The application of food safety interventions in primary production of beef and lamb: A review

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Abstract

The production of safe red meat depends on effective control of pathogenic microorganisms at all stages of the "farm-to-fork" chain. Eight microorganisms have been selected as the focus of the PathogenCombat project: Shiga toxin producing *Escherichia coli* (STEC), *Mycobacterium avium* subspecies paratuberculosis (Map), *Listeria monocytogenes*, *Campylobacter jejuni*, *Penicillium nordicum*, invasive variants of Saccharomyces cerevisiae, hepatitis E virus and tick borne encephalitis virus. The need and potential for coordinated control of the selected food-borne pathogens by on-farm interventions is assessed using a decision tree and a review of the relevant scientific literature. Control measures to reduce the carriage of these pathogens in ruminants prior to slaughter are reviewed with reference to the current regulations and guidelines relating to the primary production. From the eight pathogens investigated, two (STEC and Map), are likely to be effectively controlled by interventions at farm level and the applicable interventions are described and discussed. Ruminants are the main reservoir for these two pathogens; hence a reduction of carriage in livestock should directly reduce human exposure through the consumption of beef and lamb.

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Keywords:
Food-borne pathogens
On-farm intervention
Decision support
STEC
Map

Contents

1. Introduction .............................................................. S 44
2. Regulators of food safety in primary production ............................................. S 44
2.1. Legislation ........................................................... S 45
2.2. The Codex Alimentarius ..................................................... S 45
2.3. Farm management guidelines .................................................. S 45
3. Carriage of microorganisms in ruminants ................................................ S 45
4. Critical aspects of primary production .................................................. S 46
4.1. Animal husbandry ........................................................ S 46
4.2. Cleanliness of animals ...................................................... S 46
4.3. Feeding ............................................................. S 47
4.4. Transport to slaughter ...................................................... S 47
5. Decision support for on-farm interventions ............................................... S 47
5.1. Outcomes from decision tree (Fig. 2) ............................................... S 48
5.1.1. Suitability of pathogens for control at farm level ..................................... S 48
5.1.2. Application of interventions .............................................. S 48
6. Potential interventions for specific pathogens ........................................... S 48
6 1. Shiga toxin producing *E. coli* (STEC) ............................................... S 48
6.1.1. Background ....................................................... S 48
6.1.2. Husbandry ...................................................... S 49
6.1.3. Cleanliness ...................................................... S 49
6.1.4. Feeding ........................................................ S 49
6.1.5. Transport ....................................................... S 49
6.1.6. Control ........................................................ S 50
6.2. *M. avium* subspecies paratuberculosis (Map) ............................................ S 50
6.2.1. Background ....................................................... S 50
6.2.2. Control ........................................................ S 50

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7. Conclusion ............................................................... S 50
Acknowledgements ........................................................ S 51
References ................................................................. S 51

1. Introduction

The most serious meat safety issues affecting consumer health and triggering product recalls involve microbial, and particularly bacterial, pathogens (Sofos, 2008). Control of these pathogens at all stages of the “farm-to-fork” chain is vital to minimise the occurrence of food-borne disease in the human population (Nørrung and Buncic, 2007). The source of most food-borne pathogens is farm animals that carry and shed these bacteria in the faeces. In many cases, farmed ruminants carrying zoonotic pathogens in the gastrointestinal tract show no signs of infection. Transfer of bacteria from the hide and gut contents to the carcass can occur during hide removal and evisceration in the abattoir (Huffman, 2002; McEvoy et al., 2000). The application of antimicrobial interventions at farm level to reduce the levels of bacteria present at slaughter and dressing should therefore, in turn, reduce the likelihood of contamination of the meat. Many other foodstuffs are treated during processing to remove or minimise the presence of pathogens (e.g. pasteurisation of milk), but direct interventions to decontaminate carcasses and fresh meat products are not widely used in Europe (Bolton et al., 2001; Sheridan and Warner Klinth, 2004). The absence of a critical control point in the production of fresh meat ensuring effective removal of microorganisms may permit pathogens carried by ruminants from the primary production phase to persist in retail meat. This is particularly true if the hygienic practices carried out at slaughter are not entirely effective. The prevention of food-borne disease in this situation would therefore rely heavily on safe food handling and preparation methods (Tomkin, 1994) which may not always be practiced in domestic food preparation (Ropkins and Beck, 2000). Therefore, control of food-borne pathogens at farm level is crucial in the production of fresh beef and lamb.

A “top-down” approach to producing animals that are free from specified pathogens is applied to intensive meat production systems such as pig and poultry production. This is based on sourcing young animals from pathogen-free breeding stock and preventing the introduction of the pathogen in the growing phase by good hygienic practices. This approach has been successfully applied to control Salmonella in poultry (Edel, 1994; Wegener, 2010) and shows promise for the control of Campylobacter in pigs (Weitjes et al., 2000). Although this approach is less applicable to cattle and sheep production where animals are farmed under less controlled conditions, it demonstrates the effectiveness of focussing control efforts for food-borne pathogens during primary production.

