On-farm contamination of animals with chemical contaminants

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Summary
Food products should not contain unsafe levels of chemical contaminants. However, it is not possible to monitor each and every one of the many thousands of chemicals that are used in our advanced societies. Chemical contaminants in foodstuffs of animal origin may be classified into three categories: natural contaminants (e.g. mycotoxins), environmental contaminants linked to industrialisation and/or urbanisation (e.g. dioxins and dioxin-like compounds) and authorised chemical products (e.g. residues of veterinary medical products). Chemical hazards may contaminate foodstuffs of animal origin all the way from farm to fork. Contamination may occur in any of the different production systems, and it is difficult to make comparisons between production systems (e.g. extensive versus intensive farming systems) with regard to food safety. Even when we take into account the latest analytical methods, which can detect ever-smaller quantities of residues, the relative importance of chemical contaminants seems to have declined during recent decades due to improvements in information and prevention. Nonetheless, individual incidents can never be ruled out and may have serious economic, health or social repercussions. Particular attention must be paid to chemical hazards, in order to reduce as much as possible the risks to livestock and to the consumer. Continued monitoring and periodic reassessment of risks posed by these contaminants (at the national level) are needed to detect or anticipate new problems, so that appropriate actions can be taken in the interest of public health. More attention should be paid to the production of detailed information, especially with regard to background data (e.g. the objectives of the monitoring, sampling methods, chemicals to be analysed, analytical methods, detection limits, raw data and specified units), in order to obtain a better basis for risk assessment. Such risk assessment provides control authorities with an effective tool for the exchange of information and measures to be taken to ensure food safety.

Keywords
Introduction

In the vast majority of cases, food products do not contain unsafe levels of chemical contaminants (101). However, there is a potential for chemicals to contaminate foodstuffs of animal origin at any point in the continuum from farm to fork; the risk is highest during primary production, but also exists during transport from farm to slaughter, during processing, distribution, retail, and finally also when preparing a meal (13).

Foodstuffs may be divided into different groups depending on the type of agricultural production system, for example family-produced foodstuffs, conventionally produced foodstuffs, organically produced foodstuffs, integrated-pesticide-management foodstuffs, foodstuffs produced under label or with market claims, and foodstuffs produced according to technical specifications set by the distribution sector. Chemical contamination cannot be excluded in any of the production systems.

Because of inadequate sampling methods, the considerable number of parameters to be considered and the high variability of the parameters measured in most studies published in the scientific literature, a comparison between production systems with regard to food safety (in particular chemical contaminants) is currently not prudent. For example, despite the widespread popularity of organic products, it appears that in some cases they present specific risks because they are produced according to natural production modes (e.g. no clearly defined hygienic requirements, lack of professionalism of the growers). On the other hand, conventional production systems require more inputs and outputs than the average family farm (e.g. large-scale trade of cereals and feedstuffs within the organic food market, internationalisation of the exchange of animals and products of animal origin). Whatever the rules and regulations of the different animal production systems, the same problems are faced by Veterinary Services, regulatory agencies and producers when attempting to produce safe food.

Many thousands of chemicals that are used in society have to be considered when assessing food safety. It is not possible to monitor all of them. For foodstuffs of animal origin, the chemical contaminants of greatest concern include:

- residues of veterinary medicinal products
- hormone and pesticide residues
- nitrates
- bacterial toxins
- mycotoxins
- phytotoxins
- algal toxins
- marine toxins
- heavy metals
- dioxins and dioxin-like compounds
- disinfectants
- polycyclic aromatic hydrocarbons (PAHs)
- processing contaminants such as acrylamide
- chemicals migrating from packaging materials.

Moreover, some animal tissues are inherently toxic (e.g. livers of puffer fish) (116). People can be exposed to chemicals through various routes, including:

- air (volatile organic compounds such as formaldehyde, ammonia and carbon dioxide)
- skin and mucosa (e.g. pesticides)
- water (e.g. heavy metals)
- food (e.g. toxins or dioxins and dioxin-like compounds) (10, 20, 21, 76, 91, 105, 133).

The need to ensure food safety throughout the food chain is evident, but it starts with primary production (i.e. at the farm) (13).

This paper provides an overview of some chemical hazards that occur during the production phase of food of animal origin. They are described here in relation to production systems, commodities and specific contaminants. Several options to prevent, monitor and manage these hazards in order to avoid chemical contaminants in the final product are also described.

What is a chemical contaminant and what are chemical incidents?

A contaminant is a potentially harmful chemical substance, of anthropogenic or natural origin, which may be present in food following deliberate treatment or accidental contamination during the production, transformation or preservation of foodstuffs. Deliberate treatment includes the use of plant protection products, veterinary medicine products, and feed and food additives. Accidental contamination may be caused by poor control of the production system or by production factors that are not controllable; for example, climatic risk can increase the production of mycotoxins if there is excessive rainfall at certain times of the year (110, 112). Several databases
A chemical incident is a release from containment of a chemical of public health or environmental concern that results in actual or potential exposure to a chemical substance or its hazardous by-products, and that causes or has the potential to cause human ill-health. This includes incidents in which two or more individuals suffer from a similar illness that is due to common exposure to one or more chemicals (153). According to the International Programme on Chemical Safety (IPCS), 436 chemical incidents of international public health importance were reported in the world during the period between 1 August 2002 and 31 July 2003 (153). This figure probably underestimates the actual number of incidents, because incidents reported in English-language media were more likely to be listed. In terms of World Health Organization (WHO) regions, the largest proportion of the 436 events occurred in the Americas (45.6%), followed by Europe (27.3%), the Western Pacific (13.8%), South-East Asia (6.2%), Africa (3.7%) and the Eastern Mediterranean (3.4%). Only one incident concerning a farm was reported in this programme (153).

