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Food monitoring and control for environmental contaminants

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Abstract

Background Environmental contaminants migrate across national borders; therefore, their release and presence in the environment cannot be fully controlled via national or regional legislation. In addition to polluting the air, rivers, the sea and soil, environmental contaminants can and often do end up in the food chain. *Aims* This paper characterises the environmental contaminants, describes their occurrence in food and outlines the associated economic impact. *Case Studies* The problem is exemplified through three groups of contaminants, namely, dioxins and polycyclic biphenyls, polycyclic aromatic hydrocarbons and trace elements. *Discussion* The status of the current harmonization efforts at a legislative and an analytical level is outlined, with a special focus on the situation within the European Union. *Conclusion* Recommendations are advanced for achieving a greater level of harmonization at an international level.

Introduction

Historic context

From ancient times, civilizations have seen the need to protect consumers from dishonest and unsafe practices in the sale of food. Assyrian tablets of stone described the method to be used in determining the correct weights and measures for food grains, while Egyptian scrolls prescribed the labelling to be applied to certain foods. In ancient Athens, beer and wines were inspected for purity and soundness, and the Romans had a well-organized state food-control system to protect consumers from fraud or bad produce. In Europe, during the Middle Ages, individual countries passed laws concerning the quality and safety of eggs, sausages, cheese, beer, wine and bread. Some of these ancient statutes still exist today. The present day Codex Alimentarius draws its name from the code used during the Austro-Hungarian Empire between 1897 and 1911 for describing a variety of products and related standards.

What are environmental contaminants?

Environmental contaminants are ubiquitous in the environment and may be found in all food products. Some, especially those known as persistent organic pollutants, bioaccumulate and are generally found in higher concentrations in animal products such as meat, milk and eggs. They arise as a result of chemical contamination in agricultural green areas (where animals are raised), in animal feeds or during the production process. Organic contaminants arise initially during industrial processes and many tend to persist in the environment as a result of their chemical stability and other physico-chemical properties. Metals and some radionuclides in foods may also be anthropogenic but they can also be the result of the geology and geography of the regions where animals, birds or fish are farmed or produced combined with the location of production and the type of feed ingredients used. Stable environmental contaminants may also be resistant to metabolism in either plants or animals, and this can lead to bioaccumulation as higher trophic levels of the food web are reached. Since fish and meat are at the top of the aquatic and terrestrial food chains, respectively, high levels of these persistent ubiquitous contaminants can accumulate in the tissues of fish and meat-producing animals. In those cases where meat and fish by-products are used for animal feed, there is further scope for the elevation in levels of

these compounds, unless they can be removed during processing.

Specific environmental contaminants

Because of the wide range of environmental contaminants in food and the lack of similarity between them, three groups of environmental contaminants, namely, dioxins and polycyclic biphenyls (PCBs), trace elements and polycyclic aromatic hydrocarbons (PAHs) were selected for considering the issues relating to the concept of harmonized monitoring and control of environmental contaminants.

Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (collectively referred to as 'dioxins') arise as a result of combustion processes, as by-products in the manufacture of organo-chlorine compounds or as a result of activity of the chlorine industry. They are chemically stable and are ubiquitous in human tissues even when there is no known history of occupational or accidental exposure. Although exposure could occur through inhalation, dermal absorption, consumption of drinking water and consumption of food, the latter is the predominant route for the general population and accounts for over 90% of human exposure. The sum of dioxins and dioxin-like PCBs is usually expressed in pico-grammes dioxins (as toxic equivalents to the most toxic 2,3,7,8-TCDD) per gramme of food.

PCBs are a group of compounds, which were manufactured until the 1980s for use in various applications including electrical products, e.g. as a dielectric in transformer oil. They are also ubiquitous environmental pollutants, and it has become widely accepted that some PCBs elicit dioxin-like biochemical and toxic responses. Assessment of the health risks of exposure to dioxin-like chemicals must therefore consider these PCBs in addition to the dioxins. PCBs have a variety of other biological effects, however, and although a consideration of 'dioxins' is incomplete without the inclusion of dioxin-like PCBs, the different types of toxic effects of these and other PCBs should also be taken into account.