Various common practices in primary production, such as following withdrawal periods for drugs before slaughter, have been implemented for food safety reasons. Many zoonotic pathogens are carried asymptptomatically by ruminants (Nørrung and Buncic, 2007); therefore producers do not observe adverse health effects in their animals and pathogen carriage is not diagnosed. Consequently, not all possible aspects of food safety in primary production are targeted by regulatory bodies or stakeholders. An obvious discipline to govern food safety at farm level is veterinary public health. Veterinary practitioners are concerned with animal health and welfare and its subsequent effects on food safety e.g. recording of microbial treatments and interventions where outbreaks of zoonotic diseases in livestock such as salmonellosis are observed. However, under common circumstances both farmer and consulting veterinary surgeon will be unaware of the asymptomatic carriage of food-borne pathogens and no actions will be taken. An in-depth understanding of specific pathogens and the development of new methods for detection and elimination of microbes is essential for effective control and therefore has to be addressed in a cooperative effort including food safety scientists, microbiologists and veterinary practitioners.

Sperber (2005) described historical quality control systems for food safety involving sampling and microbiological testing of the end product to identify the presence of unacceptable levels of pathogenic bacteria. This method has now been largely superseded by the Hazard Analysis and Critical Control Points (HACCP) system, which is based on the identification of hazards and the introduction of standardised control measures at defined points in the production process. The HACCP system is very efficient at controlling identified hazards in highly regulated food processing environments but it is less relevant at the on-farm stage of meat production due to the lack of clearly defined hazards and applicable control measures. Additionally, HACCP systems that are readily implemented in linear production processes are not well suited for processes such as on-farm production of ruminants. However, Horchner et al. (2006) used a HACCP-based approach to derive on-farm food safety control measures for red meat production in Australia, but instead of proposing defined CCPs, concluded that a simple set of good agricultural practices (GAP) are effective in controlling food safety hazards at farm level. In this article, we have reviewed on-farm interventions targeting specific pathogens and discussed targeted control measures which are effective from a microbiological perspective but are not necessarily widely implemented in primary production. The regulators of food safety in primary production are also reviewed to identify the organisations and regulations that can influence coordinated changes across the primary production sector.

For the purpose of this article we have focussed on the potential control of eight food-borne pathogens selected as the target organisms of PathogenCombat, an Integrated Project of the European Commission focusing on food quality and safety. These comprise: Shiga toxin producing Escherichia coli (STEC), Mycobacterium avium subspecies paratuberculosis (Map), Listeria monocytogenes, Campylobacter jejuni, invasive variants of Saccharomyces cerevisiae, Penicillium nordicum, hepatitis E virus and tick borne encephalitis virus. This profile of pathogens has been selected as the basis of PathogenCombat to provide readiness for future control of pathogens for which knowledge gaps currently exist. The likely impact of interventions at farm level and the most promising means of encouraging producers to apply interventions are reviewed individually for each of these microbes to assess the effectiveness of on-farm food safety applications.

2. Regulators of food safety in primary production

Food safety science provides the basis for the legislation and guidelines which regulate food production through identification of the hazards involved in each phase of production and the development of methods to control these hazards. Information on the behaviour of pathogenic microorganisms, efficient methods of detection and control measures to eliminate the microbe is vital for the control of food-borne pathogens at all stages of food production. In primary production, understanding the epidemiology of pathogens in the animal reservoir is also important to produce control measures that can be applied effectively at farm level. Identification of risk factors for the presence of pathogens in herds and controlled studies to confirm the effectiveness of proposed interventions allow modifications of management factors to be recommended.
2.1. Legislation

General food law for all stages of food production within the European Union is covered by Regulation (EC) 178/2002, which lays down a basic legal framework of food safety measures that must be carried out to protect consumer health and to allow free trade of safe food that meets consistent standards throughout the EU. It covers both food produced for human consumption and animal feed. The responsibility for compliance with the Regulation rests with the food business operator and this is enforced by the competent authority in each Member State. Each country also has its own laws governing food safety. The Regulation states that: “In order to ensure the safety of food, it is necessary to consider all aspects of the food production chain as a continuum from and including primary production and the production of animal feed up to and including sale or supply of food to the consumer because each element may have a potential impact on food safety.”

Annex 1 of Regulation (EC) 852/2004 on the hygiene of foodstuffs describes the hygiene regulations which apply to primary production, including animal production. This legislation describes the responsibilities of farmers as food business operators in detail. Hygiene and record-keeping are the two main areas covered and recommendations are also provided for guidelines at local or national level to good hygienic practice in primary production. Whilst producers are obliged to investigate animal diseases and provide the abattoir with this information, asymptomatic carriage of pathogens is not explicitly mentioned. Regulation (EC) 853/2004 lays down specific hygiene rules for food of animal origin and the requirements for meat production from domestic ungulates (e.g. cattle and sheep) are covered in Annex III of the Regulation, but this does not include on-farm production. Animal health and welfare regulations are covered in Council Directive 98/58/EC and additional directives lay down the regulations for individual species of farmed animals. These welfare regulations are often compatible with good management practices that can help to minimise the carriage of pathogens in live animals.

2.2. The Codex Alimentarius

The Codex Alimentarius (Codex) is a set of food standards, guidelines and codes of practice produced with the aim of protecting consumer health and facilitating international trade. The Codex Commission is responsible for producing and updating the Codex according to scientific evidence. It was established by the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (WHO) and now consists of 182 member governments worldwide and the EU as a member organisation. Compliance with the Codex recommendations is voluntary, but the Codex may be referred to in the event of a trade dispute. Many governments and non-governmental organisations use the Codex guidelines as the basis for legislation and regulations: EU legislation complies with or exceeds the requirements of the Codex. The “Code of Hygienic Practice for Meat” CAC/RCP 58-2005 acknowledges the importance of measures to produce safe meat in the primary production phase and recommends general control measures that should be applied.

