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Animal feed contamination

Effects on livestock and food safety

Edited by Johanna Fink-Gremmels

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Animal feed contamination

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Preface

It is a pleasure to introduce on behalf of all authors *Animal Feed Contamination: Effects on livestock and food safety*, a handbook devoted to animal feed contamination. As indicated in the subtitle, feed contamination with microbiological or toxicological agents can affect animal health, productivity and welfare, but at the same time, feed safety is an essential prerequisite for the production of safe and wholesome food products from animals fit for human consumption. The sentences above indicate the diversity of the disciplines that are involved in animal feed production and the assessment of animal feed safety. However, even a handbook of this size can only incompletely address all aspects of feed contamination, as the chemical substances occurring in forages and plants used in feed production with nutritional and anti-nutritional or toxic properties are virtually innumerable. Likewise there are many opportunities for microbiological deterioration and/or contamination with animal pathogens and potentially zoonotic agents. Hence this handbook aims merely to provide an introduction to the complex matter of animal feed contamination, highlighting a number of subjects of recent concern, as well as illustrating the impacts of harmonization of legislation and strategies put in place by the global feed industry on feed quality and safety.

The main areas addressed in the handbook include **microbiological hazards**, contamination of feed materials by **persistent organic pollutants and toxic metals** and the risks associated with the presence of **natural toxins**. On a global level, antimicrobial resistance is considered to be one of the major threats to the successful therapeutic use of antibiotics to combat human and animal bacterial infections. This is one of the topics treated in the section devoted to **veterinary medical products** as additives or contaminants in feed materials. An **emerging technology** linked to feed production is **genetic modification of crops**, as GM crops are an important source of the plant biomass used as feed material. Their safety for the animal, the consumer of animal-derived products, and diverse ecosystems is a matter of controversial debate. Other emerging technologies generate new challenges for those responsible for feed safety, for example in the case of the production of **biofuel** from plant materials, providing guidance on safe levels for the use of the by-products of biofuel production in feeds. A short introduction to the potential risks associated with nanoscale feed ingredients is also presented.

The final part of the handbook is devoted to technical aspects of **Quality Management**. Authorities in all continents have set legal standards to guarantee feed safety for the animal as well as safe food supplies for the consumers of animal-derived products. Safety assessment is increasingly based on a stratified procedure, including all four components of **risk assessment** such as hazard identification and characterization, exposure assessment and risk characterization. The feed industry is requested to endorse these strategies and comply with the legal provisions, which include **proper sampling techniques** and analytical controls. To this end the industry has established technical protocols (HACCP and GMP) for sourcing, tracing, processing and transportation and the related quality standards for feed materials and compound feeds.

Every author or group of authors presents relevant information from an individual angle, from his or her professional experience, and from the scientific literature available. This has led to diversity in the outlines of the individual chapters, and diversity is also inevitable given the inherent complexity of the topic under consideration. However, we do hope that this handbook is considered a useful introduction to the multifaceted area of animal feed safety and that it provides relevant information about quality control and intervention strategies.

J. Fink-Gremmels

1

Introduction to animal feed contamination

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Abstract: Global acquisition of feed materials has become common in order to achieve economically viable production of animal feeds. At the same time this globalization increases the risk for potential microbiological and toxicological contaminants that determine the quality and nutritional value of feeds, but more importantly also the safety of animal-derived foods such as milk, meat and eggs. Quality control programmes require a stratified multidisciplinary approach addressing the entire food chain, from agricultural sourcing through processing to animal nutrition and assessment of animal and human health risks.

Key words: food and feed safety, concentrated animal feed operations, microbiological and chemical hazards, socio-economic impact of feed production, risk management and communication.

1.1 Animal feed production

Animal feed production is a silent industry that only reaches newspaper headlines at times of crisis; these crises include, for example, the emergence of unknown pathogens in livestock, such as prions (causing transmissible bovine encephalitis) (Sakudo *et al.*, 2011), unexpected sources of dioxin contamination of milk, meat and eggs (Hoogenboom *et al.*, 2010; O'Donovan *et al.*, 2011) and the presence of residues or unauthorized substances such as melamine in milk, milk products and animal feeds (Qin *et al.*, 2010).