Trace elements include the essential minerals of chromium, copper, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, selenium and zinc, which are of interest because of their possible health effects, both positive and negative, and the elements, arsenic, cadmium, lead, mercury and tin, which have no known beneficial biological functions and for which long-term exposures may be harmful to health. The main sources of these metals and other elements in food are from the environment. However, some are intrinsic in food, such as iron in the liver, and some, such as arsenic, can be endogenous (e.g., in Bangladesh, where there is groundwater contamination), whereas others such as lead normally arise as a result of pollution from industry and other human activities. Elements can also arise in food as a result of certain agricultural practices; for example, cadmium can be traced to the use of phosphate fertilizers in farming. Manufacturing processes are also potential sources of contamination; for instance, tin can be introduced to the food supply through the canning process. It is also possible to introduce trace metals during food preparation when metal, glazed ceramic or enamelled cooking utensils are used. The levels of minerals and elements in food vary considerably from 4.525 $mg\,kg^{-1}$ of cadmium in bivalve molluscs other than oysters (EFSA, 2009) to 1 $\mu g\,kg^{-1}$ of mercury in cornflakes and peanut butter (NZFSA, 2005). This large range of possible concentrations illustrates the capability that is demanded of an analytical methodology in order to provide reliable results.

PAHs consist of a large family of aromatic compounds containing three or more fused aromatic rings made up of carbon and hydrogen. The term is most often used for unsubstituted parent compounds and their alkyl-substituted derivatives, but can also be used for functionalized derivatives, such as chloro- or nitro-PAHs and heterocyclic analogues such as indole, quinoline, benzothiophene, 9-cyanoanthracene and dibenzothiophene. There are about 250 compounds generally included in the term PAHs (Cano-Lerida *et al.*, 2008). PAHs and their derivatives are widespread in the environment and are found in the atmosphere, surface water, sediments and soil, food and lipid tissues. They arise from both natural and anthropogenic sources, such as burning fossil fuels, and other processes involving incomplete combustion (European Commission, 2002). Although PAHs are present in some foodstuffs as a result of environmental exposure, the processing of food by smoking, drying, barbecuing and other cooking methods is the largest source of PAHs in food (Mottier *et al.*, 2000). Charcoal grilling in particular can generate high levels of PAHs, and quantities are related to factors such as fat content, temperature and cooking time. The levels of non-substituted PAH in food thus vary to a great extent.

Stakeholder environment

The major stakeholders in the context of this paper are: (1) national and international authorities, (2) internationally operating validation, standardization and/or proficiency testing bodies, (3) providers of analytical methods, (4) food

manufacturers using hazard analysis and critical control points and standard methods and (5) consumers.

National and international authorities are seen as key stakeholders because of their mandates to protect consumer safety and ensure fair trade and consumer confidence. Within the European Union (EU), a network of Community Reference Laboratories (CRLs) and National Reference Laboratories (NRLs) was set up to assist the work of public authorities. Their role includes work on the harmonization of food control across the EU. NRLs work closely with the Central CRLs appointed by the European Commission and with official national control laboratories within their own country. The CRL and NRLs also provide a channel for communication among relevant authorities and provide input for the production of standard operating procedures, codes of practice and guidance documents. They also provide input about compliance audits, organize inter-laboratory comparisons and arbitrate in cases of dispute.

Further rapid responsiveness and communication is facilitated via the Rapid Alert System for Food and Feed (RASFF), in place since 1979. Keeping its structure simple with clearly identified contact points and information exchange in clear and structured formats ensures the effectiveness of this alerting and information-exchange mechanism.*

The CRLs, NRLs and RASFF together have a key operational role in the development, implementation and communication of harmonized monitoring of environmental contaminants.

Legislative considerations

Different global regions have different approaches to regulation, legislation and enforcement. The degree and scope of food safety regulation correlates strongly with socio-economic development:

- In least-developed, very poor regions, ensuring an adequate food supply in order to prevent starvation is the highest priority, and less attention is given to good agricultural practice. Food safety controls in these countries may be practically non-existent.
- In developing countries and also in several industrialized countries, the lack of comprehensive food safety controls can result from a weak institutional capacity in conjunction with low wages.