2.3. Farm management guidelines

A number of voluntary farm assurance schemes are established at local and national level for beef and lamb producers in European countries. Producers belonging to the scheme must adhere to agreed standards of animal welfare and hygiene and can sell their product under the recognised label of the scheme. Farmers are therefore able to obtain a premium price for their product; retailers are supplied with a standardised product and consumers receive additional reassurance about the quality and origins of the meat they are purchasing. The assurance standards comply with existing EU and national legislation and may also include additional requirements. EU food law and Codex guidelines are written to apply to a range of production systems, but the quality assurance standards are tailored to the members of the scheme and can lay down practical requirements for the relevant production system. The standards set by these schemes are usually the regulations that farmers are most familiar with and compliance is regularly assessed by on-farm audit. An example of a successful quality assurance scheme at national level is the Quality Meat Scotland (QMS) Assurance Scheme for cattle and sheep, which is the largest quality assurance scheme for Scottish beef and lamb production and allows participating farmers to sell their produce as Scotch beef or lamb. All stages of the food production are included in this scheme: to comply with the requirements, producers must adhere to the required standards (Quality Meat Scotland, 2008) on their farm and may only use feed suppliers and transporters that are approved by QMS.

3. Carriage of microorganisms in ruminants

Identifying the main sites of carriage and the sources of microbes carried by ruminants is essential for the recommendation of interventions to prevent contamination or infection from occurring or to remove microbes from defined sites. An estimation of when microbes are most likely to be transmitted to these sites also allows interventions to be performed at the appropriate point in time to minimise carriage at these sites at slaughter. An important distinction must be made between contamination of meat with microbes from the gut or hide of the animal at slaughter and the presence of a pathogen (e.g. Map) within the muscle tissue.

Microbes are continuously present on the hide and in the gastrointestinal tract of ruminants (Fig. 1). Many of these are the normal commensal bacteria that are present on the body surfaces of animals, but pathogens can also be acquired at all stages of production, either on the farm of origin or during transport, holding and slaughter, and persist at these sites without causing any signs of infection in carrier animals. Muscle tissue is intrinsically sterile unless the animal it comes from had been systemically infected or microbial contamination occurs during slaughter or processing (Huffman, 2002). Good hygienic practices in the abattoir can reduce, but not totally eliminate, the probability of such contamination occurring.

The pathogens present on the hide and in the guts are often closely linked as faecal contamination is a common route for the transfer of pathogens onto the hide. However, due to the differences in the likely time of exposure, the pathogens in the gut and on the hide at slaughter may have different origins. For pathogens to enter the gut, they must be ingested by the animal with feed or water, from the environment or from the hide of other animals e.g. via mutual grooming. Withholding feed or changes to the diet can also alter the conditions within the gut and produce a more favourable

![Fig. 1. Main sites of carriage of microorganisms in ruminants.](Image 326x66 to 547x210)
environment for the survival of pathogenic microorganisms (Hogan et al., 2007). A pathogen is likely to have been ingested at least several hours previously to be present within the gut at the time of slaughter; hence on-farm interventions to prevent this carriage are promising. The hide can become contaminated with faeces from the animal itself or from other animals through direct or indirect contact. This can occur at any stage before hide removal, including during transport and when animals are held in the lairage before slaughter. Cross-contamination between animals from different farms at this stage appears to be an important source of contamination of hides with *E. coli* O157 (Mather et al., 2008) and it is likely that this also occurs with other pathogens. Therefore, even animals that are free from contamination when they leave the farm due to effective interventions may have contaminated hides at slaughter if appropriate controls are not in place during transport and holding.

Some pathogens such as *M. avium* subspecies *paratuberculosis* (Map) (Alonso-Hearn et al., 2009) and parasites including *Toxoplasma gondii* (Tenter et al., 2000) can be widely disseminated in the muscle and edible viscera of infected animals and cannot be removed once they are present in the meat. The animal will have been infected for some time when the pathogens are present in the muscle tissue; in the case of Map, the animal will usually have become infected several years earlier. Farm level interventions are crucial to prevent Map infection and are particularly important on breeding units as most infections occur early in life.

The probable sources of microorganisms at each site of the body are described in Table 1 and used to identify critical points for exposure as well as estimate an approximate length of time before slaughter when the contamination at each site was likely to have occurred. This information allows points to be identified in primary production where implementation of targeted food safety interventions seems promising.

### 4. Critical aspects of primary production

#### 4.1. Animal husbandry

Control measures applied at farm level will target pathogens at all of the main sites of carriage. Pathogens which persist within the meat (e.g. Map) are acquired on farms and must be controlled at this stage as interventions applied later in primary production, during slaughter and processing will be ineffective at removing these pathogens. Ingestion of microbes that are carried in the gut will usually occur on the farm before animals are transported for slaughter and effective on-farm control measures should significantly reduce the carriage at slaughter.

