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MiniReview

Meat: An overview of its composition, biochemical changes and associated microbial agents

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Abstract: Meat has long been known for its nutritive composition which could explain why it is being consumed by many people worldwide. The protein profile of meat consists of amino acids that have been described as excellent due to the presence of all essential ones required by the body. It has also been proved that protein and vitamins (especially A and B12) in meat could not be substituted for by plant sources, further justifying the nutritive importance of the former. Various biochemical changes and microorganisms are associated with meat, during the process of slaughter, processing and preservation. This review explained the general compositional constituents of meat and the different types of microbial agents that could be found, both as a result of contamination or natural flora, during processing. The pathogenic nature and spoilage potential of some of these microorganisms are also included. The nutritional advantages inherent in the consumption meat are also stressed. The current review could prove very useful as good insight in many countries, especially in developing ones, where increased level of hygiene and good manufacturing practices are being required during meat processing.

Keywords: Nutritive composition, protein profile, biochemical changes, hygiene, good manufacturing practices

Introduction

In many developing countries, especially Nigeria meat is widely consumed a source of protein; it is either eaten cooked or processed into other forms to avoid associated spoilage (Olaoye *et al*., 2010; Olaoye and Onilude, 2010). Meat is defined as 'the edible part of the skeletal muscle of an animal that was healthy at the time of slaughter (CFDAR, 1990). Chemically meat is composed of four major components including water, protein, lipid, carbohydrate and many other minor components such as vitamins, enzymes, pigments and flavour compounds (Lamber *et al*., 1991). The relative proportions of all these constituents give meat its particular structure, texture, flavour, colour and nutritive value. However, because of its unique biological and chemical nature, meat undergoes progressive deterioration from the time of slaughter until consumption (Lamber *et al*., 1991).

Meat is a nutritious, protein-rich food which is highly perishable and has a short shelf-life unless preservation methods are used. Shelf life and maintenance of the meat quality are influenced by a number of interrelated factors including holding temperature, which can result in detrimental changes in the quality attributes of meat (Olaoye and Onilude, 2010). Currently, little attention has been given to the awareness of meat and its consumption among many consumers of the product in many developing countries, such as Nigeria. In this review, the general composition, biochemical changes and associated microbial agents of meat are discussed. This would let the consumers to be aware (or rather remind them) of the nutritional advantages derivable from meat and possible microbial agents that could be associated.

Meat: composition and nutritive value

Broadly, the composition of meat, after *rigor mortis* but before post-mortem degradative changes, can be approximated to 75% water, 19% protein, 3.5% soluble, non-protein, substances and 2.5% fat (Table 1). The proteins in muscle can be broadly divided into those which are soluble in water or dilute salt solutions (the sarcoplasmic proteins), those which are soluble in concentrated salt solutions (the myofibrillar proteins) and those which are insoluble in the latter, at least at low temperature - the proteins of connective tissue and other formed structures (Lawrie and Ledward, 2006). The sarcoplasmic proteins are a mixture of several hundred molecular species. Several of the sarcoplasmic proteins are enzymes of the glycolytic pathway and may be present in more than one form (isozymes). Proteins of beef consist of essential amino acids such as leucine, isoleucine, lysine, methionine, cystine, phenylalanine, threonine, tryptophan, valine, arginine and histidine; of these the last two are considered essential for infants. Amino acids are important for maintenance and repair of body tissues in human (Lawrie and Ledward, 2006).

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Table 1. Chemical composition of typical adult mammalian muscle