While, according to the WHO, food safety is a basic human right, and thus of importance to all, in practice, relatively rich countries prioritize food safety much higher than poorer countries, since affluence is linked to a higher awareness about health and diet, better availability of analytical equipment and expertise and more comprehensive legal frameworks. Some critics of stricter food safety regulations from developing or least-developed nations will point out that these standards represent mere tools for protecting domestic markets (or in the case of the EU, the EU market when competing with third countries) from international competition. The WTO Appelate Body has addressed several such cases, as well as conflicts between developed trading blocks such as the EU and the United States. At the same time, studies by the World Bank suggest that stricter food safety regulations can also be a means for advancing economic development (Jaffee & Henson, 2004; World Bank, 2005).

Basic food law

Worldwide, food legislation is increasingly science based. A risk-based approach is also applied in Europe. The European Food Safety Authority (EFSA) is in charge of assessing risk, and their opinions are taken into account by the risk managers, i.e. the legislators. If an insufficient scientific foundation exists, the so-called Precautionary Principle may be applied, to avoid placing human health at risk. The basic food laws of all Member States must comply with the risk-based Regulation (EC) No. 178/2002 that defines the general principles and requirements of food law. Clauses 1 through 4 of Article 14 (*Food Safety Requirements*) are particularly significant. Clause 1 states that if food is unsafe, it shall not be placed onto the market. Clause 2 defines unsafe food as food that is either injurious to health or unfit for human consumption, while Clause 3 requires any decision to bear in mind the conditions of use throughout the food chain and information provided to the consumer. Clause 4 takes this point further by requiring that any decision, whether or not a food is injurious to health, must be based not only on short/long-term effects on the consumer but also the succeeding generations, the consequences of acute versus chronic effects and whether any subgroup of the population may be particularly at risk.

*The RASFF releases three types of notifications: alert notifications are released when contaminated food is identified requiring measures from different countries; information notifications are released when contaminated food has been identified and removed before reaching a wide distribution – the notification in this case is meant as a warning that enhanced monitoring might be required in a specific sector. News notifications are general information bulletins.

Environmental contaminants and the law

Environmental contaminants are regulated differently from pesticides and veterinary medicines because they are not intentionally manufactured for use in farming and so there is no similar approval process regulating their use. Some countries have limits for selected environmental contaminants such as dioxins, PCBs, PAH and heavy metals. Even in regions with comparable economical development and a desire to enforce food control measures, there can be different technical approaches to regulation. For example, the USA uses a slightly different subset of PAHs compared with the EU, possibly reflective of uncertainties in the evaluation of the underpinning scientific data. In Australasia, food legislation is set by Food Standards Australia New Zealand, drawing on international practices and local relevance.

In Europe, the maximum permitted levels of these contaminants for defined foodstuffs are based on toxicological evidence and stated in Regulation EC (No.) 1881/2006. This Regulation includes maxima for total dioxins and dioxin-like PCBs. With regard to PAHs, the maximum levels are defined for benzo[*a*]pyrene (BaP) only (used as an indicator substance) but there are instructions to monitor other PAHs with a view to including these in future legislation (European Union, 2005). More recently, following an EFSA opinion (EFSA, 2008), the EU has recommended the analysis of three additional PAH next to BaP, namely, chrysene, benz[*a*]anthracene and benzo[*b*]fluoranthene.

A tiered system of limits in food exists through:

- *Maximum limits*, which, if exceeded, should result in food being withdrawn from sale,
- *Action limits*, which, if exceeded, should trigger an investigation by the industry or the authorities to identify sources and to take action in order to remove or control the problem and
- *Target levels*, which are long-term goals with values set to ensure that the population is not exposed to levels that could exceed the acceptable intake value.

EU member states have agreed that food safety is best addressed at the European level with member states' food-safety legislation harmonized through Community law. Current draft legislation routinely undergoes stakeholder consultations and economic impact assessments at an early stage.

Law enforcement

The enforcement of legislation rests with the competent authorities in each member state. These work under the jurisdiction of those ministries bearing responsibility for consumer protection alone or in combination with regional authorities. Food businesses are expected to abide by the legislation, thus implementing monitoring procedures or food management processes like the hazard analysis and critical control points throughout the food chain covered by their operations. Food sold has to be safe according to the basic food law and the related regulations or directives applying to specific food commodities and hazards.