The animal feed industry, however, is a truly global business of great economic importance. It is linked to concentrated animal feeding operations, with ever- increasing farm sizes trying to meet the increasing protein demands of the growing world population. Intensified animal production required the development of new principles of animal breeding, animal nutrition and feed composition (Thorne, 2007). The most impressive example of these changes is probably that of the broiler chicken, whose body weight at hatching is increased by up to 5000 times in the short 35 days of a broiler's lifespan. Diets for monogastric animals such as pigs and chickens may contain up to 60% cereal grains to achieve high productivity. This implies that in this case animal nutrition is in competition with resources that can be also used for human nutrition (Weckwerth, 2011). The grazing of cattle, originally widespread, has been substituted by dairy farms at which the cows are given an individualized diet containing up to 80% of concentrates, mixed according to the availability of energy-rich feed materials on the world market. The growing production of bioethanol/biodiesel adds to this division of resources and has resulted in a dramatic increase in the world market price of many feed materials such as soybeans, cereal grains and oil plants (Robertson and Swinton, 2005). The socio-economic impact of this competition is contributing to the global debate on the prudent use of the available natural resources and farmland and the prevention of land grabbing by strong economies such as Europe, where the net imports totalled more than 38 million ha in 2009 and 2010 (www.farmlandgrab.org; United Nations, 2010).

Considering these recent developments it is clear that the major concern in feed production is the availability of sufficient supplies of feed materials. As these are becoming increasingly limited, animal nutritionists have to meet the challenge of exploring the special dietary needs of high-producing animals while still ensuring that feed supplies remain safe and cost-effective. The high demands for an optimal feed utilization rely not only on diets able to provide the animal with all essential macro- and micro-nutrients but also require feed materials free of anti-nutritive factors and microbiological or toxicological hazards. Subsequently, feed safety has emerged as one of the most important parameters affecting animal husbandry, health and productivity.

1.2 Feed safety

1.2.1 From farm to fork

At the beginning of this millennium the European Commission presented its White Paper on Food Safety (EC, 2000; COM/99/0719 final) which was intended to improve transparency and safety along the entire food production chain. The term *from farm to fork* signalled the responsibilities of all stakeholders in the production chain to take effective measures to minimize risks to both animal and human health (www.ec.europa.eu/food/omtro_en.htm). Any food that reaches the consumer should be free from hazards such as microbiological or chemical (abiotic) contaminants. For both microbiological and toxicological hazards, the responsible international authorities (FAO/WHO and the Codex Alimentarius Commission (CAC), the US Food and Drug Administration (FDA), the US Environmental Health Protection Agency (EPA) and the European Food Safety Authority (EFSA)) present risk assessments and establish maximum tolerable limits for contaminants, which serve as the reference for quality assurance programmes. In the initial phase of the production of foods from animal origin, feed quality is the most crucial factor that can lead to exposure of animals to undesirable contaminants. Therefore, within the European feed legislation it is stated that 'products intended for animal feed must be sound, genuine and of merchantable quality and therefore when correctly used must not represent any danger to human health, animal health or to the environment or adversely affect livestock production' (Commission Directive 2002/32/EC).

The feed industry has endorsed this need for transparency in the sourcing and processing of feed materials and in the use of feed supplements and additives. The latter require premarketing approval by the competent authorities prior to their use in feeds for farmed animals, including fish. Embedded in the One-Health Concept, integrated quality control programmes along the entire production chain should reduce the risk for animals and humans. It should also be mentioned that quality controls at the start of a production chain are a prerequisite for an economically viable agro-industry, thus preventing the need for rejection and destruction of food that is considered unfit for human consumption.