Component	% weight
Water	75
Protein	19
Myofibrillar (11.5) - myosin, actin, connectin (titin), N2 line protein (nebulin), tropomyosins, troponins, actinins (α, β and γ), myomesin, desmin, filamin, vinculin, talin, etc.	
Sarcoplasmic (5.5) - glyceraldehyde phosphate dehydrogenase, aldolase, creatine kinase, glycolytic enzymes (such as phosphorylase), myoglobin, haemoglobin etc	
Connective tissue and organelle (2.0) - collagen, elastin, mitoehondrial, cytochrome c and insoluble enzymes	
Lipid - neutral lipid, phospholipids, fatty acids, fat-soluble substances	2.5
Carbohydrate - lactic acid, glucose-6-phosphate, glycogen, glucose, - traces of other glycolytic intermediates	1.2
Miscellaneous Soluble Non-Protein Substances	2.3
Nitrogenous (1.65) - creatinine, inosine monophosphate, di- and tri-phosphopyridine nucleotides, amino acids, carnosine, anserine	
Inorganic (0.65) - total soluble phosphorus, potassium, sodium, magnesium, calcium, zinc, trace metals	
Vitamins - various fat- and water-soluble vitamins	qm

qm, quantitatively minute
Source: Sawyer (1975), Greaser *et al*. (1981)

Meat is a very good source of various micronutrients: low-fat pork contains 1.8 mg iron, 2.6 mg zinc; and pigs' liver contains 360 mg magnesium, 20 mg iron and 60 µg selenium per 100 g. A daily intake of 100 g of meat and liver can supply up to 50% of the recommended daily allowance for iron, zinc, selenium, vitamins B1, B2, B6, B12 and 100% of vitamin A (Biesalski and Nohr, 2009). The importance of meat as an essential source of some micronutrients is due to the fact that it is either their only source, or they have a higher bioavailability. Vitamins A and B12 occur exclusively in meat and can hardly be compensated for by plant-derived provitamins (Biesalski, 2005). Iron has a higher bioavailability from meat than from plants (heme iron), as has folic acid which is nearly 10-fold more, especially from liver or eggs, compared to vegetables (Biesalski, 2005).

The vitamin contents of some raw meats are shown in Table 2. Vitamin A, one of the micronutrients in meat, is essential for the growth and development of various cells and tissues. Its active form, retinoic acid (RA), controls the regular differentiation as a ligand for retinoic acid receptors and is involved in the integration of cell formation, i.e. the formation of gap junctions (Kurokawa *et al*., 1994). The incidence of lung diseases is enhanced by moderate vitamin A deficiency and repeated respiratory infections can be treated therapeutically with moderate vitamin A supplementation (Biesalski, 2005). Vitamin A is also responsible for lung development and maturation and for the development of other tissues, and control of these processes seems to be dependent on the expression of RA receptors. Although liver is the best available source of vitamin A, it has a 'bad reputation' due to other potential constituents of this organ, such as heavy metals, hormones or xenobiotics (Biesalski, 2005). In order to obtain the recommended 1 mg retinol per day from vegetables, 500 mg of mixed and β-carotene rich vegetables have to be eaten daily, while 100 g of liver twice a month is sufficient and is neither toxic nor teratogenic (Biesalski, 2005; Nohr and Biesalski, 2007). Vitamin B12 (cobalamin) can be taken up only from animal products; it does not exist in plants. Thus, for example, in the UK about 25% of vegetarians and 50% of vegans had suboptimal intakes and, in consequence, low to very low serum levels – about 25% below the threshold level (130 ng/L) for developing neurological signs (Lloyd-Wright *et al*., 2000). In addition, elderly people are particularly at risk of vitamin B12 deficiency, mainly due to suboptimal intestinal absorption (Biesalski and Nohr, 2009).

Table 2. Vitamin content of various raw meats

Vitamin (units/ 100 g)	Beef	Veal	Pork	Bacon	Mutton
A (I.U)	trace	trace	trace	trace	trace
B1(thiamine, mg)	0.07	0.10	1.0	0.40	0.15
B2(riboflavin, mg)	0.20	0.25	0.20	0.15	0.25
Nicotinic acid (mg)	5	7	5	1.5	5
Pantothenic acid (mg)	0.4	0.6	0.6	0.3	0.5
Biotin (µg)	3	5	4	7	3
Folic acid (µg)	10	5	3	0	3
B6 (mg)	0.3	0.3	0.5	0.3	0.4
B12 (µg)	2	0	2	0	2
C (ascorbic acid, mg)	0	0	0	0	0
D (I.U.)	trace	trace	trace	trace	trace

