venison with pathogens is clearly required.

3. Pork from wild boar and feral pigs

As wild boar are ancestral to domestic pigs both are members of the species *Sus scrofa*, although various subspecies of wild boar have been proposed (Genova, 1999). Wild boar and domestic pigs can freely interbreed. Wild boar are native to Europe and Asia, but in other parts of the world escape or release of domestic pigs and/or farmed wild boars has led to the establishment of feral pig or wild boar populations (Cushman, Tierney, & Hinds, 2004; Long, 2003; Wilson, 2005). Feral pigs often have characteristics typical of wild boar, such as ridged backs, large tusks, broad shoulders, short hindquarters and black coat colour, even when their immediate antecedents do not include wild boar (McIlroy, 2001; Queensland Government, 2006; Wilson, 2005). Most animals are shot in the field, with or without the use of dogs to drive the animals or bring them to bay (Maillard & Fournier, 1995; McIlroy, 2001), but some are captured and delivered to packing plants without or after fattening (Forsyth & Parkes, 2004).

Carcasses of feral pigs and wild boar are usually skinned, whereas the carcases of domestic pigs are mostly subject to scalding, dehairing and singeing before the carcasses are eviscerated and dressed without removal of the skin (Gill, 2005a). Skinning of feral pig and wild boar carcasses is necessary, because scalding of carcasses eviscerated in the field would damage the carcass, the usual treatment of uneviscerated domestic pig carcasses would not adequately remove the relatively extensive and thick black hair from the carcases of the wild animals, and black skin on carcasses or cuts would be unacceptable to most customers and consumers.

For boar carcases it has been reported that total counts recovered from carcases skinned in the field or at a carcass dressing facility ranged from $10^2$ to $10^5$ or $10^2$ to $10^6$ cfu/g, respectively; and that the numbers of coliforms recovered from the two types of carcass ranged from $10$ to $10^4$ or $10^2$ to $10^5$, respectively (Decastelli, Giaccone, & Mignone, 1995). For carcases of feral pigs skinned at an abattoir, the ranges of total and coliform counts were $10^1$–$10^2$ and $0$–$10^4$ cfu/g, respectively (Bensink, Ekaputra, & Taliotis, 1991). These numbers are substantially higher than the numbers of those organisms generally found on the carcases of domestic pigs processed at large pork packing plants (Gill et al., 2000).

However, for meat from Japanese wild boar on retail sale, it was found that the numbers of aerobes and coliforms recovered from the product ranged from $10^4$ to $10^5$ and $10$ to $10^4$ cfu/g, respectively, and that these numbers were substantially less than the numbers of those groups of organisms recovered from pork from domestic animals (Naya, Horiuchi, Ishiguro, & Shinagawa, 2003). The latter result may have been due to the meat from the domestic animals having been stored in vacuum pack for extended periods, while the same meat was presented for sale soon after the animals were killed. Whether or not that was the case, the findings of the two studies of carcases indicate that the microbiological conditions of wild boar and feral pig carcases may often be compromised by their being eviscerated and skinned under poorly controlled conditions, but evidently at the time of retail sale the condition of meat from those animals can be comparable with that of pork from domestic animals.

Few *Salmonella* were recovered from carcases of wild boar in Italy (Decastelli et al., 1995), and no *Salmonella* and only one *E. coli* O157 were recovered from faecal samples from wild boar carcases in Sweden (Wahlström et al., 2003). However, *Salmonella* were recovered from 34% of Australian feral pig carcases, with 13 serovars being identified (Bensink et al., 1991). *Salmonella* were recovered from a few samples of Japanese wild boar meat on retail sale in one study, but were not detected in a second study of the same product (Kanai et al., 1997; Naya et al., 2003). It therefore appears that while *Salmonella* may be infrequent on wild boar or feral pig meat from some sources, it may be prevalent on meat from animals in some regions.

Campylobacters have been recovered from the faeces of some wild boar carcases (De Boer, Wilde, & Hartog, 1983; Wahlström et al., 2003), but not from carcases or meat on retail sale (Decastelli et al., 1995; Kanai et al., 1997). *Y. enterocolitica* have been recovered from large fractions of samples of faeces from wild boar carcases or wild boar meat on retail sale, while *Listeria monocytogenes* have been recovered from a few samples of both types (Hayashidani et al., 2002; Kanai et al., 1997). Although the recovered *yersinias* included pathogenic strains, the *yersinias* were not pathogenic.