Measures which involve simple changes to existing management practices and are effective against more than one pathogen are most promising as widely used farm level interventions to control pathogens. Good standards of hygiene on farms are also required by EU law. Interventions that are easy and inexpensive to apply and have a number of benefits for both food safety and the general standards of animal husbandry in primary production are most likely to be adopted by producers. For example, a seven-point farm management plan to reduce the prevalence of pathogenic *E. coli*, *Campylobacter* and *Salmonella* in cattle has been described, based on available evidence from field studies (Ellis-Iversen and Watson, 2008). It recommends: “Dry and clean bedding, stable rearing groups, empty and clean water troughs every 2–3 weeks, rodent control, closed herd (or at least closed young stock section), avoid young stock contact between herds, leave a down-time period between manure spreading on or close to grazing fields before allowing cattle to graze.” These measures also contribute to the control of other zoonotic pathogens and are practicable on almost all farms. In addition, they may have direct benefits for the producer in terms of controlling animal-specific pathogens and improving herd health and animal welfare.

#### 4.2. Cleanliness of animals

EU legislation and the Codex Code of Hygienic Practice for Meat both state that animals presented for slaughter must be clean. This was reiterated in the Pennington Report published in 1997 following a major outbreak of *E. coli* O157 in Central Scotland and the report emphasised that animal cleanliness is the responsibility of the farmer (Pennington, 1997). In the UK, the cleanliness of cattle and sheep presented for slaughter is graded into categories on a scale of 1 (clean and dry) to 5 (filthy and wet) in accordance with the Meat Hygiene Service’s Clean Livestock Policy. Only animals which are classed as category 1 or 2 can go forward for slaughter without further interventions. The hide is one of the main sources of bacteria that can be transferred to the carcass during dressing and minimising the visible contamination of the hide at slaughter assists in preventing the transfer of pathogens to the meat. However, even the hides of visibly clean animals are frequently contaminated with pathogens such as *E. coli* O157 and *C. jejuni* (Reid et al., 2002) which indicates that hides should always be viewed as a potential source of contamination.

Reid et al. (2002) found that the levels of bacteria on the hide are generally highest at the brisket as this is the area in contact with the floor when cattle are resting. This is also the site where the initial cut is made at the start of the hide removal process and there is a high probability of spreading contamination to other sites on the carcass. It seems likely that providing sufficient clean, dry bedding will be the most effective means of preventing heavy soiling of the brisket area. This is particularly relevant as clipping and cleaning of this area in live cattle is difficult and potentially dangerous. The cleanliness of cattle prior to slaughter significantly affects the level of contamination of the carcass at the brisket and hock after hide removal, as these are the sites that come into contact with the hands and knives of abattoir personnel most frequently. Contamination of other sites on the carcass, such as the back, was found to be unrelated to hide cleanliness (McEvoy et al. 2000).

Davies et al. (2000) identified cattle aged less than 20 months; dry diets; short-haired cattle; clipped cattle and a journey of less than 150 miles to slaughter as factors associated with cleaner cattle when presented at the abattoir. The Food Standards Agency (FSA) and the Health and Safety Executive (HSE) in the UK have published guidelines for farmers on optimal management practices for producing clean animals for slaughter that recommend hay or cereal finishing diets, appropriate building design, keeping animals dry while loading, suitable bedding and stocking densities, and maintaining good overall animal health. However, further interventions may be required before slaughter if cattle or sheep do not meet the required standards of cleanliness.
Farmers are advised to clip the affected areas of the hide if animals have a large amount of dried material adhered to the coat before loading for transport to slaughter. This can be a dangerous procedure in beef cattle that are unaccustomed to handling and farmers are understandably keen to avoid this where possible. The FSA and HSE guidelines describe best practice for clipping cattle when this is necessary but many farmers would prefer clipping to be carried out on the slaughter line, post-mortem. A study by McCleery et al. (2008) investigating the effects of ante- and post-mortem hide clipping found that ante-mortem clipping in the lairage resulted in the lowest levels of bacteria on carcasses. Levels in animals clipped post-slaughter were higher, but similar to those from clean animals that did not require clipping. Clipping ante-mortem increases meat pH, which indicates that the procedure is stressful for the animals and reduces meat quality. However, this study did not compare the effect of clipping on farm before transport. Many producers wish to see a move away from on-farm clipping for health and safety reasons, but any change to the currently accepted best practice of on-farm clipping must be based on scientific evidence. A study evaluating different methods of post-mortem hide decontamination found that hide clipping increased the total viable counts of bacteria when carried out experimentally on hides after removal (Small et al., 2005), but the effect on bacterial contamination of carcasses could not be assessed in this study. Pre-slaughter washing to remove visible contamination does not prevent microbiological carcass contamination (Biss and Hathaway, 1996; Byrne et al., 2000) and is not widely used in Europe.

4.3. Feeding

Feedstuffs can also be a source of pathogens and cause infection (Horchner et al., 2006). By sourcing feed from approved suppliers and manufacturers that follow good hygienic practices and storing feed carefully to prevent contamination or spoilage, farmers can help to prevent the transmission of pathogens to their animals via feed. Withdrawal of feed and water before slaughter is sometimes recommended to reduce gut fill and faecal contamination of animals during transport but this practice can disrupt the normal gut microflora of ruminants and leave them susceptible to an increase in the levels of pathogenic bacteria in the gastrointestinal tract (Hogan et al., 2007). Feeding hay before transport and slaughter was found to result in drier faeces and cleaner cattle in comparison to fasted animals or those kept at pasture (Gregory et al., 2000) and also produced lower levels of generic E. coli and Enterobacteriaceae in the rumen and faeces than in fasted animals (Jacobson et al., 2002). Similar results were obtained for small ruminants: sheep and goats fasted for 12 h had lower levels of E. coli, Enterobacteriaceae and total coliform bacteria in the rumen than animals fasted for 24 h (Gutta et al., 2009).