Source: Lawrie and Ledward (2006)

There are several groups of people that could be at risk of deficiencies of one or more micronutrients: elderly people for vitamins A, D, E, folate, iron and calcium, mostly because of diseases and an age-adapted lifestyle, less because of physiological problems (with the exception of iron and vitamin B12 uptake due to gastric mucosal atrophy) (Biesalski and Nohr, 2009). In pregnant women, risk of deficiency of vitamin D, folic acid, zinc and iron is due to enhanced demands, especially when meat is avoided in the diet (Fogelholm, 1999; Saletti *et al*., 2000). Supplementation is recommended, especially for folic acid, in order to avoid serious birth defects. Vitamin A deficiency also seems to be a risk, as shown by Schulz *et al*. (2007) for women with twins or births at short intervals. Vegans are at risk of deficiency of micronutrients which are found exclusively in animal-derived food, e.g. vitamin B12, riboflavin and selenium, and even supplementation with B12 and selenium is sometimes not sufficient (Boelsma *et al*., 2001). People dieting to lose weight could obviously be at risk of micronutrient deficiencies (Biesalski and Nohr, 2009). However, the levels of iron, magnesium, zinc, fat-soluble vitamins and essential fatty acids should be controlled during the diet. A meta-analysis has shown that protein-rich diets that were low in carbohydrates but with a moderate-to-high fat content resulted in a better weight loss than diets low in protein and fat, but high in carbohydrates (Bravata *et al*., 2003). Better satiety, higher energy expenditure and greater loss of fat cell mass were supposedly responsible for the weight loss.

Biochemical changes in meat during post mortem

In the living animal, aerobic metabolism is used to obtain energy. After slaughter, aerobic metabolism begins to fail due to the stored oxygen supply being depleted. After exsanguination, cessation of blood circulation shifts muscle metabolism from aerobic to anaerobic. It was reported that when muscle contracts in an anaerobic environment, glycogen disappears and lactic acid becomes the principal end product of glycolysis; whereas under aerobic conditions, lactic acid does not accumulate as it is oxidized to CO_2 and water (Mayes, 1993). One molecule of glucose will generate 3 moles of ATP via anaerobic glycolysis providing the high-energy phosphates necessary for post mortem (anaerobic) muscle contraction. Creatine phosphate is rapidly depleted as a result of postmortem metabolism, yet ATP may be maintained for several hours from anaerobic glycolysis. Accumulation of lactic acid in postmortem muscle reduces the localized pH and muscle is converted to meat. Conversion of glycogen to lactic acid will continue to lower muscle pH until the glycogen (or ATP stores) are depleted or until the contractile proteins cease to function as a result of low intramuscular pH (Koohmaraie, 1992).

The sequence of chemical steps by which glycogen is converted to lactic acid is essentially the same post-mortem as *in vivo* when the oxygen supply may become temporarily inadequate for the provision of energy in the muscle; but it proceeds further. Except when inanition or exercise immediately pre-slaughter has appreciably diminished the reserves of glycogen in muscle, the conversion of glycogen to lactic acid will continue until a pH is reached when the enzymes effecting the breakdown become inactivated (Lawrie and Ledward, 2006). In typical mammalian muscles this pH is about 5.4–5.5. An initial level of 600 mg glycogen/100 g muscle is required to attain this pH. Muscles which have an ultimate pH of 5.4–5.5 after post mortem glycolysis may still contain some residual glycogen, even though it is generally considered that there will be no residual glycogen if the pH fails to fall to 5.4–5.5 during post-mortem glycolysis (Immonen *et al*., 2000; Lawrie and Ledward, 2006). The final pH attained, whether through lack of glycogen, inactivation of the glycolytic enzymes or because the glycogen is insensitive (or inaccessible) to attack, is referred to as the ultimate pH; this is generally about 5.5, which is the iso-electric point of many muscle proteins (Immonen *et al*., 2000). Both the rate and the extent of the post-mortem pH fall are influenced by intrinsic factors such as species, the type of muscle and variability between animals; and by extrinsic factors such as the administration of drugs preslaughter and the environmental temperature; exercise preslaughter is also a known factor which produces dry firm dark (DFD) meat which has a pH of around 7.0 (Shimada *et al*., 2004).

