Risk and the food safety chain: animal health, public health and the environment

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Summary

Food safety related to the consumption of animal-derived protein encompasses a wide variety of production and processing procedures which begins with the farm and inputs to the animals on the farm (e.g., feed and water) and includes the environment in which animals are reared. Hazards may be physical, artificial or naturally-occurring chemicals, organisms which cannot reproduce outside a specified life-cycle (e.g., parasites such as tapeworm in pigs) or viruses. Other microbes reproduce in the gastrointestinal tract of food animals as well as on the surface of food and in the environment. Methods of risk assessment for physical and chemical hazards have been used for many years. However, with microbial pathogens which can survive and grow on meat, in soil, water or other media, risk assessment methods are at the early stages of development. Due to the broad habitat range, the role of microbial pathogens in the food safety of meat, poultry, fruit and vegetables is important. The use of antibiotics in livestock species may accelerate the development of antibiotic-resistant strains of microbial pathogens, potentially complicating treatment for both animals and humans. The authors discuss the food chain, risk analysis and hazard analysis and critical control points in relation to foodborne pathogens, and introduce general strategies for improving pathogen control on the farm.

Keywords


Introduction

Animal production food safety is concerned with hazards which may be associated with meat, poultry or other animal products which form part of the human diet. Animals may ingest chemical agents or toxic plants, or may be treated with therapeutic drugs. Physical hazards can enter the food chain in a variety of ways, either on the farm or during the numerous processing steps. Biological agents, such as viruses and parasites, can also contaminate the food supply of the animals. Since chemical or physical hazards (and some biological hazards) cannot reproduce in or on meat, numbers do not increase with time, once contamination has occurred. However, for those microbial hazards which can survive and reproduce in, or on, meat or in the environment (e.g. animal, soil or water), management of the hazard becomes a challenge. A single undetectable organism at one link in the food chain can reproduce to the extent that a large number of people may become ill.

The safety of foods of animal origin can be described as a chain which commences on the farm (which includes a variety of environmental inputs to farm animals), and continues with transportation, the slaughterhouse, further processing steps, merchandising events and finally ends with the consumer (Fig. 1). This depiction of food safety demonstrates the close association between the events of the food chain. Pathogens entering this chain can be transmitted eventually to humans, causing disease. The image of a chain emphasises the continuity between the initial steps of food animal production on the farm to the ultimate destination,
hazards which entered the product affected the immediate safety of products of animal origin. For example, in the family. As the source of meat production and consumption members. Concern about food safety is not a new issue. Originally, meat production, processing and consumption considered commensal organisms appear to have developed medical issues involved in food safety has developed slowly over the years. In addition, microbes which were formerly created a public focus on chemical and pesticide practices and routine testing for trichinella-free pork programmes are being developed with specific on-farm efforts on the farm, reports of the presence of trichinellosis in cattle in the USA have diminished. Where available, technology was used to support organoleptic inspection: for example, microscopic examination of diaphragm muscle from a pork carcass was used to evaluate the number of Trichinella spiralis cysts in pork muscle. Too many cysts resulted in carcass condemnation. Together with efforts on the farm, reports of the presence of trichinellosis in pork in the USA have diminished. Today, certification programmes are being developed with specific on-farm practices and routine testing for trichinella-free pork.

The 1962 publication of Silent Spring by Rachel Carson created a public focus on chemical and pesticide contaminants (6). By this time, antibiotics and other modern drugs were inexpensive enough to be used to treat food animals and consequently, residues of therapeutic drugs began to appear in meat. As a result, the focus of food safety efforts was directed more vigorously towards chemicals, toxins and drug residues. Tests to detect and measure contaminants were developed, and a better understanding of food safety assurance was acquired.

Fig. 1 Links in the food chain
This diagram stresses the interrelation between the sequential processes by which foods of animal origin are produced and consumed. In reality, the feedback loops are more complex and vary by species, processing activities and other operations. One feedback loop is illustrated with the movement of some slaughter link products returning to the farm input link.

food for humans to eat, and also draws attention to the role of the environment for both animal and human health. Dividing this continuum into links of a chain helps to explain the relationship of the parts and in addition supports the use of risk assessment for foodborne disease as a whole (30). The analogy also retains the useful idea of a continuum for animal health, public health and the environment.