The actions taken to protect public health are multiple and include, for example, advising against eating seafood obtained from contaminated water (e.g. 6, 102), banning the use of contaminated drinks, and food recalls (153). There are also many regional initiatives to ensure food safety, such as the rapid alert system for food and feed (RASFF) in the European Union (EU). The RASFF was established to provide control authorities with an effective tool for the exchange of information on measures taken to ensure food safety (51). During the year 2004, more than 1,800 notifications concerning chemical contaminants were exchanged between EU Member States. These are listed according to chemical hazards in Table I, which shows that mycotoxins, residues of veterinary products and heavy metals are of particular concern as chemical hazards in the food chain.

### Table I
Alert and information notifications based on the rapid alert system for food and feed according to chemical hazard type in the European Union (according to Regulation [EEC] No. 178/2002 [51])

<table>
<thead>
<tr>
<th>Chemical hazards</th>
<th>Alert</th>
<th>Information</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mycotoxins</td>
<td>44</td>
<td>837</td>
<td>881</td>
</tr>
<tr>
<td>Residues of veterinary medicinal products</td>
<td>41</td>
<td>101</td>
<td>142</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>14</td>
<td>82</td>
<td>96</td>
</tr>
<tr>
<td>Pesticide residues</td>
<td>7</td>
<td>41</td>
<td>48</td>
</tr>
<tr>
<td>Food additives</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Biotoxins</td>
<td>7</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Feed additives</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Other chemical contamination</td>
<td>273</td>
<td>363</td>
<td>636</td>
</tr>
<tr>
<td>Total</td>
<td>388</td>
<td>1,442</td>
<td>1,830</td>
</tr>
</tbody>
</table>

a) Alert notifications are sent when the food or feed presenting the risk is on the market and when immediate action is required;
b) Information notifications concern a food or feed for which a risk has been identified, but for which the other members of the network do not have to take immediate action because the product has not reached their market.

Consumer perception: a powerful lever for policy-makers

Many examples demonstrate that public confidence in the safety of the food supply is affected by incidents involving different classes of chemical contaminants, different animal species and different links in the food chain. Examples are:

- in the past, the association of diethylstilbestrol (DES) with vaginal cancer in daughters of women treated with this hormone raised questions about the safety of DES as a growth promoter in animals (e.g. 117);
- in 1979, there was widespread distribution of chicken and egg-based products and fat contaminated with polychlorinated biphenyls (PCBs) across the United States of America (USA) and as far away as Canada and Japan. The contamination was traced to an accidental leakage of PCBs from a transformer stored in a pig-slaughtering plant in Montana (35). Twenty years later, a Belgian PCB incident occurred when a mixture of PCBs contaminated with dioxins was accidentally added to a stock of recycled fat used in the production of animal feeds for more than 2,500 farms (poultry, pigs and cattle). This resulted in a major food crisis, which rapidly extended to the whole country and could be resolved only by the implementation of a large PCB/dioxin food-monitoring programme (14, 15). Several studies concluded that this incident would probably not have caused adverse effects in the general Belgian population (15, 121, 141). These episodes illustrate the need for vigilance on fat recycling and for a professional risk assessment as a basis for measures to be taken;
- recently, nitrofen contamination of organic poultry meat, eggs, pork and organic feed was found in Germany (45), despite the fact that nitrofen has been banned in the EU since 1988 (1990 for the former German Democratic Republic) (49). Nitrofen is a contact herbicide that was found to be teratogenic and carcinogenic (73). This example shows that unauthorised chemicals can be found a long time after they have been banned.
- scombrototoxic or histamine fish poisoning is a common seafood-borne disease (especially of tuna, mackerel, bonito
and skipjack) (60, 100, 156). Around 10% of the infectious intestinal disease outbreaks reported to the Communicable Disease Surveillance Centre were associated with fish, and about half of those were due to histamine fish poisoning (7, 61). This is the most common cause of seafood poisoning in the USA (89). A variety of factors, including misdiagnosis, result in its under-reporting (156).

All of the above incidents affect the confidence of consumers in food and may subsequently result in (excessively) severe food safety laws and regulations. In this respect, it should be noted that rapid, clear, complete, written communication (including information about uncertainties) about chemical incidents must be the rule for all producers, operators, Veterinary Services and regulatory agencies.