Association of undesirable microorganisms with meats

Microbial contamination and disease outbreaks associated with meat

Muscles of healthy animals are regarded as sterile, but the slaughtering and butchering process of animals provides bacteria with an opportunity to colonize meat surfaces. Contamination of meat is a continuing possibility from the moment of bleeding until consumption. In the abattoir itself there are many potential sources of contamination of meat by micro-organisms (Table 3). These include the animal hide and hair, soil adhering thereto, the contents of the gastrointestinal tract (if inadvertently released during dressing operations), airborne contamination, aqueous sources (the water used for washing the carcass, or for cleaning the floors and equipment), the instruments used in dressing (knives, saws, cleavers and hooks), various vessels and receptacles, and the personnel (Holzapfel, 1998). Aerosols produced during dehiding, evisceration, and carcass splitting are also important sources of contamination (Mead, 2004). Air circulated from heavily contaminated refrigeration coils in meat and poultry processing plants is also a major source (Stanbridge and Davies, 1998). The initial microbial load of a carcass surface is determined by the hygiene of the abattoir as well as handling practices (Guerrero *et al*., 1995).

Many foodborne diseases are associated with consumption of meat. Some of the meat carcasses on sale might be contaminated with one pathogen

Table 3. Typical microbial counts from sources of microbial contamination in an abattoir, at incubation temperature of 20°C

Sources	Bacteria	Yeasts	Moulds
Hides (cfu/g)	3.3×10^6	580	850
Surface soils (cfu/g)	1.1×10^5	5×10^4	1.2×10^5
Gastrointestinal contents: Faeces (cfu/g)	9.0×10^7	2.0×10^5	6.0×10^4
Gastrointestinal contents: Rumen (cfu/g)	5.3×10^7	1.8×10^5	1600
Airborne contamination (no. deposited from air / cm^2/hr) - cfu	140	-	2
Water used on slaughter floors (cfu/ml)	1.6×10^5	30	480
Water present in receptacles from immersion cloths (cfu/ml)	-	1.4×10^5	-

Source: Lawrie and Ledward (2006)

or another (Mor-Mur and Yuste, 2010) and this could be very common in developing countries. The pathogens of concern in fresh and frozen meat and meat products include *Salmonella* spp., *Escherichia coli* O157:H7 and other enterohaemorrhagic *E. coli* (EHEC), *Listeria monocytogenes*, *Staphylococcus aureus*, *Yersinia enterocolitica*, *Campylobacter* spp., *Clostridium perfringens* and the potential for *Cl. botulinum* in cured hams and sausages (Mor-Mur and Yuste, 2010). The most frequent outbreaks associated with consumption of contaminated meat are caused by *Salmonella* spp., *L. monocytogenes*, and *Y. enterocolitica* (Sofos, 2008; Pesavento *et al*., 2010). Some diseases could be associated with consumption of meat depending on the processing techniques and level of hygiene practices adopted. Shown in Table 4 is a compilation of a brief description of infections caused by bacteria and the reported associated meat sources.

A model showing potential risk of infections in the food chain and meat safety is given in Figure 1. This model suggests that farmers, producers, and consumers have useful roles to play in preventing or reducing contamination of meat and meat products. Fatal outbreaks of foodborne disease caused by *E. coli* O157:H7 and *L. monocytogenes* have increased consumer awareness and aroused interest by public health authorities and the industry in improving sanitary conditions and controlling pathogens in meat production and processing. Strict farming, manufacturing, and hygienic practices, consistent with an effective hazard analysis critical control point system, are the basis for controlling pathogen contamination (Sofos, 2008). Measures concerning the production of microbiologically safe meat and derived products are divided into those guided by the rigid legislative approach and those that follow a more scientific approach based on risk analysis. Management of meat safety risks involves all sectors: from the producer through the processor, distributor, packer, retailer, food service worker, and consumer (Snijders and Collins, 2004; Sofos, 2008).