The available data suggest that while *Salmonella* may be frequent in some wild boar or feral pig populations, it and other enteric pathogens may be relatively uncommon in other populations. In those latter areas contamination of wild boar or feral pig meats with enteric pathogens may be infrequent despite poor carcass dressing practices.

Nematode parasites of the genus *Trichinella* localize in the muscle tissue of a wide range of omnivorous or carnivorous animals and birds (Pozio, 2001). They are also sometimes found in horse meat, which has been an important cause of human trichinellosis in Europe in recent years (Gill, 2005b). However, human trichinellosis has historically been acquired by the consumption of encysted *Trichinella spiralis* in undercooked pork (Campbell, 1988). In most developed countries pork from domestic animals is now extremely unlikely to be infected with *Trichinella*.

In contrast, infection of wild boar meat with *Trichinella* and/or outbreaks of trichinellosis associated with the consumption of wild boar meat have been reported from several countries in Europe, and North and South America (García, Mora, Torres, Jercic, & Mercado, 2005; Greenbloom et al., 1997; Riccardo, Cristina, Vittorio, & Lorenzo, 2002). In addition, farmed wild boar in Norway have been
found to be infected with *Trichinella* at an incidence far greater than that for domestic pigs (Sukura, Nüveaho, Veijalainen, & Oivanen, 2001). The high level of infection in farmed wild boar has been ascribed to their being reared in conditions that do not preclude contact with wild animals that harbour the parasite. The *Trichinella* species found in wild boar meat include not only *T. spiralis* but also *T. britovi* and *T. pseudospiralis*, both of which have been involved in outbreaks of human trichinellosis (Ranque et al., 2000; Schynts et al., 2006). As *Trichinella* are found in wild animal and bird populations throughout the world, infection of meat from wild boar and feral pig with *Trichinella* capable of causing disease in humans must be expected.

4. Ratite meats

The ratites are a family of flightless birds (Perrins & Middleton, 1985). Meats from the largest members of this group, ostrich (*Struthio camelus*), emu (*Dromaius novaehollandiae*), greater rhea (*Rhea Americana*) and lesser rhea (*Pterocnemia pennata*) are currently being marketed. Although some controlled or subsistence hunting of the wild birds still occurs, they are generally protected species. Meat from them is then largely obtained from farmed birds.

Ostriches are native to Africa and the Middle East, but are now extinct in the latter region. They have been farmed since the middle of the nineteenth century, first in South Africa and subsequently in other countries for the principle purpose, until recently, of producing feathers for the fashion industry and for industrial and household cleaning equipments (Osterhoff, 1979; Shanawany, 1996). Collapse of the market for feathers in 1914 resulted in ostrich farming disappearing from most countries except South Africa. However, ostrich farming has revived since the 1980’s, with skins now being the most important product but with an increasing market for ostrich meat (Anonymous, 2000; Deeming, 1994; Sales & Horbanczuk, 1998).

Farmed ostriches have been bred for commercially desirable qualities, and are somewhat smaller, with shorter legs, and are more docile than the wild birds (Anonymous, 2006). In countries where the ostrich industry is well developed, most birds are slaughtered at specialized plants with runways and pens designed to avoid panicking and bruising of birds (Cooper, 1999). At such plants the birds are electrically stunned, and are raised by the legs for sticking and bleeding. Feathers are plucked by hand, to avoid damage to the skin, and the carcass is skinned before evisceration (Paleari, Corsico, & Beretta, 1995). In countries where the ostrich industry is developing, the birds are usually shot in the head, in the field or at the abattoir, using a small bore rifle, shot gun or captive bolt. The carcasses of birds killed in the field might not be raised for sticking, and might be plucked before transport to an abattoir at which a number of species are slaughtered, but otherwise carcass dressing generally involves procedures similar to those used at specialized plants (Morris et al., 1995).