The need for international harmonisation and collaboration in the evolution of analytical performance

Analytical procedures for the detection of chemical contaminants in foodstuffs of animal origin need international harmonisation and collaboration because of the risks to trade and animal and public health in case of non-compliance with legal limits. The evolution of analytical procedures has improved the capacity to detect both greater numbers of chemical contaminants and smaller amounts of such contaminants (Table II). However, developing countries may not be able to obtain the expensive methodology, laboratory materials and operators required to guarantee the necessary monitoring (118). Another factor to consider when selecting methods is that several groups of chemical contaminants, such as residues of antibiotics, can be more efficiently detected with a simple method by monitoring microbial growth. We also need to distinguish between natural occurrence of antibiotics and occurrence that results from intentional treatment, and this task requires more expensive techniques, such as liquid chromatography coupled to mass spectrometric detection (143). A comparison between conventional and organic production farm systems may help explore the effects of deliberate antibiotic treatment. Zero tolerance for antimicrobials in food is still a matter of debate. However, the order of parts per billion (ng/g) as safe food levels seems, in many cases, reasonable for public health purposes (59, 62).

In Europe, in order to achieve harmonisation of analytical methods applied by Member States to monitor chemical contaminants, minimum criteria have been introduced for the performance of analytical methods (44, 47) and harmonised standards for testing for certain residues in products of animal origin imported from third countries (48, 131).

Table II
General analytical procedures for the detection of chemical contaminants in foodstuffs of animal origin

<table>
<thead>
<tr>
<th>Group of chemical contaminants</th>
<th>Analytic method (for typical compounds of the target group)</th>
<th>Limit of detection (order of magnitude)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residues of antibacterial and parasitic drugs</td>
<td>HPLC-DAD (UV) or HPLC-FLD, GC-MS, GC-ECD, LC-MS, bio-assays</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Residues of hormones</td>
<td>GC-HRMS, GC-MS, LC-MS, bio-assays</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>ICP-MS</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Nitrates</td>
<td>anion exchange HPLC</td>
<td>μg/g (ppm)</td>
</tr>
<tr>
<td>Bacterial toxins</td>
<td>LC-MS, bio-assays</td>
<td>ng/g (ppb) ; pg/g (ppt)</td>
</tr>
<tr>
<td>Mycotoxins</td>
<td>LC-MS</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Phytotoxins</td>
<td>HPLC-DAD, LC-MS</td>
<td>mg/g (ppm); ng/g (ppb)</td>
</tr>
<tr>
<td>Marine toxins</td>
<td>LC-MS, HPLC, bio-assays</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Polychlorinated biphenyls</td>
<td>GC-ECD, GC-MS</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Dioxins and dioxin-like compounds</td>
<td>HRGC-HRMS, bio-assays</td>
<td>pg/g (ppt)</td>
</tr>
<tr>
<td>Pesticides</td>
<td>GC-ECD, GC-MS, LC-MS</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons</td>
<td>HPLC-DAD (UV) or FLD, GC-MS, LC-MS (in development)</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Acrylamide</td>
<td>LC-MS</td>
<td>ng/g (ppb)</td>
</tr>
<tr>
<td>Chemicals released from packaging materials</td>
<td>ICP-MS, GC-MS</td>
<td>ng/g (ppb)</td>
</tr>
</tbody>
</table>

GC-ECD: gas chromatography-electron capture detector  
GC-HRMS: gas chromatography-high resolution mass spectrometry  
GC-MS: gas chromatography-mass spectrometry  
HPLC: high performance liquid chromatography  
HPLC-DAD (UV): high performance liquid chromatography-diode array detector (ultra violet)  
HPLC-FLD: high performance liquid chromatography-fluorescence detector  
HRGC-HRMS: high resolution gas chromatography-high resolution mass spectrometry  
ICP-MS: inductively coupled plasma-mass spectrometry  
LC-MS: liquid chromatography-mass spectrometry
Risk of chemical contaminants

The four elements of risk assessment are hazard identification, hazard characterisation (dose–response assessment), exposure assessment and risk characterisation. Estimating the risk associated with dietary intakes of chemical residues by the consumer is a vital and integrated part of regulatory processes. The exposure of the consumer is compared directly to the acceptable daily intake (ADI) (e.g. of pesticides, veterinary medicinal drugs), to the tolerable daily intake (TDI) (e.g. of heavy metals, mycotoxins) and the tolerable weekly (WTI) or monthly (MTI) intake (e.g. of dioxins and dioxin-like compounds). For pesticides or medicinal drugs such as antimicrobial substances, the first step is to compare the detected amounts of residues with the maximum residue level (MRL) authorised in foodstuffs. If the residue level in the food exceeds the MRL, the theoretical maximum daily intakes and the ADI have to be taken into account in order to assess the risk to the consumer. The exposure is obtained using the basic equation:

\[
\text{exposure (mg/kg bw/day)} = \frac{\text{consumption (kg/kg bw/day)}}{\text{residue level (mg/kg)}}
\]

The establishment of the ADI and the TDI is based on the results of toxicological studies that involve the determination of the lowest no-observed-adverse-effect level divided by a safety factor (e.g. of 100), taking into account the interspecies and intraspecies variability (101). Because of the possibility that short-term excursions might give rise to acute toxicity, the concept of the acute reference dose has been developed.

Classification of chemical contaminants

Chemical contaminants may be classified into three categories:

a) natural contaminants

b) environmental contaminants linked to industrialisation and/or urbanisation

c) authorised chemical products.

Natural contaminants

A number of natural contaminants, such as various toxins produced by bacteria (bacterial toxins), fungi (mycotoxins), plant pathogens (phytotoxins) and algae (algal toxins), affect the food chain. In addition, inherently toxic animal tissues may contaminate humans.