4.4. Transport to slaughter

Cross-contamination of cattle hides with E. coli O157 during transport and in the lairage has been demonstrated (Dewell et al., 2008) and this is highly likely to occur with other bacterial agents. To ensure that on-farm interventions to prevent hide contamination remain effective up to the point of hide removal, animals from farms which implement such interventions need to be transported and held separately to prevent cross-contamination between animals at markets, during transport and in the lairage. In addition, haulers need to adhere to good hygienic practices e.g. cleaning and disinfection of vehicles; still it seems unavoidable that contact will occur between animals from different farms. The probability of pathogen transmission as a result of such contact is likely to be reduced if a sufficient proportion of farms applied effective interventions and the overall prevalence of certain pathogens is low; hence a coordinated and broad uptake of interventions is needed to achieve a sustainable reduction of pathogen carriage across the primary production sector.

The stress associated with transport has been shown to increase the shedding of Salmonella species, although no such effect was observed in adult cattle for E. coli O157 (Barham et al., 2002) or Campylobacter (Beach et al., 2002). The distance that animals are transported to slaughter does appear to have an effect on the faecal shedding of L. monocytogenes (Fenlon et al., 1996) and the cleanliness of the animals on arrival (Davies et al., 2000). Animals may ingest pathogens during transport that can become established and multiply in the gut before slaughter if transport and holding in the lairage is prolonged.

5. Decision support for on-farm interventions

A number of on-farm interventions and management practices to assist with the production of safe red meat have been described in the scientific literature. However, the effectiveness of these measures in preventing food-borne disease in consumers is dependent upon their implementation by primary producers. Decision support trees have been used as part of a HACCP-based approach to investigate whether a range of food safety hazards could be effectively controlled at farm level in Australian red meat production (Horchner et al., 2006). For the purpose of this article, a decision tree was developed to conceptualise the main questions that must be considered by regulatory bodies and stakeholders when assessing whether on-farm interventions are appropriate to manage identified microbiological hazards. The proposed framework also helps to select the most effective and appropriate method to ensure that these interventions are implemented efficiently (Fig. 2). The decision tree was deliberately kept simple to allow it to be applied to a wide range of microorganisms, including newly emerging pathogens, while focusing on the key points that the different stakeholders (e.g. producers, processors and authorities) need to agree on.

Fig. 2. Decision tree for application of on-farm interventions to control microbiological hazards in beef and lamb production.
5.1. Outcomes from decision tree (Fig. 2)

5.1.1. Suitability of pathogens for control at farm level

Each of the eight organisms selected by PathogenCombat, an Integrated Project within Framework 6 of the European Commission and focusing on food quality and safety was assessed using the proposed method and the conclusion for each step of the decision-making process was drawn from a review of the available scientific literature (Table 2).

Through the use of the decision tree, it was concluded that of the eight microorganisms targeted by PathogenCombat, only STEC and Map are likely to be effectively controlled by on-farm interventions in beef and lamb production systems. The evidence on which this conclusion was reached and specific interventions and farm management practices to control each of these pathogens are discussed further, as are the measures to encourage the application of the intervention by producers.

The remaining six pathogens were unlikely to be effectively controlled by interventions in primary production. Both L. monocytogenes and C. jejuni are carried by ruminants and cause disease in humans, but no pathogen-specific control measures are available for these microbes at farm level which would significantly reduce the potential contamination of the final product. L. monocytogenes infection in ruminants causes losses and is often linked to feeding silage of poor quality. Infected animals are very unlikely to enter the food chain as they usually succumb or will be identified at ante-mortem inspection. Feeding only silage of high quality, prevents listeriosis in livestock and a wide range of products are available to facilitate adequate fermentation of silage, in order to maximise the quality of the silage and, as a side effect, prevent losses due to listeriosis. L. monocytogenes is ubiquitous in both farm (Fenlon et al., 1996) and food processing environments (Slade, 1992) and contamination found on the final product is likely to originate from the processing stage (Barros et al., 2007); hence interventions to avoid consumer exposure to L. monocytogenes seem only of limited impact, if applied on farm level.

Campylobacter is widespread in the farm environment and is intermittently shed by ruminants of all ages but does not cause clinical symptoms. A better understanding of the pathogen and its carriage in ruminants is required if practical interventions are to be developed (Stanley and Jones, 2003). Studies in broiler chicken flocks have shown that flies can carry and introduce the infection into naïve flocks where it spreads rapidly and can persist through all subsequent stages of the production chain (Berndtson et al., 1996; Hald et al., 2008). This illustrates that it is extremely difficult to exclude Campylobacter, even from highly controlled environments such as broiler houses, and it is therefore unlikely that interventions would be effective in more extensive systems such as those used in cattle and sheep production. There is no evidence at present that any of the four remaining pathogens (P. nordicum, S. cerevisiae, tick borne encephalitis virus and hepatitis E virus) are transmitted from the primary production phase to humans through the consumption of beef or lamb or can be successfully controlled by interventions in the primary production.