Carcasses dressed at small abattoirs are reported to carry total aerobes at mean numbers about 10³ cm⁻², and *Enterobacteriaceae* or coliforms at mean numbers ≤10 cm⁻² (Forte, Novello, Conversano, Tantillo, & Giraldo, 2003; Gill & Jones, 1999; Gill et al., 2000; Severini, Ranucci, Miraglia, & Branciari, 2003). The conditions of the carcasses appear to be similar when birds were killed in the field or at the abattoir, and when skinning was carried out with or without the injection of food grade nitrogen under the skin to loosen it (Sales & Oliver-Lyons, 1996). However, in a study of ostrich carcasses produced at a large specialized plant, the mean numbers of aerobes and *Enterobacteriaceae* on carcasses were found to be >10⁶ and >10⁵, respectively (Karama, 2001). In the absence of other published data there is no way of knowing if the relatively poor microbiological condition of carcasses at the one large plant is typical for such plants. If it is, it might be because relatively high speeds of processing at large plants, and concern to ensure that the valuable skin is not damaged could result in the prevention of contamination of the meat receiving less attention at large than at small plants.

Much ostrich meat is of pH >6.0 (Morris et al., 1995), so it could be expected to spoil relatively rapidly in vacuum packs; and in air or modified atmosphere packagings if the high pH is indicative of the meat being depleted of glucose (Gill & Gill, 2005). The commercial product also may often be relatively heavily contaminated, with bacteria at numbers >10⁶ cfu/cm² or g at the time of packaging. The storage lives of only a few days at chilled temperatures that have been reported for ostrich meat, from commercial sources and in various packagings would then be expected (Alonso-Calleja, Martínez-Fernández, Prieto, & Capita, 2004; Capita, Díaz-Rodríguez, Prieto, & Alonso-Calleja, 2006; Seydim, Acton, Hall, & Dawson, 2006). However, a storage life for ostrich meat at chilled temperatures of about 21 days was attained when the meat was frozen after vacuum packaging and subsequently held at 0°C (Otrebma, Dikeman, & Boyle, 1999). Apparently, freezing of vacuum packaged ostrich meat for storage before display at chilled temperatures is a usual practice at some packing plants.

The extent to which ostrich meat may be contaminated with enteric pathogens is uncertain. The mean number of generic *E. coli* on dressed carcasses at one abattoir were about 1/100 cm² while at another the mean number was about 10⁵/cm² (Gill et al., 2000; Karama, 2001). That suggests that faecal contamination of carcasses may be far more common at some than at other abattoirs. *Salmonella* were recovered from >20% of carcasses at one abattoir and detected, using a DNA probe, in >30% of wash waters from carcasses at a second abattoir, but no *Salmonella* were detected in samples of meat from carcasses at the second facility (Gopo & Banda, 1997; Karama, 2001). Samples from >100 carcasses from eight US abattoirs yielded only one *Salmonella*, and no *E. coli* O157:H7 (Ley, Morishita, Brisker, & Harr, 2001). These data suggest that contamina-
tion of ostrich meat with *Salmonella* or *E. coli* O157:H7 may be rare. However, *Salmonella* infections of farmed ostriches and other ratites may be increasing (Vanhooser & Welsh, 1995; Welsh, Vanhooser, Dye, & Nieman, 1997), so *Salmonella* contamination of ostrich meat may be more frequent than the available literature indicates.

There appears to be only one report of *Campylobacter* on ostrich meat, with the organisms being recovered from 10% of about 200 carcasses (Ley et al., 2001). Nonetheless, *Campylobacter jejuni* infections of ratites are known to occur (Post, Ayers, Gilmore, & Raleigh, 1992), while campylobacters of the same genotypes have been isolated from ostrich and human sources (Siemer et al., 2004; Siemer, Nielsen, & On, 2005). Contamination of ostrich meat with campylobacters may then be relatively frequent.

Emus are native to Australia and greater and lesser rheas to Argentina and Chile. The wild birds have in the past been killed in large numbers, to prevent their damage of crops rather than for food (Perrins & Middleton, 1985). All three species have been farmed since the 1980s, initially in their countries of origin, but increasingly elsewhere. The types of product obtained from the birds are the same as those obtained from ostriches and, in addition, emu oil is valued for perceived medicinal properties (Adams, Brittin, Maga, 1999; Gill et al., 2000). The pH of meat obtained from emus slaughtered after transport to an abattoir was found to be high, as with ostriches, but meat of ‘normal’ pH (5.5–5.8) was obtained when stress before slaughter of birds was avoided (Berge, Lepetit, Renerre, & Touraille, 1997). That suggests that meats from emus and, possibly, rheas would generally have relatively poor storage qualities similar to those reported for ostrich meat, but that meat of lower pH with better storage qualities may be obtainable from all those birds if pre-slaughter stress could be avoided (Sales & Horbanczuk, 1998).