Hazards and history
Eating involves intimate contact between the gastrointestinal tract and material from outside the organism. The thin and delicate tissue of the gastrointestinal tract is one of the barriers which protect the body against toxins, bacteria or other hazards. Technical understanding of the scientific and medical issues involved in food safety has developed slowly over the years. In addition, microbes which were formerly considered commensal organisms appear to have developed pathogenic strains. Humans have long been interested in the safety of the food they eat. Folk narratives (e.g. Sleeping Beauty) feature stories of poisonings. Kings would employ official and well-trusted ‘tasters’ who served as sentinels for the safety of food for the kings and other royal family members. Concern about food safety is not a new issue.

Originally, meat production, processing and consumption were performed on the premises of the consumer. Any hazards which entered the product affected the immediate family. As the source of meat production and consumption became separated, concerns arose about the wholesomeness and safety of products of animal origin. For example, in the early nineteenth century in the United States of America (USA), there was active concern about several livestock diseases which were spreading around the country, including two zoonoses, brucellosis (Brucella abortus) and tuberculosis (Mycobacterium bovis). Working together to conquer these diseases on the eve of the twenty-first century has strengthened the liaison between animal and human health professionals.

The United States Congress took action in May 1884 by establishing an animal health service, the Bureau of Animal Industry (BAI), in the United States Department of Agriculture (USDA). The goals of the BAI were to control and prevent the spread of livestock diseases and to prohibit interstate transportation or export of diseased livestock. Daniel Salmon, veterinarian and first administrator of the BAI, recognised the interrelationships between animal health and public health by including a physician, Theobald Smith, as a member of his first team. Smith developed an interest in the effects of bovine tuberculosis in humans and played an important role in developing strategies for the eradication of tuberculosis from cattle in the USA (35). These early programmes relied primarily on astute skills of observation, for there were few laboratory tests, vaccines or other technologies to support veterinary or human public health efforts.

The aim of the BAI in 1884 was to curb the spread of animal diseases, and through this work, the BAI also contributed to public health by slowing the spread of zoonoses. Following publication of The Jungle (32) in 1906, the United States Congress passed laws directed towards producing wholesome meat from healthy animals. The 1906 Meat Inspection Act required that animals be inspected prior to and after slaughter by veterinarians or other inspectors using the informed senses of sight, smell and touch (organoleptic inspection). These organoleptic inspections were stipulated to ensure that meat from diseased animals did not enter the human food supply. Where available, technology was used to support organoleptic inspection: for example, microscopic examination of diaphragm muscle from a pork carcass was used to evaluate the number of Trichinella spiralis cysts in pork muscle. Too many cysts resulted in carcass condemnation. Together with efforts on the farm, reports of the presence of trichinellosis in pork in the USA have diminished (35). Today, certification programmes are being developed with specific on-farm practices and routine testing for trichinella-free pork (25).
Healthy animals, good slaughter inspection, hygienic practices throughout the slaughter, processing and refrigerated distribution stages, along with chemical and residue testing, sufficed to provide wholesome and safe meat and poultry for human consumption. Zoonotic bacterial pathogens were assumed to result in illness for animal hosts as well as for humans. Thus, an animal which harboured a pathogen would display visible signs of illness, rendering the animal clearly unsuitable for slaughter. In the 1980s, however, several outbreaks of human disease altered this view of food safety.

In 1987, a review of human illness data collected between 1976 and 1986 showed a six-fold increase in egg-related outbreaks of Salmonella Enteritidis (SE) in the north-eastern USA (33). Tracing back from the affected individuals showed that eating eggs which were not fully cooked was a common factor in these epidemics. When the eggs involved were traced back to the farms of origin, the chickens laying the eggs were visibly healthy and showed no signs of disease. Further research demonstrated that the SE organisms were present in the reproductive tissue of poultry and were being shed into eggs. With time and appropriate temperature for microbial reproduction, a dose harmful to egg consumers could develop.

In the same decade, evidence began to accumulate that yet another microbial agent, Escherichia coli O157:H7, caused human illness yet had no observable effect on animal health (7, 9). The emergence of these foodborne organisms has influenced the current desire to understand more fully how microbial pathogens enter and move through the food chain, and the conditions which promote or inhibit growth for each microbe. Most of these pathogens are associated with animal faeces, although the organisms can also survive or grow in other media such as animal food, water or soil.