5.1.2. Application of interventions

Legislation and regulations are necessary to ensure food safety; however, ensuring that legislation is applied as intended is time consuming and strict enforcement difficult. Therefore, where interventions beneficial to food safety generate direct benefits for farmers in terms of improved production and animal welfare, compliance should be achieved with a minimum of additional regulation (Fig. 2: outcome A from decision tree). Map infection is a good example of this, as productivity is compromised in affected animals. In this case it is in the interests of the producer to tackle this animal health and welfare issue; hence actions should focus on knowledge exchange, support and facilitation of coordinated interventions across the sector.

Under EU legislation (Regulation (EC) 852/2004), farmers are required to implement general hygiene measures to control pathogens in their livestock and maintain accurate and transparent records. Furthermore, producers must report outbreaks of “communicable diseases transmissible to humans through food” to the competent authority. However, asymptomatic carriage of food-borne pathogens will only be diagnosed if testing is mandatory under production regulations or attractive due to monetary incentives (Fig. 2: outcome B).

Quality assurance schemes are in a position to require compliance from their members as a condition of the scheme or to provide financial incentives for producers who apply the intervention. The requirement to perform a certain intervention could also be incorporated into national or European legislation if this is considered to be appropriate by policy makers.

Where effective interventions in primary production are unavailable or unlikely to significantly improve the microbiological safety of the final product (Fig. 2: outcome C), food safety efforts have to be concentrated at later stages of the food production chain. In an integrated production chain, interventions should focus on the production step where they are most effective.

6. Potential interventions for specific pathogens

6.1. Shiga toxin producing E. coli (STEC)

6.1.1. Background

E. coli O157 is the STEC serotype most commonly associated with severe human infections within the EU (EFSA, 2007). A review of the epidemiology of STEC in Continental Europe by Capriolo and Tozzi (1998) found that the strains present vary greatly between different regions. The incidence of human STEC cases is lower in Continental Europe than in North America or the United Kingdom and a higher proportion of cases are caused by non-O157 strains. The incidence is also higher in northern than southern Europe. However, most of the scientific work to identify controls at farm level for STEC has concentrated on O157 and specific characteristics of this serotype allow targeted control measures to be developed.

The Pennington Report following a Scottish E. coli O157 outbreak in 1997 recommended control at the pre-slaughter stage to reduce the levels of contamination of food and several other studies have found that a reduction in the prevalence of E. coli O157 in cattle would significantly reduce the risk to consumers (Elder et al., 2000; Jordan et al., 1999; Lejeune and Wetzel, 2007). The procedures carried out during slaughter...

Table 2

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Carriage in ruminants</th>
<th>Effective intervention at farm level</th>
<th>Control with direct benefit to producer</th>
<th>Action</th>
</tr>
</thead>
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<td>Yes</td>
<td>No</td>
<td>Give incentive for implementation</td>
</tr>
<tr>
<td>Mycobacterium avium subspecies paratuberculosis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Inform producers and facilitate uptake of intervention</td>
</tr>
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<td>Listeria monocytogenes</td>
<td>Yes</td>
<td>No</td>
<td>Low priority for farm intervention</td>
<td></td>
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<tr>
<td>Campylobacter jejuni</td>
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<td>Low priority for farm intervention</td>
<td></td>
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<td>Penicillum nordicum</td>
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</tr>
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and processing are effective at minimising contamination of meat with *E. coli* O157 and also at reducing this over each stage of processing (Chapman et al., 2001; Elder et al., 2000), but cannot totally prevent the contamination of food with *E. coli* O157. Once contamination with STEC has happened, processing steps further along the production of fresh meat products cannot effectively remove the microorganism, illustrating that for some foodstuffs, primary production represents the critical step in the provision of a safe end product. Clearly, control measures must be optimised at each stage of production, but measures should also be intensified at pivotal productions steps to contribute to the microbiological safety of the final product. Reducing the prevalence in live ruminants presented for slaughter is the basis for effective interventions during processing (Loneragan and Brashears, 2005).

The majority of studies have focussed on cattle as the main hosts of *E. coli* O157 and proposed interventions to be applied to cattle, but sheep can also carry and actively shed the bacteria (Franco et al., 2009; La Ragione et al., 2009). Interestingly, in a study series conducted by Chapman et al. (2000, 2001), *E. coli* O157 was isolated more frequently from raw lamb products than beef, but the prevalence was lower in sheep faeces and carcasses.

### 6.1.2. Husbandry

Establishing farm level risk factors for *E. coli* O157 is complicated by the transient nature of faecal shedding in cattle (Matthews et al., 2006) and the seasonal and geographical variation in prevalence (Gunn et al., 2007). As a result, the findings from studies identifying management practices which help to control *E. coli* O157 on farms should be interpreted with caution. However, some practices have consistently been found to be associated with *E. coli* O157 carriage by different studies. Housed cattle are more likely to shed *E. coli* O157 than those kept at pasture (Ellis-Iversen et al., 2009; Syngle et al., 2003). Ensuring that clean, dry bedding is available; maintaining established groups of animals and keeping cattle in smaller groups have all been demonstrated to reduce the burden of *E. coli* O157 in housed groups. A closed herd policy may also be beneficial (Ellis-Iversen et al., 2007; 2008).