Bacterial toxins

Foodstuffs of animal origin may be contaminated with naturally occurring bacterial toxins (e.g. botulinum neurotoxins, staphylococcal enterotoxin). Time and temperature manipulation of a food product contaminated with enterotoxigenic staphylococci can result in the formation of enterotoxin, which can produce food-borne illness when the product is ingested. The staphylococcal enterotoxins are extremely thermostable and can remain biologically active after exposure to retort temperatures (12). Botulinum toxin is regarded as the most lethal substance known (69) and has been a concern in the food industry for a long time (127). Implications for the safety of human food are important (26, 122): botulism is a deadly disease caused by ingestion of the preformed neurotoxin produced from the anaerobic spore-forming bacteria *Clostridium botulinum* (127).

Mycotoxins

Mycotoxins are natural secondary metabolites produced by fungi, which develop on agricultural crops (108, 157). While fungi are destroyed during processing, most of the mycotoxins remain in the final product (28) because of their thermal and acid stability (66). Mycotoxin-contaminated foods may be responsible for toxic effects in animals and humans (108, 115). The main route of exposure of animals and humans to mycotoxins is via foodstuffs, although aerial and dermal routes are also reported (108). The Food and Agriculture Organization estimates that 25% of all harvests are contaminated (2). Dealing with the problem is complex, because a single toxigenic fungus is able to produce different mycotoxins, and a particular toxin can be produced by more than one fungus species (25). Toxigenic fungi from the three genera *Fusarium*, *Penicillium* and *Aspergillus* are widespread in various agricultural products and considered to be economically important worldwide.

The proliferation of the fungi and the synthesis of the mycotoxins can take place before harvest or afterwards, during storage, transport or transformation of the product (53, 109). This phenomenon is very complex and depends on a combination of factors such as the temperature, humidity or oxygenation level of the substrate. Thermal stress, humidity stress (e.g. dryness) and physical stress (e.g. lesions caused by insects) enhance the contamination by fungi and the synthesis of mycotoxins (33, 66, 118, 157). Human disorders are usually the result of chronic exposure to low mycotoxin doses (25, 108). Mycotoxins, such as aflatoxins produced by some *Aspergillus* species, have been found in a large number of agricultural products, including foodstuffs of animal origin (34, 128). They are classified as carcinogenic (74). In order to minimise human and animal exposure to mycotoxins, most industrialised countries carry out regular analyses of
food and feed supplies (19). These products may be exported to developing countries, which are less restrictive (17).

The synthesis, degradation, dilution or concentration of mycotoxins during the treatment of meat and transformation and conservation of milk and its by-products are poorly documented (90).

Phytotoxins
Phytotoxins are products of plant pathogens or host–pathogen interactions that directly injure plant cells and influence the course of disease development or symptoms (blights, leaf spots and galls). Both fungal and bacterial pathogens produce a number of secondary metabolites that are toxic to plant cells, although these metabolites may not be important in plant disease (11). Both neurotoxic poisonous alkaloids and hepatotoxic peptides have been isolated in toxic algae inflorescences (e.g. Microcystis, Anabaena or Aphanizomenon). Usually, the intoxication only occurs if the bloom is dense (warm weather, sunny, eutrophic waters). Algal intoxications affect animals and humans (56).

Marine (algal) toxins
A number of algae can produce heat-resistant toxins which are not destroyed when the algae are eaten by a predator (150). Marine poisoning results from the ingestion of crabs, fish and shellfish that contain toxic substances, and causes substantial illness in coastal regions (neurological symptoms: ciguatera, tetrodotoxin poisoning and paralytic shellfish poisoning) (76). In parts of the Pacific, the number of cases of marine poisoning exceeds 1,200 per 100,000 people per year (146).

Inherently toxic animal tissue
Natural examples of this phenomenon include the bio-accumulation of vitamin A in the livers of some arctic animals in such amounts that a single meal of such tissue can be acutely toxic for a human (116).

Environmental contaminants linked to industrialisation and/or urbanisation
Environmental contaminants are linked to atmospheric deposition, pollution of the soil and pollution of water. Heavy metals, dioxins and dioxin-like compounds, and PAHs are some of the most important chemicals that are found in the environment, especially in the most densely inhabited and/or industrialised countries.

Heavy metals
The level of heavy metals reflects the level of industrial pollution of the local environment. Plants that are contaminated by atmospheric deposition absorb only limited quantities of heavy metals, and the relative importance of heavy metals and metalloids is tending to decline due to improved information and prevention. Nonetheless, individual incidents can never be ruled out and may have serious economic, medical or social repercussions. Particular attention must be given to this problem, in order to minimise the risk to livestock and to the consumer (122). Heavy metals such as mercury tend to bio-accumulate in fish and shellfish due to the remarkable capacity of these animals to turn inorganic mercury into organic compounds that are more easily transferable throughout the aquatic food chain (36).