*Salmonella* and *Campylobacter* diseases in emus and rheas have been reported (Post et al., 1992; Shah & Dholakia, 1987; Welsh et al., 1997), so some contamination of emu and rhea meats with those organisms could be expected.

5. Meats from crocodilians

In the mid-twentieth century, the numbers of wild crocodilians in Africa, the Americas and Australian were greatly reduced as a result of the animals being hunted for their skins. Consequently, in several countries, conservation policies that allowed for the rearing of crocodiles or alligators in captivity were adopted (Jenkins, 1987). Crocodile or alligator farming is now well established in Australia (*Crocodylus porosus* and *Crocodylus johnstoni*), Southern Africa (*Crocodylus niloticus*) and North America (*Alligator mississippiensis*, *Crocodylus acutus*), and it is being developed elsewhere (Anonymous, 2002). Crocodile or alligator meat for human consumption is largely obtained from farmed animals.

Farmed animals may be shot in the head while penned (Warwick, 1990). The carcasses may be moved to a chiller for bleeding (Hoffman, Fisher, & Sales, 2000). The carcass may be washed with an antimicrobial solution of chlorine, a chlorine release compound or bisulphite, and it is usually placed on a table for skinning (Madsen, Milne, & Chambers, 1992; Rickard, Thomas, Bradley, Forbes-Faulkner, & Mayer, 1995). The cloaca is usually plugged with paper, and the throat may also be plugged or the head may be enclosed in a plastic bag. The skin is incised along the back to allow for its removal without damage to the highly valued skin on the underside (Ashley & David, 1987). The carcass is usually not eviscerated, but muscles from the back and legs, and the tail are removed as meat for human consumption. The meat may be decontaminated by dipping in a solution of an organic acid or other antimicrobial, but such treatments are apparently relatively ineffective as the reductions in numbers of aerobes that have been reported are less than an order of magnitude (Madsen et al., 1992; Rickard et al., 1995).

Reports on the numbers of aerobes present on the skins of and meat from carcasses of crocodiles or alligators seem somewhat contradictory. However, when allowance is made for the inefficient recovery of bacteria in some studies, by impression of an agar sausage on the tissues or swabbing them with cotton wool, it appears that the numbers of aerobes on skin and meat of carcasses from farmed animals are likely to be about 10⁶ and 10⁵ cfu/cm², respectively (Madsen et al., 1992; Rickard et al., 1995; Madsen, 1996). After freezing, the microbiological condition of the meat may be little different (Madsen, 1993). If wild animals are killed or captured and the carcasses are dressed as are those of farmed animals, at a suitable facility, the numbers of bacteria on skins and meat might be less (Oblinger, Kennedy, McDonald, & West, 1981) as the natural waters may not be as polluted as the ponds of crocodile or alligator farms (Madsen, 1994).

The pH of crocodile meat when it is removed from carcasses is likely to be >6.0, but the ultimate pH that the meat might attain is uncertain because rigor apparently develops only slowly (Hoffman et al., 2000). The storage quality of chilled crocodile meat has apparently not been studied, probably because most of the meat is frozen for storage and distribution (Mitchell, Reed, & Houlihan, 1995).

About 10% of the bacteria present on meat from farmed crocodiles may be *Enterobactiaceae* or coliforms. *Salmonella* have been frequently recovered from meat from farmed crocodiles (Manolis, Webb, Pincher, Mel-
ville, & Hollis, 1991; Rickard et al., 1995; Madsen, 1996), but were not recovered from meat from wild alligators (Oblinger et al., 1981). Aeromonas hydrophila was found to be prevalent in meat from farmed crocodiles (Madsen, 1996). In addition, Trichinella of unidentified species have been found in muscle tissue of farmed crocodiles (C. niloticus) in Zimbabwe (Mukaratirwa & Foggin, 1999), although attempts elsewhere to experimentally infect crocodiles (Caiman sclerops) with various Trichinella species were unsuccessful (Kapel, Webster, Bjorn, Murrell, & Nansen, 1998). It therefore, appears that contamination were unsuccessful (Kapel, Webster, Bjorn, Murrell, & Nansen, 1998). It therefore, appears that contamination of crocodile and alligator meat with Salmonella, and probably other enteric pathogens must be expected, but whether or not the meat can be infected with Trichinella must be uncertain until the matter has been further investigated.