Salmonella is a familiar genus to public health specialists. Salmonella Typhi causes typhoid fever, a severe and debilitating illness. Transmission of this disease was known to occur through contact with human faeces and, over the past century, the development and enforcement of infra-structural controls for handling sewage in a rapidly diminishing number of typhoid cases. In addition, consumer education efforts were directed to sanitary and hygienic practices for food handling. By 1945, relatively few cases were being reported in the USA. Since 1945, however, there has been an astonishing increase in human illness associated with numerous non-Typhi Salmonella. These other Salmonella are chiefly associated with manure from livestock or poultry. The entry of these organisms and other pathogens which are introduced by faeces into the human food chain, whether through meat, poultry, fruit or vegetables, is at the centre of current concerns regarding the safety of food from pathogenic micro-organisms. A newly developing field, risk assessment, provides a basis for understanding and managing the hazards efficiently.

Risk assessment has been used by engineers (29), financial managers (16), economists (23) and others for many years. The United States Food and Drug Administration (FDA) has used a variety of methods to assess the safety of food additives, foods and drugs. The concern of the FDA has historically been focused on additives, chemicals or toxins which may enter the food chain, but which do not reproduce. Early work on risk assessment for replicating organisms, focused on the likelihood of introducing plant or animal pests or diseases into a country or region through imported commodities (13, 22, 24) or veterinary biologicals (27). However, use of risk assessment to predict the likelihood of occurrence and growth or spread of replicating organisms is relatively recent. Risk assessments for water-borne pathogens have also been studied (17, 19, 31). An early attempt to develop ideas for risk assessment of microbial pathogens as part of governmental food safety programmes was presented at the conference on 'Tracking foodborne pathogens from farm to table' (2, 30). Predictive microbial modelling enables estimates to be made of microbial growth under varying time, temperature and physical conditions (34). Combining the likelihood of risk occurrence models with growth models promises to provide powerful insight into microbial movement through the food chain. These models can help to predict consumer exposure and estimate dose-responses in humans from pathogen exposure (14).

Risk analysis

Risk analysis is composed of three parts: risk assessment, risk management and risk communication (1). The terms are derived from colloquial language, but have been assigned specific meanings in the professional risk assessment community. However, the assignment of word and meaning has not been consistent. Thus, the words or phrases may have different meanings to different groups. Within the agricultural sector, the goal is to develop and use consistent definitions to simplify communications (1). Gathering scientific evidence from a number of fields, risk assessment can be defined as a process which answers three questions:

a) which hazards might occur (hazard identification)?

b) what is the likelihood that a hazard will occur?

c) what is the severity, in biological terms, if a hazard does occur?

Questions a) and b) together are referred to as risk. As a trio, these questions form the most basic definition of risk assessment (20). It is worthwhile mentioning that risk is often used interchangeably with the term hazard. The lack of precision in risk-related nomenclature makes communication more challenging among scientists, risk assessors, risk managers and the public.
Probabilistic definitions of risk are useful to indicate the likelihood of the occurrence of the hazard, and are useful within links of the food safety chain to isolate and predict risk within that link. The risk output from one link becomes an input to the evaluation of risk in the next successive link. However, the actual level of contamination passed from one link to the next varies, and contaminating microbes may either die off or may multiply, enter the food chain in many places and ultimately reach the consumer (exposure assessment). To predict the dose of microbes to which an individual may be exposed, microbial growth under a variety of conditions and food-handling practices in kitchens, in public eating places and the home must be properly understood. The individual response to a given dose (number of pathogens) is important for predicting input and for understanding the severity of illness by estimating the number of micro-organisms required to make humans ill (26). Ultimately, however, the goal is to prevent the pathogen from reaching the consumer.

After risk assessment is completed, attention turns to risk management (Fig. 1). In parallel with the three questions of risk assessment, risk management also poses three, as follows:

a) what can be done to mitigate the hazard?

b) what are the costs of each mitigation measure and what benefits (risk reduction) will be gained?

c) what is the impact of current decisions on future options?