### 6.1.3. Cleanliness

The presence of *E. coli* O157 on hides is strongly associated with the presence of the bacteria in the faeces, indicating that interventions to reduce faecal shedding should reduce carcass contamination from the hide (Loneragan and Brashears, 2005). Additionally, the probability of a carcass testing positive for *E. coli* O157 increases if either of the adjacent carcasses on the slaughter line is positive (Mather et al., 2007). However, McEvoy et al. (2000) found that the presence of visibly dirtier animals on the processing line appeared to have no effect on carcass contamination. This suggests that interventions that specifically target pathogens will be more effective at preventing cross-contamination between carcasses than interventions that aim for visibly cleaner hides. A simulation model also found that improving hide cleanliness would have little impact on contamination with *E. coli* O157 in comparison to interventions to reduce the prevalence in live cattle (Jordan et al., 1999). This insight has not been translated into practices, i.e. ruminants are not routinely tested for the presence of specific pathogens, either in the finishing unit or at slaughter, as it would be the case for other species (Wegener, 2010). Visual inspection of the hide is the method of choice to assess the risk of microbial carcass contamination and hide clipping is the most effective measure to remove dirt and bacteria from the hide. This practice reduces the bacterial contamination e.g. spoilage bacteria, but does not prevent contamination with *E. coli* O157 in a reliable manner.

### 6.1.4. Feeding

Animal feed production and its microbiological safety is strictly regulated under European law and comprehensive guidelines are laid out in the Codex Alimentarius CAC/RCP 54–2004 “Code of Practice on Good Animal Feeding”. *E. coli* O157 has been isolated from commercial cattle feed in the United States (Hancock et al., 2001) and this is a possible route of infection for herds in Europe as well. *E. coli* O157 can persist in water trough sediment and remain infectious to cattle for several months (Lejeune et al., 2001). It therefore seems sensible to assess animal feed and drinking water as potentially significant reservoirs of the bacteria for groups of cattle. However, in a study by Ellis-Iversen et al. (2009) the water source and frequency of cleaning of the water troughs did not affect *E. coli* O157 in cattle and when measures to improve feed and water hygiene were applied on farms, no effect was observed (Ellis-Iversen et al., 2008).

Forage feeding prior to slaughter was found to reduce the faecal shedding and acid resistance of generic *E. coli* and was recommended as an effective intervention (Diez-Gonzalez et al., 1998). A reduction in the acid resistance of the bacteria is considered desirable as the bacteria will be more susceptible to human stomach acid if ingested and less likely to reach the intestine and cause disease. There has been much debate regarding the efficacy of this intervention since the beneficial effects were first described. A review of the available literature regarding the effect of diet immediately before slaughter by Callaway et al. (2003) concluded that feeding hay prior to slaughter offers significant benefits in terms of controlling the level of faecal shedding of *E. coli* O157, but a similar review by Hancock et al. (2001) argued that little is known about the effect of this intervention on *E. coli* O157 as opposed to generic *E. coli* and that the stress associated with a drastic dietary change could increase the shedding of other pathogens. However, providing hay to cattle in lairage has been identified as a protective factor against contamination of the hide with *E. coli* O157 (Mather et al., 2007). Callaway et al. (2003) concluded that hay feeding is not practicable in American feedlot systems, but it may be possible in the management systems used in Europe. Forage containing sainfoin (*Onobrychis vicifolia*) causes a marginal reduction in faecal shedding, but this is unlikely to be sufficient to have any practical application (Berard et al., 2009).

A number of potential interventions specifically targeting *E. coli* O157 that are administered in the feed have been described, such as prebiotics, competitive exclusion by non-pathogenic bacteria and bacteriophage treatments (Loneragan and Brashears, 2005; Lejeune and Wetzel, 2007). Chlorate preparations used as feed additives before slaughter appear to reduce faecal levels of *E. coli* O157 at slaughter with no adverse health effects in treated animals (Anderson et al., 2005). Antimicrobial therapy with a substance such as neomycin added to the feed does reduce bacterial shedding. However, this clearly cannot be recommended as antimicrobial feed additives are subject to legal restrictions in many countries and is generally resisted by consumers as it has been linked to the development of antibiotic-resistant strains of bacteria (Loneragan and Brashears, 2005).

### 6.1.5. Transport

The effect of transport stress on the faecal shedding of *E. coli* O157 in cattle appears to vary with the age of the animals. No effect was observed in adult cattle (Barham et al., 2002), but long-haul transport without preconditioning increased shedding in calves (Bach et al., 2004). Cross-contamination between animals can occur through close contact and increased defecation during transport, particularly over long distances, or when animals are held in contaminated lairages (Dewell et al., 2008). A study by Mather et al. (2008) found that the likelihood of hide contamination was higher when groups of animals from different farms were transported together and when a commercial transporter was used. The hides of over half of the cattle tested in this study were positive for *E. coli* O157, but 84% of the positive hides were contaminated with a subtype that had not been detected in any animal on the finishing unit. This finding suggests that contamination of the hide from other animals when groups from different farms are mixed during transport is an important source of *E. coli* O157 on animal hides at slaughter.
6.1.6. Control

A small proportion of cattle shed high levels of E. coli O157 when the recto-anal junction is transiently colonised by the bacteria (Low et al., 2005) and these ‘supershedders’ maintain the infection in the cattle population (Matthews et al., 2006). An intervention that can avoid this colonisation would prevent high-level faecal shedding and should effectively reduce the carriage of E. coli O157 in groups of cattle. Controlling faecal shedding would also reduce the probability of hide contamination. A simulation model indicated that the greatest potential impact on carcass contamination would be associated with reducing faecal shedding of the pathogen by vaccinating animals against E. coli O157 (Jordan et al., 1999). A vaccine based on the type III secreted proteins necessary for attachment of the bacteria to the mucosa (Rogan et al., 2009) is available in North America, but it is not licensed for use in Europe. A promising and practical method to eliminate colonisation and supershedding of E. coli O157 consists of rectal lavage of animals with a chlorhexidine solution (Naylor et al., 2007). This method has the potential to sustainably reduce the prevalence of E. coli O157 in cattle.