Dioxins and dioxin-like compounds
Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are cyclic aromatic compounds. Their dispersion in the atmosphere is likely to occur mainly in particulate aerosols (152). These compounds are not produced intentionally but frequently occur as unwanted by-products in chemical processes such as the synthesis of pesticides or of PCBs (136). Combustion processes are recognised as the major sources of PCDDs and PCDFs. Most thermal reactions which involve the burning of chlorinated organic or inorganic compounds appear to result in the formation of these substances. Both PCDDs and PCDFs have been detected in emissions from the incineration of various types of wastes, particularly municipal, medical and hazardous wastes; from the production of iron, steel and other metals; from fossil fuel plants; and domestic coal and wood fires, especially those involving chlorine-containing materials such as polyvinyl chloride and PCBs (37).

Polychlorinated biphenyls are aromatic synthetic chemicals that were produced between 1930 and 1970 and commercialised in relatively large quantities for use as dielectrics, hydraulic fluids, plastics and paints (125). The universal distribution of PCBs throughout the world suggests that they are transported in air (151).

Dioxins (PCDDs and PCDFs) and PCBs with dioxin-like toxicity (dioxin-like compounds) are found in the environment, are persistent and, being fat-soluble, tend to accumulate in higher animals, including humans. Their resistance to degradation and low volatility means that these substances may be transported over long distances and give rise to exchanges of pollutants between countries. In addition, dioxins released into the environment many years ago continue to contribute to contemporary exposure (42).

Humans are exposed to dioxins and dioxin-like compounds predominately through their diet, with dairy
products, eggs, meat and fish contributing roughly 90% of the exposure (57, 87, 111, 121, 134), although no single food group emerges as the principal contributor (64). A common hypothesis explaining the presence of dioxins in livestock is that animals consume feed that has been contaminated by emissions from combustion sources via atmospheric depositions. Dioxins, which have a high affinity for lipid-rich tissues (94), bio-accumulate in the fats of these animals and are passed on to the humans who consume them (58).

Various effects have been reported in animals exposed to PCDDs, PCDFs and PCBs (145). Many of the toxic effects of dioxins were high-dose effects (43). The most commonly reported pathologies are endometriosis, developmental neurobehavioral effects, developmental reproductive effects and immunotoxic effects (81, 83, 145, 149). Dioxins are carcinogenic in several animal species (93), including humans, and increased risk of cancer has been demonstrated at exposure levels more than 100 times the normal intake of the general population (129). Dioxins are classified as human carcinogenic by the International Agency for Research in Cancer (96, 130).

The concept of toxicity equivalency factors has been established for the evaluation of congeners other than 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) (the most toxic) and of mixtures of dioxins (50, 139). Using the available toxicological database on dioxins in 1998, the WHO established a TDI in humans between 1 pg and 4 pg toxic equivalents (TEQ)/kg body-weight/day (bw/d) (140). For the health risk assessment of dioxin-like compounds, the WHO consultation focused on the most sensitive effects that are considered adverse (hormonal, reproductive and developmental effects) seen at low doses in animal studies (rats and monkeys). Human daily intakes corresponding with body burdens similar to those associated with adverse effects in animals could be estimated to be in the range of 14 pg TEQ/kg bw/d to 37 pg TEQ/kg bw/d. To arrive at the TDI, a composite uncertainty factor of 10 was used (149). The upper limit of the TDI should be considered as the maximum tolerable intake on a provisional basis, with the ultimate goal being to reduce human intake levels below 1 pg TEQ/kg bw/d. More recently a WTI of 14 pg TEQ/kg bw/week (43) and a MTI of 70 pg TEQ/kg bw/month (50, 80) were also determined, to reflect the long half-life of TCDD.

The above three methodologies assume a threshold for human cancer risks. Another recent international evaluation based on a non-threshold effect (38, 39) estimates the lifetime risk for all cancers to be $1 \times 10^{-3}$ risk/pg TEQ/kg bw/d. When evaluating standard diets in different parts of the world the results indicated that the estimated intakes of dioxins and dioxin-like compounds approach or exceed the monthly tolerable intake of 70 pg TEQ/kg bw/month (155).

Food incidents have occasionally been reported with dioxins and dioxin-like compounds involving different animal species and occurring at different links of the food chain. Incidents may be caused by environmental contamination (e.g. lightning on pylons with old transformers in cattle pasture) (31), feed contamination (e.g. contamination of dairy products, due to high concentrations of dioxins in citrus pellets which were added to the cattle feed) (23) or by failure in the process (e.g. leakage of PCBs from a transformer stored in a pig slaughtering plant, as was the case in Montana) (35).

**Polycyclic aromatic hydrocarbons**

The PAHs originate from incomplete combustion (pyrolysis) of organic materials, for instance during industrial processes (e.g. burning of fossil fuels) (30), and have carcinogenic properties (71, 72). Rapid industrialisation and/or urbanisation resulted in excessive release of PAHs into the environment (atmospheric deposition), particularly into estuaries. Exposure to these ubiquitous environmental contaminants appears practically unavoidable. Fish appear to be sensitive because the bio-concentration from water, via the gills and skin, and ingestion of contaminated food are possible routes for PAHs to accumulate in tissue (84). The route depends mainly on feeding preference, general behaviour and trophic level of the fish (52, 85, 104). The Environmental Protection Agency in the USA recommends a guideline concentration of 0.67 ng PAHs/g wet weight for fish for human consumption (39, 84).