There is a relationship between the occurrence of *E. coli* O157:H7 or *Salmonella* spp. or both in cattle faeces and the occurrence of these pathogens on derived carcasses (McEvoy *et al*., 2004). Pathogens present in faeces are frequently transferred to the hide, which is a major source of carcass contamination during dressing. That transfer can be through cross-contamination during transport and lairage. Bovine buccal cavity is also a source for *E. coli* O157:H7 (Keen and Elder, 2002). Thus, the pathogen may be present at the beginning of the slaughter process, and persist on meat cuts during fabrication. With the exception of clostridia and aerobic bacilli, foodborne pathogenic bacteria are heat sensitive and should be killed by proper cooking, especially when present as surface contaminants (Sofos, 2008; Mor-Mur and Yuste, 2010).

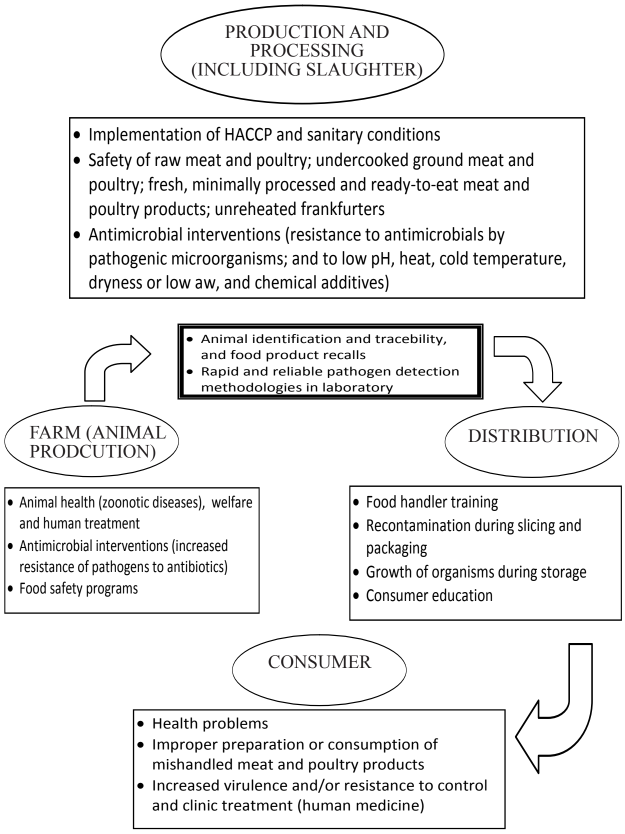

Figure 1. A Model for meat safety (Source: Mor-Mur and Yuste, 2010)

Descriptive features of some pathogens associated with meats

a) *Campylobacter* spp.

In contrast to the relatively low occurrence of

Table 4. Description and sources of meat causing infection by bacteria

Bacteria	Symptoms / diseases	Sources of infection
Campylobacter jejuni (O:19, O:4, O:1), other *Campylobacter* spp.	Reactive arthritis, pancreatitis, meningitis endocarditis, Guillain–Barré and Miller Fisher syndromes	Raw and undercooked poultry and poultry products, meat products
Salmonella Typhimurium (DT104, DTU302), *Salmonella* Enteritidis (PT4, PT8, PT13, PT14b)	Gastroenteritis	Poultry, roast beef, ham, pork sausage, salami
Enterohemorrhagic *Escherichia coli* (*E. coli* O157:H7, other serotypes of Shiga toxin producing *E. coli*)	Haemorrhagic colitis, haemolytic uremic syndrome, thrombotic thrombocytopenic purpura	Undercooked ground beef, turkey roll, salami, roast beef, venison jerky
Listeria monocytogenes	Meningitis or meningoencephalitis, septicemia, abortion	Raw meats and meat products (salami), ready-to-eat pork products, unreheated frankfurters, undercooked chicken, organ meat
Arcobacter butzleri, other *Arcobacter* spp	Septicemia, bacteremia	Raw poultry, pork and beef, meat products
Aeromonas hydrophila, *Aeromonas* spp.	Peritonitis, endocarditis, pneumonia	Minced beef, pork, and chicken, smoked sausage, liver pâté, boiled ham
Enterobacter sakazakii	Bacteremia, necrotizing enterocolitis, appendicitis	Minced beef, cured meats, sausage meat