Thus an array of risk mitigations is considered and the option which provides the maximum risk reduction for the minimum cost is selected. There are techniques available to assist in choosing the best policy, scientifically and economically, when there are many hazards and many potential mitigation methods available (21). However, decision makers – whether in industry or government – must also consider laws, social policy, political realities and public concern (28). Once risk reduction or risk mitigation option(s) have been selected, mechanisms to monitor and evaluate the effectiveness of the programme must be implemented.

Throughout the process of risk assessment and risk management, risk communication must be both an active and interactive process leading to an open exchange of information and opinion about risk which results in better understanding and better risk management decisions. Risk communication serves as a forum for the exchange of information between all those who will be affected by the outcome of the risk assessment and risk management activities. Good risk communication, public awareness and international harmonisation of food safety methods will result in safer products for citizens of all countries. Risk reduction or risk mitigation can occur within any link of the food safety chain.

Identifying hazards for food safety

Hazard types

Hazards may be physical, chemical or biological in nature. Physical damage to food animals may result in bruised meat and injection site injury. These affect primarily the wholesomeness and quality of meat or reflect animal welfare concerns. Other physical hazards, such as buckshot or injection needles, may be introduced inadvertently into animal tissue. Organoleptic inspection continues to be useful in detecting such physical hazards. There are strong economic, consumer-driven incentives to avoid such incidents.

The animal production link also represents an opportunity for the introduction of chemical or toxic hazards. These may arise from the use of animal therapeutic or growth-promotion chemicals, as well as from food, water or environmental sources. Pesticides are an example of a chemical hazard. The combination of public health control programmes (testing and enforcement), voluntary implementation of animal residue avoidance programmes by producers and environmental precautions has led to improved safety from chemical and toxic hazards.

There are two kinds of biological hazards: those which reproduce in or on meat and poultry, and those which do not. Those which do not reproduce include viruses and parasites, such as tapeworms. Viruses of public health concern are primarily associated with contaminated water sources and aquaculture species, so the provision of clean water supplies for the production of fish and other aquatic species is important, as is the provision of clean drinking water for animals and for processing purposes.

Pathogenic microbes which reproduce on meat and poultry are organisms primarily associated with intestinal flora of food animals, which are passed into the manure. Until recently, scientists assumed that public health was affected only by microbes which make animals sick. These zoonotic agents were avoided by ensuring that only healthy animals entered the food supply. However, recognition that organisms which are harmless to animal hosts can be harmful to humans is a perception which has expanded significantly in the last fifteen years. It also became clear that the farm to slaughter (transportation) link of the food production chain offers an opportunity to prevent pathogen entrance into and propagation through the food chain. To improve food safety at the animal production and intermediate stages prior to slaughter, the USDA/Food Safety and Inspection Service (FSIS) considers that the voluntary application of good management practices (GMPs) and residue assurance programmes based on hazard analysis and critical control point (HACCP) principles contributes to risk reduction.
GMPs are regarded as pre-requisites to the development of HACCP systems (3). Critical control points for the definition of opportunities to control zoonotic pathogens have not been analytically identified in or on live animals. Until these are developed, GMPs for hygienic animal production are considered the most effective means of reducing risks.

A newly emerging category of public and animal health hazards is related to the development of antibiotic resistance in bacteria which are common to both animals and humans. One such example is Salmonella Typhimurium phage type DT104. This organism causes disease in both animals and humans and is resistant to a number of antibiotics, namely: ampicillin, chloramphenicol, streptomycin, sulphonamides and tetracycline (R-type ACCSut). Outbreaks of this organism have occurred in the United Kingdom and the United States (17). Since S. Typhimurium phage type DT104 affects both animal and public health, teams of experts in both the veterinary and human medical professions are needed for investigations. Emerging antibiotic resistance in certain micro-organisms has given rise to public health campaigns on the judicious use of antibiotics by physicians (11). Veterinary public health experts are also focusing educational campaigns on the judicious use of antimicrobial agents in animals to reduce the emergence and spread of antibiotic-resistant bacteria in animals. This collaboration demonstrates that the combined expertise of human health and animal production specialists is necessary to develop risk mitigation strategies to combat antibiotic resistance.

In 1997, the President of the USA announced a national food safety initiative. The goal of the initiative is to reduce foodborne illnesses to the maximum extent possible. The activities associated with this initiative are intended to have a positive impact on food safety in the USA as well as in countries importing food from the USA. Co-operation among stakeholders in many countries is a necessary input to systems which attempt to assure the safety of meat and poultry products for consumption world-wide.