1.2.2 A truly multidisciplinary task

The assessment of feed safety is an extremely complex issue that has long been underestimated. Feed safety assessment in fact requires expertise in multiple disciplines such as agriculture and crop production, feed processing and technology and animal nutrition. Added to these basic disciplines, feed safety assessment also requires an understanding of microbiology and biosecurity measures, toxicology and animal health sciences (veterinary medicine) and ultimately experience in risk assessment methodologies.

Risk assessment has evolved into a well-structured scientific approach, with transparent rules, extensive data sourcing and distinct statistical procedures. The four essential elements of a quantitative risk assessment are hazard identification and characterization, exposure assessment and risk characterization. The ultimate outputs of risk assessment procedures are health-based guidance levels expressed as acceptable daily intake and tolerable weekly intake levels that carry no or a negligible risk for human health (Dorne, 2010). This stratified procedure must also be implemented in the assessment of feed safety for feeds used in food-producing animals. In addition, public interest has today extended to include the impact of large-scale animal production and feed sourcing on the environment and the role of farmers as eco-agricultural stewards (Thorne, 2007; Sachs, 2010).

1.2.3 Animal health and welfare

As previously mentioned, feed material may be the source of microbiological and chemical hazards (Frazzoli and Mantovani, 2010). Technical processes such as cleaning, disinfection and heating are generally employed to damage and destroy microbiological contaminants that could otherwise cause contamination of food derived from these animals. These processes are cost-intensive and the efficacy of preventive measures needs to be established and controlled for any feed material and compound in feed. Hence the limitations are obvious: highly process-resistant agents such as prions (TSE-BSE) require inactivation processes that compromise the palatability and nutritional value of feed materials (animal by-products) (Sakudo *et al.*, 2011). The innate resistance of many bacteria (anaerobic, spore-forming organisms) to inactivation procedures such as heat and acid treatment leads to an ever-present risk of viable pathogens being present in individual feed batches, which are then introduced into animal facilities. Perhaps the most prominent example of an unresolved, long-lasting problem in feed hygiene is contamination with enterobacteriaceae such as *Salmonella*, *Campylobacter* and anaerobes (*Clostridium* spp.) in poultry units (Mataragas *et al.*, 2008; Fosse *et al.*, 2009).

Problems relating to toxic and anti-nutritive chemical substances are on an even wider scale. The EC European Catalogue of Feed Materials currently covers more than 700 entries, and all of these feed components may be potentially contaminated with one or more toxic substance(s). In the past, interest focused particularly on environmental pollutants and contaminants such as persistent organic pollutants (POPs), present in a broad variety of feed materials and able to accumulate in animal tissues. This is also true of dioxins and dioxin-like polychlorinated biphenyls and of many other polyhalogenated chemicals that are used in industrial processes and hence reach the environment (Fries, 1995; Antignac *et al.*, 2006; Yu *et al.*, 2010). Toxic heavy metals (cadmium, lead and mercury) and other chemical elements (arsenic, chromium, copper and zinc) occur naturally, but industrial processes may increase their concentration in distinct geographic regions, leading to their accumulation in plants that are consumed or harvested as feed for animal consumption (Schauder *et al.*, 2010; Lopes *et al.*, 2011). Moreover, recently identified new endpoints of toxicity, such as for example developmental neurotoxicity of methyl-mercury, gain increasing attention (Dorne *et al.*, 2011; Farina *et al.*, 2011).

Natural toxins such as toxic plant metabolites (i.e. glycosinolates, saponins, alkaloids, including pyrrolizidin alkaloids, and terpenes) and bacterial and fungal toxins (mycotoxins) have long been known to the veterinary professionals as causes of acute intoxications in individual animals, but have been largely ignored in risk assessment exercises. Their antinutritive properties and toxicological profile as substances with immunosuppressive and/or reprotoxic effects, however, have placed natural toxins high on the priority list for current risk assessment and statutory limits to protect animal health and performance. The risk assessment of such natural toxins is characterized by a high level of uncertainty as outlined in detail in the Opinions of the EFSA Panel on Contaminants in the Food Chain (http://www.efsa.europa.eu/en/panels/contam.htm). Hazard identification of natural toxins is often based on simple case reports describing the adverse effects of a plant or plant material on animal health. These reports tend to lack a clear indication of the toxin concentration and the amount consumed. However, in order to accurately characterize this type of hazard, the dose–effect relationship needs to be established. Moreover, adverse effects observed after consumption of feed materials by the animal could be associated with one or more plant secondary metabolites (PSMs) and the number of possible mixtures of undesirable substances multiplies in complex feed mixtures and animal diets (Fink-Gremmels, 2010). Remarkable progress has been made in methods for analysing the complex pattern of natural toxins occurring in animal feeds, but the technical challenge still remains, as specialized technical knowledge in modern (multi-toxin) analyses is required.