Source: Mor-Mur and Yuste (2010)

outbreaks of campylobacteriosis, *Campylobacter* spp. is currently considered the leading cause of sporadic bacterial gastroenteritis, with *C. jejuni* being the most frequently implicated in clinical diagnosis (Mor-Mur and Yuste, 2010). In Canada and the UK, among many other countries, the number of reported cases of campylobacteriosis exceeds the combined number of salmonellosis and shigellosis cases. Between 1979 and 1987, *C. jejuni* was implicated in 53 foodborne outbreaks in the USA, affecting 1,547 individuals and resulting in two deaths (Mor-Mur and Yuste, 2010). Campylobacteriosis usually occurs during the summer months and involves diarrhoea, fever, and abdominal cramping as well as other complications (Ray and Bhunia, 2008), some of which are shown in Table 4. *C. jejuni* O:19 and other serotypes (O:4, O:1) are some of the most common etiological agents of Guillain–Barré syndrome and its variant Miller Fisher syndrome. The infective dose of *C. jejuni* could be 500 organisms or lower, depending on the host susceptibility (Stern and Kazmi, 1989; Godschalk *et al*., 2006).

Raw and undercooked poultry are the primary sources of a *Campylobacter* infection. A considerable proportion of broilers (88%) and poultry at retail (98%) has been found contaminated with the pathogen. Epidemiological studies show that ca. 50% of sporadic cases of campylobacteriosis are associated with handling or eating poultry. Meat products can also contribute to illness (Inglis *et al*., 2004). These authors reported the chronic shedding of *Campylobacter* spp. in cattle and that a high percentage (83%) of cattle was contaminated with *Campylobacter* spp; the most prevalent taxa detected were *C. lanienae* (49%) and *C. jejuni* (38%). *Campylobacter* spp. are obligate microaerophiles and the species most commonly associated with diarrhoeal disease grow optimally at 42°C and 37°C, but not at 25°C (Health Protection Agency, 2007). Because of difficulties in culturing the organism, in the past, *Campylobacter* cases were reported as caused by unknown agents or erroneously by other organisms, especially *Salmonella* spp. *Campylobacter* spp. do not survive well in food, and are relatively fragile and readily killed by heat treatments (Meng and Doyle, 1998). *Campylobacter jejuni* has the ability to survive refrigeration and freezing, which is of obvious relevance to food safety and public health (Mor-Mur and Yuste, 2010).

Strategies for rapid and accurate detection of animals contaminated with high numbers of *Campylobacter* cells are necessary, and removal of those animals may prevent contamination of equipment and carcasses within the abattoir. *Campylobacter lanienae* may be an enteric pathogen to cattle, and that novel species of *Campylobacter* may be chronically shed in large numbers in faeces. The fact that *C. lanienae* is not typically detected in diagnostic facilities along with its prevalence in cattle faeces raises questions regarding its potential impact on human health (Inglis *et al*., 2004).

b) *Salmonella* spp.

Salmonella is an enteric pathogen associated with animal and slaughter hygiene. In the EU, eggs and egg products are the most frequently implicated sources of human salmonellosis (Mor-Mur and Yuste, 2010). Meat is also an important source, with poultry and pork implicated more often than beef and lamb (EFSA, 2008). The two most common *Salmonella* serotypes are Typhimurium and Enteritidis. In human salmonellosis, *S.* Typhimurium is the most frequent serotype. Human salmonellosis infections can lead to uncomplicated enterocolitis and enteric fever, the latter being a serious disease that may involve diarrhoea, fever, abdominal pain, and headache. *Salmonella* spp. can also cause systemic infections, resulting in chronic reactive arthritis (Meng and Doyle, 1998; Echeita *et al*., 1999; D'Aoust and Maurer, 2007).