**The role of the environment**

The problem of microbial food safety is one of contamination. The muscles of a healthy animal grazing on a pasture are sterile: that is, no bacteria of faecal origin are present in the muscle tissue. Many of the microbial pathogens of current concern survive in the environment, in water, on pastures and in food, unless precautions are taken to ensure pathogen control. Transportation may favour contamination as animals are placed in close proximity to others and stress may further enhance cross-contamination by these pathogens. Slaughter and processing procedures can also enhance such spread (9).

Environmental contamination by animal manure can occur in a variety of ways in the food chain. In the kitchen, for example, invisible microbes on raw chicken may contaminate the cutting board. If this cutting board is not thoroughly cleaned and disinfected, the faecal pathogens may be transferred to the next item which touches the board. Poor hygiene in processing or in the kitchen can contribute to the spread of these microbes from one place to another. On the farm, the use of human or animal manure as a fertiliser can introduce pathogens to the soil or directly to the surface of fruit and vegetables. Water sources for livestock or irrigation can be contaminated (4, 5). A suspected source of Salmonella Enteritidis phage type 4 in eggs is contamination of poultry environments by human sewage. Faecal matter from wild species may also be a source of contamination. For example, deer faeces in an orchard may have been the source of the E. coli O157:H7 which caused human illness from drinking unpasteurised apple juice (8). In yet another example, small seeds, such as those of alfalfa or radishes, may harbour microbial pathogens in tiny surface crevices. When such seeds are used to generate sprouts for human consumption, the bacteria grow vigorously under the warm, moist conditions suitable to sprouting (10). To demonstrate the importance of cross-contamination, data from the United States Centers for Disease Control and Prevention (CDC) gathered between 1982 and 1996 show that fewer than half of the outbreaks associated with E. coli O157:H7 were caused directly by beef. Thus, the consumer may be affected by manure-borne pathogens even if beef is not in the diet (8, 10). HACCP systems in processing plants and pre-harvest certification programmes for produce are being implemented in the USA. In addition, strict new inspection programmes for fresh fruit and vegetables have recently been announced.

Besides soil, water and food, pathogens can survive on animal hides, on crops, in slilage and in decomposed manure. Composting and other processing of animal manure to kill pathogens will be an important component of food safety, just as the control of human sewage was necessary to control typhoid fever.

**Enhancing animal health systems to improve public health**

Many hazards present in the food chain are introduced at the animal production stages and are spread during slaughter and processing. Once food reaches the consumer, useful facts can be learnt about dose and response, but it is too late to prevent the passage of microbes to the consumer. By emphasizing science-based risk assessment and by identifying preventive HACCP activities early in the food chain, the number of risk reduction and mitigation options are increased.

When hazards cause human disease but no disease in animals, intervention strategies are more difficult to determine. This is the case with a number of emerging and re-emerging human
Risk reduction and control systems in animal production stages are based on GMPs which can be developed and supported by risk assessment tools. These industry standards are incorporated in voluntary programmes (referred to as quality assurance, residue avoidance, risk reduction, total quality management, preconditioning, and sustainable agriculture programmes). An example is the Code of Practice for Good Animal Feeding drafted by the Expert Consultation on Animal Feeding and Food Safety of the Codex Alimentarius (12). The primary objective of Codex is to encourage adherence to GMPs during the production, harvesting, handling, storage, processing and distribution of feed for food-producing animals, and to encourage good feeding practices of food animals. Successful prevention of chemical contaminants at the animal production level has been achieved by HACCP and GMP strategies combined with pre-process testing for residues, parasitic pathogens and S. Enteritidis in eggs (3). Successful prevention of chemical adulterants at the animal production level has been achieved by preventive HACCP strategies based on risk assessments of animal husbandry practices from farm to pre-slaughter preparation.


conclusion

A number of emerging microbial zoonotic foodborne pathogens which cause human illness are closely associated with animal manure. Each link of the food chain should be carefully analysed to demonstrate where, and how, specific hazards can be introduced into each livestock group, e.g., dairy cattle, beef cattle, poultry and eggs. (The USDA/FSIS is currently engaged in a complete risk assessment for eggs and egg products from the pre-pullet stage to the consumer.) HACCP systems and GMPs linked to risk assessment are promising pathways for the development of interventions which can prevent or reduce the likelihood of hazard occurrence. Proper analysis can also suggest directions for research or data collection as well as needs for technological interventions. The information necessary to accomplish the goal of food safety will come not only from science but also from businesses which specialise in particular links of the chain. Careful analysis will also facilitate comparisons among countries seeking to harmonise food safety requirements.