Analytical methods are an important tool for checking compliance with legislation. Against the background of a contradictory result, it is essential to produce robust and reliable analytical data in order not to destroy food wrongly identified as non-compliant as this can result in high economical damage. In turn, this needs to be balanced against the risk to health when a food exceeding the legislative limits is wrongly identified as compliant. It is therefore essential that procedures of exporting countries are in accordance with those used by the authorities in the importing countries. It is equally important that the limitations of analytical methods are understood by all parties and that mechanisms are established that allow the checking of in-house methods to ensure that they are fit for purpose. For this reason, the European Commission has charged the CRLs with the organization of proficiency tests, and obliges the NRLs to participate in these tests. While these procedures have resulted in significant improvements within the EU, there is still an implementation deficit in several areas. An even bigger problem is posed by the lack of harmonization of analytical methods with non-EU countries.

Towards a harmonization guideline for environmental contaminants

Features of environmental contaminants

Environmental contaminants include a wide range of chemically and structurally diverse chemicals. They may be present at part per million (e.g., iron) to part per trillion concentrations (e.g., dioxins) and they have different toxicities both within a group of contaminants such as dioxins or between different types of contaminants such as lead compared with BaP. For these reasons, analytical methods are, and will continue to be, specific to specific analytes, in defined matrices and for a given concentration range. One size does not, and will not, fit all.

Tolerable Intakes reflect the toxicity of a contaminant, and define an estimated maximum amount to which an individual may be exposed per day, week or month over a lifetime

without an appreciable risk to health. Tolerable intakes are the basis for setting maximum levels in food.

Dioxins

The WHO/FAO Joint Expert Committee on Food Additives established, in June 2001, a provisional tolerable monthly intake of 70 pg WHO-TEQ kg^{-1} bw $month^{-1}$, where TEQ represents toxic equivalents. Thus, exposure is expressed as the sum of exposure to individual dioxins and dioxin-like PCBs expressed relative to the most toxic dioxin 2,3,7,8-tetrachlorodibendo-*p*-dioxin (2,3,7,8-TCDD). Current estimates of consumer exposure show that the intake of dioxins and dioxin-like PCBs is between 1.2 and 3 pg WHO-TEQ kg^{-1} bw day^{-1}, which is a range that overlaps with the range of the recommended limits. It is therefore important that steps are taken such that the amount of these substances found in food is reduced.

Trace elements

Trace elements are assessed for safety by comparing dietary intake estimates with recommended safe levels. The figures usually used are the Provisional Tolerable Weekly Intake values and Provisional Maximum Tolerable Daily Intake values as recommended by the FAO/WHO Joint Expert Committee on Food Additives. Some of the largest exposure routes to toxic trace elements, especially mercury and arsenic, are from fish, shellfish and sea mammals, which can bioaccumulate these contaminants from polluted waters and feed.

PAH

Some PAHs are known or suspected to be genotoxic carcinogens. As such, and according to the current toxicological understanding, there is no safe level of exposure and intake from food should, therefore, be as low as reasonably achievable. This is known as the ALARA principle. Most work carried out on PAHs monitors BaP as an indicator substance. The choice of BaP as an indicator substance was based on its prevalence and the fact that it is one of the most toxic PAHs. Foodstuffs represent the largest source of exposure of PAHs to non-smoking humans, and in addition a few incidents of direct occupational exposure due to combustion processes have been recorded. Previous work on the UK Total Diet Study Survey (from 2000) revealed that the fats and oils group contained one of the highest concentrations of PAHs at 11 μg kg^{-1} (sum of 19 PAHs) (Food Standards Agency, 2002).