From 1984 to 2005, there were 17 major outbreaks of human salmonellosis (*S.* Typhimurium and *S.* Enteritidis being involved in at least seven of those outbreaks) from meat, poultry, and derived products, mostly in North America and Europe (Mor-Mur and Yuste, 2010). The sources were raw and minced pork; cooked chicken and turkey; raw, ground, and roast beef; liver pâté, deli meats, kebab, and so on. Six outbreaks had ca. 100 to 400 confirmed cases, four outbreaks with ca. 600 to 850 cases, and one outbreak with >2,100 cases in Spain in 2005 (D'Aoust and Maurer, 2007). The considerable increase in human foodborne salmonellosis in the 1980s was caused predominantly by *S.* Enteritidis PT4 in Europe and PT8 and PT13 in the USA and Canada (Mor-Mur and Yuste, 2010). Infections by atypical *Salmonella* spp. have been described (e.g. several outbreaks of *S.* Enteritidis anaerogenic PT14b, an uncommon phage type) to be associated with consumption of contaminated chicken (Guerin *et al*., 2006).

Unlike *S.* Enteritidis, *S.* Typhimurium DT104 is widely distributed in the food-producing animal populations, especially in cattle (Mor-Mur and Yuste, 2010). The pathogen spreads rapidly among animals, of the same or different species, and to humans. DT104 has been isolated from a wide range of meat and poultry products: roast beef, ham, pork sausage, salami, and chicken. An increase in the prevalence of *S.* Typhimurium DT104 has been reported worldwide (Mor-Mur and Yuste, 2010). Tollefson *et al*. (1998) stated that, while less than 1% of all cases of salmonellosis can be attributed to *S.* Typhimurium DT104, most multiple antibiotic-resistant *Salmonella* isolates are DT104 or a closely related type; however, the number of cases of infection with DT104 is continuously growing. The combination of multi-resistance towards antibiotics and the ability to spread rapidly makes DT104 an important public health problem (Rugbjerg *et al*., 2004).

c) Enterohaemorrhagic *Escherichia coli*

Enterohaemorrhagic *E. coli* (EHEC), i.e., *E. coli* O157:H7 and other serotypes of Shiga toxin-producing *E. coli*, are foodborne pathogens of primary concern (Mor-Mur and Yuste, 2010). They are etiological agents of haemorrhagic colitis. In some cases, complications may occur, such as haemolytic uremic syndrome and thrombotic thrombocytopenic purpura. EHEC other than *E. coli* O157:H7 have been increasingly associated with such complications. The severity of the illness and the low infective dose (<100 organisms) make *E. coli* O157:H7 among the most serious foodborne pathogens (Acheson, 2003; Meng *et al*., 2007). *E. coli* O157:H7 is an enteric organism associated with animal and slaughter hygiene. It may be present in the faeces and intestines of healthy bovines (McEvoy *et al*., 2004). Swine and poultry are also possible reservoirs of *E. coli* O157:H7 because the organism can colonize the caeca. The pathogen has also been isolated from other domestic and wildlife animals - sheep, goats, deer, dogs, horses, and cats (Meng *et al*., 2007). Therefore, meat can be contaminated during the slaughter operation and processing (Juneja and Marmer, 1999). Most people infected with *E. coli* O157:H7 pick up the organism from cattle, which are a major reservoir, either through direct contact with faeces or by consuming meat or milk (Anon, 2004).

The organism is not a rare contaminant in meats. Many outbreaks of EHEC have been associated with consumption of undercooked contaminated ground beef (Mor-Mur and Yuste, 2010). For example, from 1982 to 2006, there were ca. 15 representative outbreaks of EHEC from meat and meat products worldwide; most of those outbreaks were in the USA (among them, one multi-state outbreak with >700 cases, including four deaths), one outbreak was in Australia (>200 cases), one in Japan (>100 cases), and one in the UK (>500 cases, 21 deaths) (Mor-Mur and Yuste, 2010). The sources were undercooked hamburgers, ground beef patty, roast beef, venison jerky, luncheon and meatballs, salami, semidry sausage, and so on. Turkey roll has also been involved in *E. coli* O157:H7 diseases (Meng and Doyle, 1998; Juneja and Marmer, 1999; Meng *et al*., 2007).