6.2. M. avium subspecies paratuberculosis (Map)

6.2.1. Background

Map causes Johne's disease in ruminants, and the association between Map and Crohn's disease in humans has been debated for many years (Grant 2005; Behr and Kapur, 2008). The Precautionary Principle is described in EU food safety law in Regulation EC/178/2002 and advises that control measures should be implemented for any putative human health hazard, even where this has not been scientifically confirmed; interventions to control Map in food production seem strongly indicated under this Regulation. Control of Map infection in ruminants is not only necessary to minimise contamination of meat (Grant 2006), but also to address the occurrence of Johne's disease which has substantial animal welfare implications.

Unlike the transient, asymptomatic infection that occurs with E. coli O157, Map causes a chronic, persistent and ultimately fatal disease in ruminants (Hayton, 2007). Young ruminants are most susceptible to infection, but clinical signs do not develop for several years. Once clinical disease becomes apparent, the bacteria are widely disseminated through the tissues and high levels are shed in the faeces, but subclinically infected animals also act as carriers of the bacteria and may shed Map intermittently. All infected animals have the potential to contaminate milk and meat and to infect, susceptible animals on the farm. Calves and lambs can occasionally become infected in utero if their dam is Map positive (Lambeth et al., 2004; Whittington and Windsor, 2009).

Most studies on the zoonotic potential of Map have focussed on milk and dairy products: viable Map has been isolated and cultured from milk and meat and to infect, susceptible animals on the farm. Calves and lambs can occasionally become infected in utero if their dam is Map positive (Lambeth et al., 2004; Whittington and Windsor, 2009).

6.2.2. Control

Interventions must focus on preventing exposure of young animals to Map, as infection lasts for life. Control measures applied at later stages of primary production will therefore have no effect if the animals are already persistently infected. In contrast to STEC, Map causes disease in livestock and is therefore often included in herd health schemes which monitor and control the infection on farms. The major obstacle to effective control and eradication of Johne's disease in herds is the low sensitivity of the diagnostic tests available, especially for detecting infected animals in the early stages of infection. Most control strategies for Map are management-based and include avoiding feeding pooled colostrum to calves, rearing calves in a clean environment free from faecal contamination of adult cattle, sourcing animals from herds accredited free from paratuberculosis, routine testing to identify Map infection in clinically healthy animals, isolating animals showing signs of Johne's disease and culling unthrifty, ELISA-positive cows (Nielsen, 2009).

Many of the management strategies to control Map mentioned are aimed at cattle originating from dairy farms, hence different measures are indicated in cow-calf herds as beef calves are reared within the breeding herd and remain with their mother for several months. As calves in such systems are reared with adult cattle, it is more difficult to prevent them from coming into contact with the faeces of infected cows in the herd. Sheep affected by Map do not usually display the chronic diarrhoea that occurs in cattle which may reduce the effectiveness of transmission within the flock. Furthermore the lower economic value of individual sheep as compared to cattle reduces the incentives to control the infection by a "test and remove" policy. Cattle and sheep tend to be infected by different strains of Map, but there is evidence that Map can be transmitted from sheep to cattle (Moloney and Whittington, 2008; Musken et al., 2001). This inter-species transmission needs to be taken into account when controlling Map on farms with both species. National control programmes for Johne's disease are in place in several countries including Australia (Allworth and Kennedy, 2000) and The Netherlands (Benedictus et al., 2000), and in most European countries voluntary herd health schemes offer guidance in eradication of Map at individual herd level. Vaccines are available which reduce the level of clinical Johne's disease but they do not prevent Map infection and affect the reliability of diagnostic tests when testing vaccinated animals (Rosseels and Huygen, 2008).

A coordinated approach between breeders and finishers is needed for successful control of Map in livestock and hence a reduced exposure to Map of consumers of lamb and beef. The infection mainly affects breeding stock as this is where losses due to disease and reduced production will be experienced by the farmer and where the majority of new infections occur in young calves. Many ruminants (especially cattle) produced for meat are sold to a specialist finishing unit to be fattened before slaughter. These animals may have been infected with Map at the farm of origin and will not reach the age where clinical signs become apparent before they are slaughtered. Minimal new infections will occur in finishing units as older animals are less susceptible to infection (Windsor and Whittington, 2009). Control of the infection in breeding herds is critical to remove the bacteria from the food chain, but there is also an additional incentive for farmers to eliminate Map from breeding stock to improve the health and productivity of the their animals.

7. Conclusion

Primary production plays an important role in the provision of safe meat. Chemical or physical treatments of carcasses to remove high level faecal shedding of Map and the dissemination of the bacteria in the tissues appears to be more common in older, often clinically affected cattle. With the changes to the regulations to control Bovine Spongiform Encephalopathy (BSE) which mean that cattle over the age of 30 months can enter the food chain in the UK, it is likely that higher levels of Map will enter the food chain under these new regulations.