A method performance approach

There are three basic approaches towards harmonization of method performance. These are:

(i) An independent stand-alone approach – where each organization adopts its own methodology without regard to methods in place elsewhere. This of course does not consider harmonization and in fact rejects the concept. But this is how new and emerging areas of work are developed and in such research environments is completely appropriate under such circumstances. It is an approach that may be used when an organization lacks the technology or the equipment required by a standard method, or where new technologies are embraced to improve established methods. There is less rationale for adopting a stand-alone approach for routine established techniques.
(ii) Method performance criteria – this approach is favoured in the EU legislation, see Regulation (EC) No. 882/2004, and has the advantage that it enables the users to embrace new technologies, provided that certain performance criteria are met. It can be implemented by reference to published criteria (e.g., Ambidge *et al*., 1990) or through legislation (e.g., Commission Decision 2002/657/EC.). This approach can be used when research methods (e.g., as described in (i) above) are used in the regulation of food contaminants, in the absence of standard methods.
(iii) To use a prescribed or standard method – this is the approach favoured in the United States. For example, Polychlorinated dibenzo-*p*-dioxins/Fs and PCBs by isotope dilution – HRGC/HRMS-MID using method US EPA 1613B, 1668A, and 1614. Here, there is a detailed description of the method in the form of a standard operating procedure. This is more appropriate for a mature analytical method where there has been sufficient time and implementation to fully validate a method. It can be seen as an example of a method that is known to fulfill the criteria listed in (ii) above, but has the disadvantage that it inhibits the implementation of new technology and method improvements and can be seen to inhibit progress.

For dioxins and PCBs, Commission Directive 2002/69/EC details various criteria that must be met for methods used for enforcement monitoring. These factors are considered in the prescribed methods listed under (iii) above, but the option falls short of prescribing a method that must be followed. These criteria cover: requirements for laboratories, requirements to be met by the analytical procedure for dioxins and dioxin-like PCBs, specific requirements for gas

chromatography (GC)/MS methods to be complied with for screening or confirmatory purposes, screening methods of analysis, requirements for methods of analysis used for screening, specific requirements for cell-based bioassays, specific requirements for kit-based bioassays and reporting of the result.

Similarly, performance criteria for methods of analysis of foods for lead, cadmium, mercury, inorganic tin and benzo[*a*]pyrene are specified in Commission Regulation (EC) 333/2007. Specific issues covered include sampling methods, sample preparation and analysis and methods of analysis to be used by the laboratory. Within these criteria are laboratory quality standards, prescribed limits of detection and quantification and prescribed requirements for precision, recovery and specificity.

In order to ensure a robust and meaningful monitoring framework, it is important to address the following features of environmental contaminants.

Sampling

Because the distribution of an environmental contaminant may be non-homogeneous in a food matrix, it is particularly important to obtain statistically representative samples for analysis in foods. Thus, the sampling plan can greatly affect the reliability of the measured result. Sampling must be sufficiently large to allow for adequate sensitivity. Because concentrations are typically in a part per billion range, and some contaminants, such as cadmium, are ubiquitous, it is necessary to define sample storage and transportation protocols to avoid incidental sample contamination. At the EU level, sampling is addressed in chapter III of Regulation (EC) No. 882/2004, among others.

Sensitivity

Because of their toxicity, both dioxins and dioxin-like PCBs need to be measured at extremely low concentrations in food, and the sum of dioxins and dioxin-like PCBs present is usually expressed in pico-gram dioxins (as toxic equivalents to the most toxic 2,3,7,8-TCDD) per gram of food. One pico-gram is 1/1 000 000 000 000 gram. PCBs, PAHs and heavy metal contaminants tend to occur at higher levels than dioxins, and the sensitivity in the microgram (10^{-6} g) or nanogram (10^{-9} g) range is normally sufficient.

The limit of detection needs to be appropriate to the toxicity; therefore, the maximum limit of the environmental contaminant is of interest. LODs and the protocol to derive them may be prescribed, as in the Commission Regulation (EC) No. 333/2007 for lead, cadmium, mercury, inorganic tin and BaP.

Selectivity

Both the low concentrations of environmental contaminants in diverse food matrices and the presence of structurally similar compounds that have very different toxicities, as within the group of PAHs and dioxins, require selective detection systems. This is achieved by a combination of extraction method, separation technique (generally, some form of chromatography) and specific detectors. Examples are solvent extraction with GC–mass spectrometry or solid-phase extraction and high-pressure liquid chromatography with fluorescence detection.