6. Bison meat

North American bison (Bison bison), which were almost exterminated during the nineteenth century, are now being increasingly farmed for meat (Hudson, 2006). The mean numbers of aerobes on bison carcasses have been reported to be about $10^2$ cfu/cm$^2$ (Gill et al., 2000; Janz & Aalhus, 2006). Muscles of bison carcasses attained pH values of <5.7 (Janz, Aalhus, & Price, 2001), and bison steaks vacuum packaged or displayed in oxygen permeable packaging had storage lives comparable with those of beef steaks prepared under good hygienic conditions (Janz & Aalhus, 2006). The storage life of ground bison meat at chillier temperatures was comparable with that of ground beef of similar initial microbiological condition (Li & Logue, 2005).

In a study of the general microbiological conditions of carcasses of several species after dressing at a small abattoir, it was found that the numbers of aerobes recovered from bison carcasses were an order of magnitude greater than the numbers recovered from cattle or deer carcasses, but that the numbers of E. coli recovered from bison and deer carcasses were an order of magnitude less than the $>10^5$ cfu/cm$^2$ recovered from beef carcasses (Gill et al., 2000). In a study of enteric pathogens on bison carcasses, the incidence of generic E. coli in samples from dressed carcasses was about 50% (Li, Sherwood, & Logue, 2004), which was similar to the incidence found in the study of Gill et al. (2000). The incidences of Salmonella and Listeria on carcasses were about 3% and 4%, respectively. However, Listeria were prevalent on the hides of carcasses and were detected throughout the year of sampling, whereas Salmonella were not recovered from hides and were detected during one month only. E. coli O157:H7 were detected on the hides of 3% of animals, but not on carcasses, and were detected during several months of the year. These findings suggest that the Salmonella found on carcasses may have originated from an in-plant source rather than from the hides or gastro-intestinal tracts of the slaughtered animals.

7. Kangaroo meat

Several species of kangaroo, including the red (Macropus rufus), eastern grey (Macropus giganteus) and western grey (Macropus fuliginosus) kangaroos, and the euro (Macropus robustus) are hunted commercially in Australia, mostly for both skins and meat. Carcasses from which meat is obtained are eviscerated in the field, then the carcasses are collected in refrigerated containers for transport to processing facilities (Bensink et al., 1991). Currently only about 30% of meat obtained commercially from kangaroos is for human consumption; most is used as pet food (Kelly, 2005). Published data on the microbiological condition of kangaroo meat indicate that the numbers of aerobes and coliforms on the meat may be relatively high, with their mean numbers being about $10^5$ and $>10^5$ cfu/g, respectively (Bensink et al., 1991). Salmonella are carried by kangaroos (Speare & Thomas, 1988) and may be relatively frequent on carcasses (Bensink et al., 1991). However, the kangaroo meat industry has developed during the past few years, so the microbiological condition of kangaroo meat destined for human consumption may now be rather better than that indicated by the few published data obtained about 1990.

8. Concluding remarks

The information available on the microbiological conditions of meats from game animals is limited. More such information is evidently desirable, particularly for meats from farmed animals, as farmed game animal meat industries in many countries seem to be expanding. Nonetheless, it is apparent that, for most species, the general microbiological condition, and thus the chilled temperature storage qualities of meat from farmed animals are likely to be better than those for meat from wild animals. When farmed animals are raised under non-intensive conditions, as most must be, it appears that meat from them as well as that from wild animals is likely to be less contaminated with enteric pathogens than is meat from domestic animals, at least when the carcasses of the latter animals are not subjected to effective decontaminating treatments. The non-intensive rearing of farmed game animals may, however, result in some being infected with Trichinella, and possibly with other parasites that might be transmitted to humans. Further investigation of the risks from parasites as well as from pathogenic bacteria associated with game meats seems to be required.

References