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La chaîne de sécurité alimentaire et les risques pour la santé animale, la santé publique et l’environnement

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Résumé
La sécurité alimentaire liée à la consommation de protéines d’origine animale est un vaste domaine dans lequel interviennent les divers aspects de la production animale et de la transformation des produits. Les risques vont de l’exploitation d’origine jusqu’à l’environnement dans lequel les animaux évoluent, en passant par les intrants fournis aux animaux, par exemple les aliments et l’eau. Ces risques peuvent avoir pour origine des agents physiques, des agents chimiques artificiels ou d’origine naturelle, des micro-organismes qui ne se reproduisent que dans le cadre d’un cycle biologique spécifique (par exemple les parasites tels que le ténia du porc) ou des virus. D’autres microbes se reproduisent dans l’appareil digestif des animaux de boucherie ainsi qu’à la surface des aliments et dans l’environnement. Des méthodes d’évaluation des risques existent depuis de nombreuses années pour les agents physiques et chimiques. En revanche, pour ce qui est des microbes pouvant survivre et se développer dans la viande, le sol, l’eau et d’autres milieux, les méthodes d’évaluation des risques sont encore en développement. Or, compte tenu de la diversité des milieux dans lesquels évoluent les agents micro biens, leur rôle est crucial pour la sécurité alimentaire des viandes, de la volaille, des fruits et des légumes. L’utilisation d’antibiotiques chez les différentes espèces animales peut accélérer le développement de souches microbiennes antibio-résistantes, ce qui risque de compliquer le traitement chez l’homme comme chez l’animal. Les auteurs analysent les différentes composantes de la chaîne alimentaire et expliquent comment appliquer la méthode de l’analyse des risques, points critiques pour leur maîtrise à la lutte contre les agents pathogènes responsables de toxi-infections alimentaires. Ils présentent également des stratégies générales permettant d’améliorer la prophylaxie dans les élevages.

Mots-clés

La cadena de protección alimentaria y los riesgos para la sanidad animal, la salud pública y el medio ambiente

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Resumen
La protección alimentaria ligada al consumo de proteínas de origen animal requiere la aplicación de diversos sistemas de seguridad en los procesos de producción y procesado, sistemas que conciernen tanto a la granja y los aportes que recibe el animal (por ejemplo alimentos y agua) como al entorno en que éste se cría. Los riesgos a los que se expone el animal pueden ser agentes físicos o sustancias químicas (de origen artificial o natural), microorganismos que sólo se reproducen en un ciclo vital muy determinado (por ejemplo parásitos como la tenia del cerdo) o virus. Existen otros microbios que se reproducen en el tracto intestinal de animales destinados al consumo humano o en la superficie de los
alimentos o en el entorno. Hace ya muchos años que vienen aplicándose métodos de evaluación de los riesgos ligados a agentes físicos o químicos. Sin embargo, y en lo que concierne a los patógenos microbianos capaces de sobrevivir y crecer sobre la carne, el suelo, el agua y otros medios, los métodos de evaluación de riesgos se encuentran todavía en su fase inicial. Debido a su amplia gama de hábitats, los patógenos microbianos son un aspecto muy importante en todo lo que se refiere a la higiene de la carne, las aves de corral, la fruta o las verduras. El uso de antibióticos sobre especies ganaderas puede acelerar el desarrollo de cepas resistentes de bacterias patógenas, complicando así eventualmente el tratamiento tanto de animales como de seres humanos. Los autores examinan la cadena alimentaria, el análisis de riesgos y el control de puntos críticos en relación con los patógenos responsables de toxi-infecciones alimentarias, y proponen estrategias generales para mejorar el control de los patógenos en la granja.

**Palabras clave**
Evaluación de riesgos - Medio ambiente - Patógenos microbianos - Salud pública - Sanidad animal - Toxi-infecciones alimentarias.

**References**