An even larger margin of uncertainty must be taken into consideration in exposure assessment. Plant metabolites and fungal metabolites have a biological function in the natural ecosystem. They may offer the plant or fungus protection against insect damage or pathogen invasion (antiviral and antimicrobial properties) or improve resistance to environmental stress factors (heat, drought, excessive rainfall, nutrient shortage). Inherent to these biological functions, the amounts of synthesized toxic metabolites vary significantly, resulting in a broad (unpredictable) range of actual feed contamination levels (Orians *et al.*, 2011). Hence exposure assessment must take this broad concentration range into account and match this with dietary requirements or common local feeding practices. The composition of a diet, however, varies widely across different geographic regions and correlates with farming practice. Even for one animal species feed composition changes continuously according to age and production status (MacLachlan, 2009). A conservative (precautionary) approach in the assessment of chemical substances in animal feed material will result in a shortage of commercially available feed, while a more generous approach means that the risk remains of adverse effects on the health, welfare and productivity of the animal and of the formation of residues in edible tissues, milk and eggs. The level of uncertainty in exposure assessment may be reduced through the collation of large sets of data on the occurrence of chemical feed contaminants and a detailed assessment of animal feed consumption patterns. Within Europe, this strategy has recently been implemented by the EFSA, who have based animal exposure assessment on large data sets established from thousands of feed analyses conducted in the different Member States during the routine control of feed materials or within the framework of national or Europe-wide monitoring programmes. This approach seems to be very cost-intensive, but still outweighs the high costs of recalling contaminated food batches from the market and, more importantly, reduces the actual risk of accidental human exposure.

1.2.4 Human hazard identification and characterization

Food from animal origin contributes to the exposure of human consumers to microbiological and chemical hazards. *Microbiological hazards* mostly comprise (zoonotic) bacteria and their endo- and exotoxins that are incompletely inactivated during food processing. Viruses are generally (animal) host-specific: food contamination with viral agents is less prevalent and can usually be attributed to secondary contamination during food processing and handling. Exceptional pathogens are prions, which have emerged as contaminants of feed and probably food with high process stability. The most prevalent food-borne diseases, however, can still be attributed to the classic pathogens such as *Salmonella*, *Campylobacter*, *E. coli*, *Listeria* and in some cases *Clostridium* species, as mentioned above. Insufficient hygienic barriers both at farm level as well as in food processing and handling account for this risk (Doyle and Erickson, 2012). One of the corrective actions employed at farm level was (and still remains) the use of antibiotics to counteract clinical and subclinical infections in animals. One well-received side-effect of the use of antibiotics is their growth-promoting effect in target animal species. The abundant use of antibiotics in livestock (including fish) seems to contribute, however, to the global emergence of antimicrobial resistance (Gilchrist *et al.*, 2007). The horizontal transfer of resistant bacteria from living animals to humans has been well documented for MRSA (Methicillin-Resistant *Staphylococcus aureus*), involving all animal species so far investigated, including pigs, cattle, horses and domestic pets. Although the pathogenicity of the typical livestock MRSA (ST398) seems to be low in humans, there are concerns about a possible gene transfer between these less pathogenic strains and the highly pathogenic hospital-acquired MRSA strains (Graveland *et al.*, 2011; Garcia-Graells *et al.*, 2011). The same applies to *E. coli* isolates expressing Extended Spectrum β-Lactamases (ESBLs) (Liebana *et al.*, 2006). As the genes encoding for ESBL are located in mobile transmissible elements (plasmids), gene transfer between animal-born isolates and human *E. coli* strains cannot be excluded. An increasing prevalence of pathogens that are resistant to multiple and perhaps in the future to all known classes of antibiotics is currently considered to be the most serious hazard for the human population.