Measurement uncertainty

No analytical result is utterly exact but will include uncertainty due to day-to-day differences in, e.g., extraction efficiencies and instrument performance. Acceptable ranges for this uncertainty may be derived from replicate analyses and used as a basis for acceptance of the data and/or rejection of a food lot. Measurement uncertainty is discussed in more detail in Council Regulation (EEC) No. 315/93 and Directive 2002/32/EC and in a European Commission Report (2004). In fact, no analytical results should be reported without an indication of the measurement uncertainty associated with the result, along with all other information necessary for interpretation of the meaning of the result.

Maintaining quality to obtain reliable results

A number of quality criteria are available to define and support harmonized food safety controls with respect to environmental contaminants. They include participation in proficiency testing exercises, quality assurance and control steps such as analysis of replicates, reference materials, blanks and spiked samples, and method validation to determine the performance characteristics.

Proficiency testing

Consistent and good laboratory performance in relation to other laboratories is essential for harmonization of food control measures. One practical way of assessing laboratory performance is through the use of proficiency testing. The ISO definition of laboratory proficiency testing is 'determination of laboratory testing performance by means of

interlaboratory comparisons'. A proficiency test is distinct from other interlaboratory tests, such as collaborative trials (used to validate a standard method), or certification study (used for establishing the true value of an analyte concentration in a reference material). It is a comparison of a laboratory's reported result for the analyte in question with the best estimate of the 'true' value of the analyte. The performance of the laboratory is expressed in terms of a score based on a target standard deviation for the analysis in question. Within the EU, the CRLs organize proficiency tests for NRLs.

Quality assurance and control steps

Because analyte concentrations for environmental contaminants in foods tend to be extremely low, measures must be defined to avoid cross-contamination at each stage of the sampling and analysis procedure, and to demonstrate the high accuracy of the results. Regular blank controls and spiking experiments or analysis of control samples should be performed as internal quality control measures.

Method validation

Sound laboratory performance and robust results are essential and usefully demonstrated by an appropriate method validation that includes the measures of variability, LOD, successful interlaboratory participation and accreditation.

Certified reference materials (CRMs)

A valuable tool to ensure accurate quantification of environmental contaminants is the use of CRMs. Because extraction efficiencies vary with the food matrix, ideally, a range of food matrices should be available for the environmental contaminant of interest. CRMs are available for example from the European Commission's Joint Research Centre's Institute for Reference Materials and Measurements.

Emerging contaminants

The knowledge base for established food contaminants such as those described above is relatively straightforward and uncontested. This is not the case for emerging contaminants, which include alkyl phenols, brominated and mixed halogenated dioxins, flame retardants – e.g. PBDEs, furan, mineral oil in sunflower oil, nanoparticles, new brominated flame retardants such as HBCDD, TBBA, nitrate, organofluorine compounds (PFOS, etc.) and phthalates.

Work is already ongoing for most, if not all, of these emerging contaminants; however, there is a need for a validated analytical methodology. Legislation exists for some of these contaminants, and is under preparation for others.

Gaps and needs

There are five main areas where further work is needed: (a) to expand the knowledge base on emerging contaminants, (b) to improve analytical methodologies for known contaminants including their validation, including the development and validation of rapid methods, (c) to improve coordination at the technical and legislative level within the EU and with non-EU countries, (d) to raise awareness among consumers about preventive behaviour in specific areas and (e) to improve toxicity data for all, and especially for emerging contaminants.

It should also be noted that CRMs are not available for all the necessary areas and proficiency tests need to be organized in a number of areas. A number of methods have not been validated by collaborative trials, although this is not a critical gap if adoptng a performance-based approach to method selection. EFSA still has a large workload ahead of it, to assess the risk of a number of different compounds. Emerging contaminants will keep the 'to do' list long for a while.

Economic impact

The economic impact of environmental contaminants ranges from a few thousand dollars or euros, to meet the direct cost of analysis, to many millions for court prosecutions, bankruptcy, lost trade, lost commercial investment, product disposal, monitoring and surveillance and loss of life, such as evidenced for the melamine contamination of milk powder in China in 2008. Intermediate economic impacts are the cost of withdrawal of a product from sale due to contamination as seen in New Zealand in 2004, when corn flour was found to be contaminated with lead during bulk shipping or when soya milk was found to contain an unacceptably high level of iodine through the addition of kelp to the product.