**Authorised chemical products**

Residues of veterinary medicinal products, of agricultural pesticides and of biocides, and nitrates are among the most important chemicals that are regulated by MRLs. The use of hormones for growth promotion in meat animals, or for enhancement of milk production in dairy animals, remains a controversial issue; the European Union has banned such use in food animals (132, 144).

**Residues of veterinary medicinal products**

Most residues of veterinary products relate to antibacterial and antiparasitic drugs. Among other effects, antibacterial residues in foods of animal origin may cause problems through:

- the direct toxicity of the residues (chloramphenicol, for example, is banned for this reason in Europe) (5, 97, 126)
- involvement in allergic reactions (e.g. β-lactam antibiotics) (79)
– triggering the development of antibacterial-resistant strains of bacteria in animals and people (27)
– interference with starter cultures for fermented food products including cheese, buttermilk and yoghurt (4, 65).

Antibacterial use in on-farm animals and the development of resistant bacteria is dealt with separately in this issue (1). The use of veterinary medicinal products requires strict adherence to the recommendations given by the producer: species, type of animal (dairy versus beef), disease condition, correct dose, route of administration, and frequency and number of treatments (59).

**Residues from agricultural pesticides**

Pesticides are chemicals specifically developed for use in the control of agricultural and public health pests (68). According to the Federal Insecticide, Fungicide, and Rodenticide Act of the USA, pesticides include any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant or desiccant (137).

Due to the widespread use of pesticides in agriculture and public health, and due to a high level of public concern in both developed and developing countries (because of the intrinsic toxicity of and potential exposure to these chemicals), the IPCS devotes significant resources to pesticides, primarily for their assessment, but also for management support. The inventory of pesticides (55), the inventory of evaluations and the summary of toxicological evaluations through 2002 are available electronically (154).

Most commonly used in agriculture are herbicides (residues of these have only occasionally been reported in fruits and vegetables, and occasionally in foodstuffs of animal origin) (95).

Several studies suggest that exposure to some fungicides (and other pesticides) may increase the risk of retinal degeneration among farmers who use them and may cause endocrine disruption, warranting further investigation (20, 32, 67, 77, 82, 92, 98, 106).

Some of the difficulties in dealing with pesticide residues arise because:

a) the number of chemicals to trace is very high

b) although many old products are no longer authorised, accidental or fraudulent contaminations can always occur (e.g. the recent experience with nitrofen in Germany, see above).

Moreover, despite their potential carcinogenicity several chemical compounds were still used, such as dichlorodiphenyltrichloroethane (DDT) in the fight against malaria in many developing countries (150). This use must have induced particular problems because such compounds persist in the environment, accumulate in the fatty tissues and increase in concentration as they pass up the food chain.

**Residues of biocide products**

Biocide products are active substances and preparations containing one or more active substance, produced in the form in which they are supplied to the user, intended to destroy, deter, render harmless, prevent the action of, or otherwise exert a controlling effect on any harmful organism by chemical or biological means (41). Insecticides and fungicides have given most concern in meat, milk and eggs (18, 103, 135, 142).

Insecticides such as organophosphates, carbamates and pyrethrins have been frequently used in veterinary practices (86, 137). These agents are used directly on animals or applied to the area where the animals are confined to control flies, mange, mites, lice, grubs and other external pests (78). They also may be acutely toxic to the people who apply them (24).

Reports of adverse effects following exposure to residues from foods that were treated with insecticides in accordance with their respective approval standards remain very rare (101). However, animals housed in pens made of treated wood, bedded on wood shavings treated with pentachlorophenol (fungicide) or fed with grain treated with fungicides may be contaminated (70, 95).

Disinfectants or sanitisers may be used in several steps of the food chain such as on the farm, in drinking water, in milk producing establishments and in processing areas for food of animal origin, including kitchen areas. In order to minimise the amount of substance applied and to avoid unnecessary residues, disinfectants or sanitisers are classified by groups of food products, and the recommendations given by the producer must be strictly followed (75, 99, 114).

**Nitrates**

Contamination with nitrates in foodstuffs of animal origin has not been thoroughly investigated (8), but several studies in vegetables indicate that food produced in organic production systems has significantly lower nitrate levels in food from conventional production systems (112, 148).
Prevention of chemical contaminants

Preventing contamination by dioxin chemicals serves to minimise their impact on food safety and public health. Prevention is the basis for improvement of awareness and information, and for establishing and implementing the hazard analysis and critical control point (HACCP) system (Table III), in which critical limits are established that take food safety objectives into account (63, 158).

Table III
The seven principles of the chemical hazard analysis and critical control point (HACCP) system

<table>
<thead>
<tr>
<th>HACCP principles</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conduct analysis of potential chemical hazards</td>
</tr>
<tr>
<td>2</td>
<td>Determine critical control points for the targeted hazard or hazards</td>
</tr>
<tr>
<td>3</td>
<td>Establish critical limits</td>
</tr>
<tr>
<td>4</td>
<td>Establish routine monitoring procedures to assess these critical limits</td>
</tr>
<tr>
<td>5</td>
<td>Establish corrective actions to be implemented if critical limits are exceeded</td>
</tr>
<tr>
<td>6</td>
<td>Establish an effective record-keeping system for the programme</td>
</tr>
<tr>
<td>7</td>
<td>Establish a system of verification to document that the HACCP programme is being followed</td>
</tr>
</tbody>
</table>

A better diffusion of health and chemical hazard data obtained through on-farm surveillance (e.g. 107) is needed to improve the awareness of farmers, veterinarians and other food-chain operators. Formal educational programmes for veterinarians and farmers must be devised in order to increase understanding of rational, safe use of drugs in food animals. For most producers, a veterinarian is their first choice for information about dairy market food safety, and more than a third report that they would pay veterinarians to perform food safety assessments (138).