In contrast to the microbiological hazards associated with handling and consumption of animal-derived foods, the prevalence of *chemical hazards* such as residues in edible products is much lower, despite the increasing concerns about long-term subclinical effects (Miraglia *et al.*, 2009). The animal has the function of a filter in which the toxin burden of chemical feed contaminants is generally reduced as a result of biotransformation and elimination by the animal. However, there are well-known exceptions to this general paradigm. Some persistent pollutants accumulate in the animal, such as heavy metals in the kidneys of herbivores, and organic pollutants in fatty tissues including fish meat. Special attention is paid to the excretion of potentially toxic substances in milk, as infants consume relatively high amounts of milk when consumption is corrected by the (low) body weight and exhibit an increased vulnerability to developmental toxicity such as neurotoxicity and immune toxicity (Miodovnik, 2011). Due to these various mechanisms the low prevalence and small concentrations of chemical residues create a very limited human exposure to chemical contaminants of milk, meat and eggs. Consumer perception, however, differs significantly from this scientific evaluation.

1.3 Risk management and communication

The competent authorities are responsible for translating the results of scientific risk assessment into enforceable and controllable legislation, aiming at optimal consumer protection. This has resulted in a broad framework of legal provision and analytical controls for chemical contaminants, and testing for compliance with statutory limits. The most recent compilation of the data from chemical residue monitoring in pig meats was conducted by EFSA (published in October 2011; http://www.efsa.europa.eu/en/efsajournal/pub/2351.htm), indicating a prevalence of non-compliant samples of less than 0.34% for all chemicals (including veterinary drugs) with the highest level of 1.26% of non-compliant samples recorded for chemical elements (heavy metals and metalloids). The total sample size included more than 800,000 analytical results provided by the national residue monitoring programmes conducted in the EU Member States. It should be reiterated that the given percentages refer to the fact that a tissue sample was non-compliant with the current legislation, which does not mean that the measured concentration constitutes a direct health hazard for the consumer of the product. Of this total number of positive samples, the actual number that exceeded statutory limits was even lower. Comparable data analyses for other animal species such as poultry, small and large ruminants and wildlife species are in progress. This evaluation of residue monitoring is of the utmost importance in identifying shortcomings in the control of the production chain from *farm to fork* and to set priorities for corrective measures. It is also of importance for risk communication, providing the consumer of animal products with the necessary information on the actual health risk. Although these results convincingly indicate that the human health risks are low, the contamination of feed with undesirable substances remains a risk for animal health and welfare. In the presence of toxic (undesirable) substances, the health status of the animal is known to decrease, thereby increasing the risk of infectious diseases. This may in turn increase the risk of products from diseased animals, which contain microbiological contaminants, entering the food chain, and also contributes to an increased use of antimicrobials (antibiotics). This in turn may contribute to the global emergence of antibiotic-resistant pathogens. It remains essential to communicate these different risk scenarios to risk management, stakeholders and consumers (Thorne, 2007).

1.4 Future trends

As a result of changes in agricultural practice and of the availability of feed materials that include more and more secondary (by-)products of technical processes (bio-energy) and recycled products, in order to protect declining natural resources, stakeholders, animal nutritionists and animal health professionals and the competent authorities will need to devote attention to feed safety at all times. In addition, the global transport of feed materials offers numerous opportunities for the post-harvest contamination of feed materials with undesirable microbiological or chemical agents. The transport of feed materials may also serve as a vector for the trans-continental transfer of (resistant) pathogens that affect not only animal but also plant health, and contribute to the spread of invasive weeds and infective agents. Global changes, such as climate change, will require production sites for feed materials to be reallocated, a measure that may prove to be of great socio-economic impact. It is likely that animal operations will fall into two entirely different sectors: on the one hand, conventional and sustainable rural (organic) farming with a low input of external feed resources, and on the other, large-scale animal operations that are needed to cover the increasing need of the world population for animal proteins. In turn, feed safety assessment has to acknowledge these different production systems and provide tailor-made solutions to enable effective integrated quality programmes that protect animal and consumer health.