Where analytical costs are high, as for dioxins, it may be sensible to develop and maintain capability at selected laboratories rather than in all countries. In contrast, PAH regulations will mainly have cost implications for governments in terms of administrative costs incurred by the instalment of greater control and monitoring procedures. This is because the largest source of PAHs in food is through food processing (by smoking, drying and cooking methods). Against this background, a possibly more cost-efficient

measure is the organization of raising awareness campaigns targeting households for the purpose of reducing the practice of specific traditional drying or cooking methods. Such campaigns are usually not very costly. Their costs can be kept to a minimum if organized by health agencies and involve the practices of medical doctors.

Currently, the potential economic burdens arising out of the health impacts of a long-term low-level exposure to environmental contaminants are simply not known. This is mainly because these health impacts – and especially those concerning cancer and endocrine disruption – are not sufficiently understood. Longitudinal epidemiological studies are needed to shed light on these impacts. In the meantime, any risk assessment involving environmental contaminants must work with scenarios concerning demographics and health effects.

Discussion

The different legislative limits concerning environmental contaminants complicate the operation of companies engaged in international trade as well as food safety monitoring agencies. There are often good reasons behind some of these differences: for instance, it may be argued that it makes sense that south European countries, where shellfish is widely consumed, have more legislation concerning this type of product than countries in the north of Europe, where consumption is typically much lower. But food standards – like environmental standards – are difficult to legitimize and, eventually implement, on the basis of the socio-economic or the geographical variation of demand. This could represent a legal problem as it implies that a consumer (or a citizen) is treated differently depending on where he or she lives. Such exceptions have been accepted for Sweden in the case of fish imported from the Baltic States (where some fishing grounds were polluted) but only on a transitional basis and on the condition of high consumer awareness. Minimum standards are therefore increasingly considered necessary for ensuring both public health and a level playing field in terms of trade. Limits are set by organizations such as the Codex. The Codex Alimentarius Commission was created in 1963 by FAO and WHO to develop food standards, guidelines and related texts such as codes of practice under the Joint FAO/WHO Food Standards Programme. The main purposes of this Programme are protecting the health of the consumers and ensuring fair food trade practices. Codex is also in charge of promoting the coordination of all food standards' work undertaken by international governmental and non-governmental organizations.

The EU aims at a harmonized approach towards risk assessment and risk management leading to legislation and analytical methodology. This is exemplified by the 2008 EFSA opinion on PAHs, which is expected to lead European legislators to consider a possible revision of European legislation. The establishment of a CRL for PAHs in 2006 is likewise expected to help address the open questions regarding analytical methodology in this domain. The drafting of international standards for food contaminants is being considered by the CEN – the European body for Standardization of methods. Discussions at an international level, beyond the EU, still have to be initiated.

A serious problem is the lack of protocols for identification and prioritization of work relating to emerging contaminants. There is often a reluctance to fund work on gathering exposure data – whether on existing or new contaminants – unless there is evidence of a toxicological problem. Work that highlights new areas of concern is therefore often performed on limited budgets without due consideration of validation needs, appropriate sampling and handling as well as repeat analyses. Greater sensibility to these issues would contribute to minimizing the risk of raising false alarms and unnecessary scares, impacting negatively on food consumption, consumer confidence and trade.

In addition to the discovery of problems relating to classes of compounds not previously studied, there are other ways through which contaminants can 'emerge' into the public view. This can be due to new science such as the availability of new evidence concerning the toxicology of 'old' compounds or due to new analytical capabilities. As an example, consider PCBs. Monitoring for the presence of PCBs was launched in the 1960 following the emergence of toxicology concerns. At that time, measurements were made in terms of 'Arochlor equivalents'. Arochlor was one of the products that was manufactured as crude mixtures of PCB. Since analytical procedures had difficulty in resolving individual compounds, an estimate of the degree of contamination was made by reference to the size and shape of a cluster of peaks observed using GC. Once capillary GC enabled better resolution and became widespread in the 1980s, and individual congeners were identified with environmental exposure, it became possible to measure a collection of specific PCB indicator peaks to compare sample contamination. In the 1990s, concern about the dioxin-like toxicity of some PCB congeners became apparent, and it was necessary to measure these as individual congeners, even though they were not necessarily the most prominent PCBs found. More recently, concerns about non-dioxin-like PCB congeners with different toxicological concerns (e.g., PCB

153 as a neurotoxin) have emerged and there is again an emphasis on monitoring, albeit of a different kind.