Due to a number of food safety failures, quality assurance is becoming increasingly important in the primary livestock production sector. The use of HACCP systems must be encouraged and disseminated to all operators in the food chain, including farmers (118, 123). An HACCP system must be highly farm-specific and focused on self-management; it should require relatively few documents and not be overly labour-intensive (88). A range of farm hazard inspection checklists should be used to help in this context (e.g. 147).

Monitoring of chemical contaminants

Monitoring systems for chemical contaminants have been set up in various countries (e.g. the National Chemical Residue Monitoring Programme in Canada) (22), often after major incidents (see the section on Consumer perception: a powerful lever for policy-makers). For example, a new monitoring system for chemical contaminants was set up in Belgium after the 1999 PCB/dioxin incident (CONtaminant SUrveillance systeM) (25, 120). This national system aims to achieve better control of the production chain, and is based on a group of actions:

- a permanent monitoring of critical raw materials
- monitoring by means of surveillance and an obligation of traceability of batches of compound feedstuffs
- investigations targeted on farms presenting a particular risk
- the introduction of a statute reflecting the contamination status
- monitoring by means of surveillance of the first transformation and the distribution
- a total system of traceability in the food industry
- a scenario to be applied in the event of any report of contamination (including an emergency plan).

The authors urge all countries to install a similar system with the aim of preventing incidents as far as possible, and having in place the necessary measures to control their consequences should they occur. The programme of controls based on this monitoring must be a continuous process where all relevant information will be taken into account (Fig. 1) (e.g. 3).

Because there are many thousands of chemicals, the general approach to monitoring is based mainly on target sampling after a risk assessment of potential sources of contamination in each country (e.g. 40). However, random sampling of slaughtered animals is advisable in order to estimate the prevalence of particular chemical compounds in an individual country, as this approach allows a comparison of prevalence levels in different countries. Testing of live animals may be considered for a detection system, and may offer an opportunity for future population studies (119). In fact, more attention should be drawn to the production of detailed results, especially concerning background data (objectives of the monitoring, sampling methods, molecules to analyse, analytical methods, detection limits, raw data and specified units), in order to obtain useful risk assessments. It is also noted that milk, meat, egg and honey products do not always originate from a specific country, and the monitoring system must take this into account. The risk assessment provides control authorities with an effective tool for the exchange of information and measures taken to ensure food safety.

Most residue-monitoring programmes employ at least screening and confirmatory tests. The screening test is
sensitive but somewhat lacking in specificity. The confirmatory test should have a higher degree of specificity but be at least as sensitive as the screening test (143). The very specific physico-chemical methods used for confirmation are usually expensive. In the case of deliberate treatment, one option used in several countries is to make the offending livestock producers pay for the confirmatory tests in cases where residues of authorised chemical products above the MRL or residues of an unauthorised chemical product are found.

Managing chemical contaminants

Food safety laws and regulations deal in particular with:

- identification and registration of animals, operators and products
- harmonised systems of traceability throughout the food chain
- guidelines for each sector and procedure for all operators
- rapid notification of incidents
- scientific advice
- risk analysis
- regular exchanges between regulatory authorities and consumers

- where necessary, an adequate use of the precautionary principle (9, 16, 113, 124).

Even though the newest tests are able to detect ever-smaller quantities of residues, the relative importance of chemical contaminants seems to have declined in the last decades due to improvements in information and prevention. Nonetheless, individual incidents can never be ruled out and may have serious economic, health or social repercussions. Particular attention must be paid to this problem, in order to minimise the risks to livestock and consumers. Continued monitoring and periodic reassessment of risks posed by these contaminants (at the national level) are needed to detect or anticipate new problems so that appropriate actions can be taken in the interest of public health.

Challenge for the future

The number of chemical incidents actually reported probably greatly underestimates the real number of cases. There is thus a need to accurately assess chemical hazards throughout the food chain in order to determine the real use of potentially harmful chemicals, assess their risks, and develop strategies to prevent accidents arising from their use.
Contamination des animaux à la ferme par des contaminants chimiques