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2

Animal feeds, feeding practices and opportunities for feed contamination: an introduction

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Abstract: Feeds for farmed livestock must satisfy the requirements of both the animals and the ultimate consumers of animal products, particularly in respect of safety. Feed legislation provides comprehensive safeguards but incidents that threaten feed and food safety still occur. The grazing animal may be faced with a number of hazards brought about by the geology of the area or industrial activity, or by plants that contain natural toxins or become infected with microbial pathogens. Harvested feeds may be contaminated in store, during processing, mixing or transportation as a result of spoilage or contact with unapproved feeds and non-agricultural materials being carried in the same vessel.

Key words: feeds, feeding, contamination opportunities, rapid alerts.

2.1 Introduction

Feeds are primarily aimed at satisfying an animal's nutritional needs for maintenance, activity, production and reproduction. However, farmed livestock are reared to produce meat, milk and eggs for human consumption and feeds for such animals must also satisfy the requirements of the ultimate consumers of all products of animal origin. Nowhere is this more important than in the consideration of food safety and it is apposite that the protection of human health is a fundamental objective of the European Food Law (EC, 2002b), with feed destined for food-producing animals considered within that context. In other words, animal feed is recognised as being part of the human food chain, and any consideration of feed safety needs to include both the risks for the animals that eat it and those that may affect the human consumer of animal products.

2.1.1 Feed legislation

Animal feed is defined rather broadly in European legislation, but there is an overriding stipulation that feeds placed on the market should be safe, sound, genuine and fit for purpose and have no adverse effect on animal welfare or the environment (EC, 2009a). Such non-specific requirements are supported by quantitative controls on the presence of undesirable substances in feed, such as toxic metals (e.g. arsenic and cadmium), persistent pollutants such as dioxins or natural toxins (EC, 2002a), and a number of materials, including treated seed, tanning wastes, faeces and waste waters that are specifically prohibited. These additional proscriptions help to complete a comprehensive safeguard against known hazards in feeds. The scope of the undesirable substances legislation was extended by the Feed Hygiene Regulation (EC, 2005) to ensure safety throughout the feed chain by imposing measures to control spoilage and contamination from crop and feed production, through storage, transport and processing to the eventual feeding of the material. It has been estimated by the EC Commission that, in 2007, some six million feed business operators fell within the scope of this Regulation (EC, 2007).

2.1.2 Feed assurance

Running alongside these legal controls, the feed industry in various countries has developed voluntary codes of practice, e.g. GMP Plus in the Netherlands, OVOCOM in Belgium, and AIC Assurance Schemes (2009a–c) in the UK. They aim to ensure safe practices in the production, processing, storage and transport of feeds, and they demand that assured farmers buy feed only from assured suppliers, who in turn purchase their raw materials only from assured producers. Independent audits ensure that each link in the chain complies with the required standard so that, collectively, these assurance schemes ensure safe food and help to build consumer confidence in the safety of the feed chain that supports the production of food products from livestock farms.

It seems self-evident that assurance schemes should be interlinked in order to provide comprehensive control throughout the feed chain, but each link has been built step by step as new threats have been identified, assessed and controlled. Formal risk assessments based on HACCP principles (Codex 2003) are an integral part of the codes of practice, and they later became a legal requirement in the EU when the Feed Hygiene Regulation of 2005 was implemented for all businesses that had any involvement with animal feed supply.

The potential risks posed by an incomplete safety chain may be envisaged in situations where there is widespread contamination of the growing crop, such as by aflatoxin in maize, and an accompanying feed shortage. Feed chain assurance should make certain that contaminated supplies are