The emergence of new scientific evidence is, however, not the only cause for the emergence of concerns among regulators about environmental contaminants. Another typical pathway is that through pressure groups or the media. Public awareness leads to mobilization and increased political pressure for designing and effecting reforms. This bottom-up way of regulatory reform, however, needs to be combined with a more structured long-term and pro-active approach.

'Legacy' contaminants may be dealt with by using a different level of urgency compared with that needed for 'current-use' contaminants. For PCBs, PCNs and other compounds that have been phased out in the past, there is little that can be done to reduce the environmental burden. What is of primary importance here is raising awareness and minimizing human exposure. For compounds that are still in use, such as some of the brominated flame retardants, there may be a need to advise against manufacture if there is sufficient evidence that such compounds pose a threat to the environment and human health. Authorization of additives should place special emphasis on their potential environmental impact if they are not fully metabolized, and therefore enter the environment in an uncontrolled manner.

It should be noted that where chemical contaminants emerge, fraud has often preceded it (although this is less the case for environmental contaminants). For example, in the case of melamine in Chinese milk powder, there was a clear economic motive to contaminate an otherwise nutritionally sound product. Because of this link, closer collaboration between scientists and legislators working in the field of food *quality* (which addresses adulteration and fraud, among others) and food *safety* (which addresses contaminants, among others) is encouraged. Likewise, an *integrated approach* to problem solving is called for. Traditionally, contaminants have been considered the problem of the society, whereas, in the case of additives, which, by definition, are intentionally introduced into a product, the manufacturer bears the responsibility and the economic burden for proposing a suitable analytical methodology and for producing suitable exposure data. However, with contaminants that are intentionally introduced into food by the manufacturer, such as melamine in certain milk products, it would be more effective if the industry were to assume the economic burden related to method development and exposure assessment. After all, it is the manufacturer's responsibility that the product placed on the market is safe, and therefore, it is also in their interest that the product can be shown to be safe, by means of a validated methodology. In fact, in the case of melamine, it is perhaps surprising that the dairy industry did not develop and validate an analytical methodology to address this issue, because it is widely known that melamine can be used to 'boost' the levels of nitrogen upon which payment for milk is based. Arguably, the costs now faced by the society in relation to melamine should be passed on to industry. For this to be done, it is necessary to revisit legislation concerning liability in conjunction with the precautionary principle in the case of food safety.

Conclusions and future challenges

Environmental contaminants vary with respect to their chemical properties and health effects; therefore, there is no one methodological approach that fits all. It is, however, possible to aim at the harmonization of method performance criteria. The European approach to harmonization through European legislation, on the one hand, and the provision of standard reference analytical methods, on the other is well established in the meantime and could provide a template for international agreements, whether at the Codex level, bilaterally or in the framework of regional or multilateral agreements.

Understanding the causal pathway is particularly difficult in the case of environmental contaminants, given that each of these contaminants is quite specific. This underlines the importance of systematic data collection on pollution and contamination as well as long-term health impacts. Such data are necessary for establishing tolerable intakes and maximum levels in food as well as for clarifying which of the almost infinite number of analyte and foodstuff possibilities are really dangerous and how. Against this background, it is worth exploring the possibilities for establishing a risk-ranking system for environmental contaminants at an international level, so that effort may first be directed to the areas of greatest risk, and in order to ensure that the workload is shared in an efficient manner (cf. Newsome *et al*., 2009). Such a system would help reduce the time lag between awareness raising about a potential problem, the enactment of legislation and the introduction of effective analytical methodologies.

Finally, a systematic approach on how to cope with emerging contaminants has to be developed. This should involve dedicated efforts in horizon scanning, and the development of a communication tool accessible to official control authorities worldwide. Such a tool would be instrumental for proposing measures to reduce the level of environmental contaminants.

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