C. Saegerman, L. Pussemier, A. Huyghebaert, M.-L. Scippo & D. Berkvens

Résumé
Les denrées alimentaires ne devraient pas contenir des concentrations en contaminants chimiques qui présentent des risques pour la santé. Il n’est toutefois pas possible de surveiller chacun des milliers de composés chimiques qui sont utilisés dans nos sociétés avancées. Les contaminants chimiques qui concernent les denrées alimentaires d’origine animale peuvent être classifiés en trois catégories : les contaminants naturels (par exemple, les mycotoxines), les contaminants de l’environnement liés à l’industrialisation et/ou l’urbanisation (par exemple, les dioxines et les composés à activité dioxine) et les produits chimiques autorisés (par exemple, les résidus de médicaments vétérinaires). Les dangers chimiques peuvent contaminer les denrées alimentaires d’origine animale de la ferme à la fourchette, en particulier lors de la production primaire, mais aussi lors du transport de la ferme à l’abattoir, lors de la transformation, de la distribution, de la vente au détail et lors de la préparation du repas. Aucun système de production n’est exclu d’une possible contamination chimique et, actuellement, la comparaison entre ces systèmes (par exemple entre les systèmes d’exploitation intensive et extensive) est difficilement réalisable du point de vue de la sécurité alimentaire.
Bien que la capacité des nouveaux tests à détecter de plus faibles quantités de résidus augmente, la relative importance des contaminants chimiques tend à décroître dans les dernières décades en raison de l’amélioration de l’information et de la prévention. Malgré tout, des incidents individuels ne peuvent jamais être écartés et peuvent avoir de sérieuses répercussions économiques, sanitaires et sociales. Une attention particulière doit être accordée à ce problème en vue d’atténuer le risque pour le cheptel animal et le consommateur. En outre, une surveillance continue et une réévaluation périodique des risques posés par ces contaminants (au niveau national) sont nécessaires pour détecter ou anticiper les nouveaux problèmes de sorte qu’une action appropriée puisse être prise dans l’intérêt de la santé publique. En vue d’obtenir une meilleure information pour réaliser des évaluations de risque, plus d’attention devrait être consacrée pour mettre à disposition des résultats détaillés, en particulier pour obtenir des données relatives aux niveaux de fond (par exemple, les objectifs de la surveillance, les méthodes d’échantillonnage, les molécules recherchées, les méthodes analytiques, les limites de détection, les valeurs brutes et les unités de mesures spécifiées). Cette évaluation de risque offre aux autorités de contrôle un outil effectif pour l’échange d’information et de mesures à prendre pour garantir la sécurité sanitaire des aliments.

Mots-clés
Contaminación de animales con sustancias químicas en las explotaciones

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Resumen
Los productos alimenticios no deben contener concentraciones peligrosas de contaminantes químicos. Pero es imposible vigilar a todas y cada una de los miles de sustancias químicas que se utilizan en nuestras sociedades avanzadas. Los contaminantes químicos presentes en los productos alimenticios de origen animal pueden clasificarse en tres categorías: contaminantes naturales (por ejemplo, las micotoxinas); contaminantes ambientales, consecuencia de la industrialización y la urbanización (por ejemplo, las dioxinas y compuestos similares), y los productos químicos autorizados (por ejemplo, los residuos de medicamentos veterinarios). Los productos alimenticios pueden contaminarse con sustancias químicas en cualquier etapa de la cadena alimentaria, en particular durante la producción primaria pero también durante el transporte de la explotación al matadero, la transformación, la distribución, la venta al por menor y la preparación de la comida. Asimismo, todos los sistemas de producción pueden sufrir contaminaciones. Además, estos últimos (por ejemplo, los sistemas de cría intensiva y extensiva) son difíciles de comparar en relación con la seguridad sanitaria de los alimentos.

Según los resultados obtenidos incluso con los métodos de análisis más recientes, que permiten detectar cantidades cada vez más pequeñas de residuos, la importancia relativa de los contaminantes químicos parece haber disminuido en las últimas décadas gracias a la mejora de la información y la prevención. No obstante, no puede descartarse la posibilidad de que se produzcan incidentes aislados, que pueden tener consecuencias económicas, sanitarias o sociales de gravedad. Debe prestarse una especial atención a los peligros químicos para reducir al máximo los riesgos que amenazan al ganado y a los consumidores. La vigilancia ha de ser permanente y los riesgos que presentan esos contaminantes deben reevaluarse periódicamente en todo el territorio nacional para detectar los problemas existentes y prever los que podrían aparecer, de modo que se puedan tomar medidas adecuadas para proteger la salud pública. Debe darse una mayor importancia a la publicación de información detallada, en particular la relativa a las finalidades perseguidas (por ejemplo, los objetivos de la vigilancia, los métodos de muestreo, las sustancias químicas que deben analizarse, los métodos de análisis, las concentraciones a detectar, los datos brutos y las unidades a utilizar) para disponer de datos más completos en los que basar los análisis de riesgos. Gracias a estos últimos, que constituyen una eficiente herramienta, las autoridades responsables de los controles pueden intercambiar información y tomar medidas adecuadas para asegurar la inocuidad de los alimentos.

Palabras clave
References


Contaminant means any substance not intentionally added to food which is present in such food as a result of the production (including operations carried out in crop husbandry, animal husbandry and veterinary medicine), manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food, or as a result of environmental contamination. Food contamination refers to the presence of harmful chemicals and microorganisms in food, which can cause consumer illness. The impact of chemical contaminants on consumer health and well-being is often apparent only after many years of processing and prolonged exposure at low levels (e.g., cancer). Unlike food-borne pathogens, chemical contaminants can cause on-farm contamination of animals with chemical contaminants. A contaminant is a potentially harmful chemical substance, of anthropogenic or natural origin, which may be present in food following deliberate treatment or accidental contamination during the production, transformation or preservation of foodstuffs. Deliberate treatment includes the use of plant protection products, veterinary medicine products, and feed and food additives.