E. coli O157:H7 does not grow at ≥44.5°C and has a minimum pH for growth from 4.0 to 4.5 (Meng *et al*., 2007). It survives better than *Salmonella* spp. and *L. monocytogenes* in acidic foods (Samelis *et al*., 2001). *E. coli* O157:H7 can survive fermentation, drying, and chill storage in most fermented sausages (Mor-Mur and Yuste, 2010). Acid-tolerant-induced cells also can have increased tolerance to other environmental stresses such as heating and antimicrobials and the organism has shown increasing resistance to antibiotics, especially streptomycin, sulfisoxazole, and tetracyclines (Meng *et al*., 2007). The organism's resistance to heat is not unusual and heating ground beef sufficiently to kill *Salmonella* spp. will also kill *E. coli* O157:H7. Fat has been found to be protective against heat inactivation (Meng *et al*., 2007).

d) *Listeria monocytogenes*

L. monocytogenes is an environmentally transmitted pathogen. It is a psychrotroph and ubiquitous, and grows well in poor substrates, which enables contamination during many phases of the food chain. The incidence of listeriosis is relatively low, but it is of major public health concern because of the severity and non-enteric nature of the disease, which reveals as meningitis or meningoencephalitis, septicemia, and abortion, mainly in populations such as young children, the elderly, pregnant women, and other immunocompromised persons (Mor-Mur and Yuste, 2010). It is also a major public health concern because of the ability of the pathogen to grow at refrigeration temperatures. The infective dose depends on the immunological status of the human host and characteristics of the organism such as its virulence factors. The dose is usually high, but in some cases it may be as low as several hundred or even less (Acheson, 2003; Swaminathan *et al*., 2007).

Cooked, ready-to-eat meat and poultry products have been the source of sporadic and outbreak-associated cases of listeriosis in North America and Europe. Contaminated frankfurters and turkey deli meat caused multi-state outbreaks of listeriosis in the USA in 1998, 2000, and 2002 (Swaminathan *et al*., 2007). Thus, ready-to-eat meals, unreheated frankfurters, and undercooked chicken can be vehicles for the pathogen. It has been found that 16% of salamis are contaminated with the pathogen (Hutchins, 1996). The organism tends to concentrate in organs and therefore, eating undercooked organ meat may be more hazardous than eating undercooked muscle tissue (Meng and Doyle, 1998; Swaminathan *et al*., 2007).

L. monocytogenes is not significantly affected by vacuum packaging and certain modified atmospheres because it is a facultative anaerobe. There is very little or no *L. monocytogenes* multiplication at ca. pH 5.0 (Glass and Doyle, 1989). Ready-to-eat meat and poultry products that have received heat treatment followed by cooling in brine before packaging may provide a particularly favourable environment for *L. monocytogenes* because of the reduction of competitive microbiota and the high salt tolerance of the organism (Mor-Mur and Yuste, 2010). Therefore, ready-to-eat foods are of great risk and it is not practical to expect them to be *L. monocytogenes* free (Swaminathan *et al*., 2007). Also because of the organism's psychrothrophic nature, there could be contamination of chilled ready-cooked products at the refrigeration stage.

There is therefore the need for industries to report positive findings on this pathogen because of its public health significance. Food regulatory agencies in many countries have accepted the argument that it is impossible to produce *L. monocytogenes* free foods and have given tolerance levels for the pathogen (Mor-Mur and Yuste, 2010).

Concluding remarks

Many nutritional advantages are inherent in the consumption of meat. However, in meat, there are some associated undesirable changes and microbial agents which could constitute major disadvantages when necessary precautions are not observed during processing.

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