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ORIGINAL ARTICLE

Incidents and impacts of unwanted chemicals in food and feeds

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Abstract

Introduction Assessing the significance of unwanted chemicals in food is problematic. The evaluation of cause and effect of many unwanted chemicals in foods and feed is complicated by cumulative low doses and the delayed onset of symptoms. *Objectives* This paper reviews incidents of unwanted chemicals in food and feed where people were adversely affected, or where an unusually high level was found and traced to a particular event and for which some socio-economic impact information was available. *Methods* Incidents and impacts were identified from the peer-reviewed scientific literature, from governmental websites, from Internet searches, from trades and consumer associations and media releases. *Results* Some 44 major events were identified from 1888 to date. Information on the impacts of these incidents is fragmentary and unsystematic, ranging from thousands of Euros to meet the cost of monitoring analysis, to many millions of Euros due to court prosecutions, bankruptcy, product disposal, revenue loss compensation, damage to brand or reputation, or loss of life. *Conclusion* An evolution is apparent from the evidence of human health effects/toxicity data, igniting legal action and legislative changes, to the implementation of monitoring and surveillance alerts to ensure that risks are identified and managed – if possible – before they reach the consumer.

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Introduction

Since the end of the 19th century, incidents of unwanted chemicals in foods and the environment, which affected the lives of people in various parts of the globe, have been documented and reported. In contrast to microbiological outbreaks, the evaluation of cause and effect of many unwanted chemicals is complicated by the delayed onset of symptoms. Organic compounds, for instance, are often fat soluble and accumulate in the body before they show an effect in the individual or in the breast-fed infant.

Unwanted chemicals in food include pesticide and veterinary drug residues, fungal toxins (mycotoxins) and other natural toxins, unauthorized use of non-compliant food additives, inappropriate ingredients and processing or environmental contaminants. Food ingredients and additives are intentionally added for flavour, colour, preservation or nutritional benefit, but may have (unexpected) adverse effects, such as seaweed in soy milk (Crawford *et al.*, 2010), or be added as an adulterant, in the case of melamine in milk powder (Yang *et al.*, 2009). Processing contaminants include chemicals such as acrylamide, nitrosamines, ethyl carbamate, chloropropanols and contaminants from food packaging (Lijinsky, 1999; Massey & Hamlet, 2007; Weber & Sharypov, 2009; Pruser & Flynn, 2011). Environmental contaminants include brominated flame retardants (BFRs), dioxins and furans (PCDD/Fs), heavy metals and arsenic, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) (Rose *et al.*, 2009). Natural toxins (other than mycotoxins) include, but are not limited to, glycoalkaloids, glucosinolates, saponins, cyanoglycosides and proteinase, and amylase inhibitors (D'Mello *et al.*, 1991).

How should an incident of chemical contamination be defined when exposure is generally to a low dose of a range of chemicals through the diet over a lifetime?

The UK Food Standards Agency (FSA) broadly defines an incident as 'Any event where, based on the information available, there are concerns about actual or suspected threats to the safety or quality of food that could require intervention to protect consumers' interests' (FSA, 2008). With this definition, in 2010, the FSA investigated 1505 incidents in the UK (FSA, 2010). However, this definition includes inadequate labelling with regard to food allergy and intolerance, microbiological and physical contamination. This is broader than the scope of unwanted chemicals considered in the current review.

To prove a relationship between exposure to a single chemical and an observed adverse health effect is problematic, exacerbated by the usual delay between exposure and onset of symptoms. However, there are reports of adverse health effects following a number of incidents of high exposure to particular chemicals and also a number of instances where episodically high concentrations of unwanted chemicals were detected in food and traced back to a particular event. From these high concentrations, one may hypothesize about potential risk based on toxicological effects derived from animal and *in vitro* studies.

The impact on society of incidents of unwanted chemicals in food or feed may be economic, environmental, social and/or political. The cost may range from a few thousand Euros, to meet the direct cost of compliance or monitoring analysis, regional or national product recalls, animal slaughter and disposals, to many millions of Euros due to court prosecutions, bankruptcy, international product recalls, more stringent food legislation, more rigorous monitoring and surveillance, damage to brand or reputation of the product or country, decline in tourist income, environmental remediation, loss of productivity and loss of life.

A compilation of selected global incidents of unwanted chemicals in food or feed is presented. The diversity and magnitude of socio-economic impacts of these incidents are illustrated with fragmentary evaluations reported in the scientific literature and through media releases.

Methods

For the purposes of this review, an incident was defined as an episodic occurrence of adverse health effects in humans (or animals that might be consumed by humans) following high exposure to particular chemicals, or instances where episodically high concentrations of unwanted chemicals were detected in the human food chain, and traced back to a particular event. The more usual daily exposure to a low background level of chemical contaminants in food was not considered as an 'incident'. Prions, which cause transmissible spongiform encephalopathies such as bovine spongiform encephalopathy (BSE) in cattle or variant Creutzfeldt–Jakob disease in humans, are considered as biological contaminants and therefore not discussed in this paper.

Incidents of chemical contamination of food were identified from the peer-reviewed scientific literature where possible, from governmental websites, from Internet searches and references therein.

Information on the economic, environmental, social or political impacts of these incidents was also sourced from peer-reviewed scientific literature and Internet sources, including governmental reports, information from trades and consumer associations, and other media releases. Economic impacts considered included the financial cost of analysis; monitoring; product recall and disposal; health care; criminal, civil and regulatory legislation; lost revenue and brand protection; lost productivity and damage to country's reputation. Environmental impacts included the cost of remediation and disposal of contaminated food. Social impacts included burden of disease (morbidity and mortality), mental trauma, consumer confidence and cultural change.

Summary information including the year, the unwanted chemical, location of the incident, a description of the affected food or feed, the impact, and the source references was tabulated. Where an incident led to an observed adverse human (or animal) health effect, this incident was identified 'H'. Where the incident was detected from an episodically high concentration of an unwanted chemical, detected from food monitoring or surveillance activity, this incident was identified 'M'.

The numerical values we used in this paper have been given in the literature relating to costs of incidents. Where appropriate, costs were converted to approximate current monetary values by applying an online conversion facility (http://www.measuringworth.com), and a common currency, Euro (€), to enable some comparison between impact type and different incidences. A conversion rate of 1€ = $1.4 USD was applied.

Results

Incidents of chemical contamination of food or feed

A list of over 40 documented incidents between 1888 and 2011 involving environmental contaminants, food ingredients, heavy metals or arsenic, mycotoxins, natural toxins, processing contaminants, and veterinary medicines in food or feed is presented (Table 1).

Not included in this collection of incidents is the association between PAH intake from smoked foods and stomach cancer in Iceland in the 1960s (Dungal, 1961). This adverse health outcome was the result of a cultural practice rather than an isolated event. Similarly, the discovery in 2002 that acrylamide may be formed in hot starchy foods (Tareke *et al*., 2002) was not considered an 'incident' and therefore was not included.

Incident causes varied from human error or inadvertent contamination through processing ($n = 19$), poor harvesting or storage of grain ($n = 8$), to the use of banned veterinary products ($n = 7$), adulteration ($n = 4$), industrial discharges ($n = 3$) or natural toxins ($n = 2$). The cause of the arsenic-contaminated cider in 1924 was not ascertained. Eight events were caused by contaminated animal feed.

Socio-economic impacts of chemical contaminants in food and feeds

Information on the impact of these incidents is incomplete. For some incidents, for example the Japanese 'Yusho' and Minamata Bay events, books were written (Kuratsune *et al*., 1996; George, 2002), whereas for others, such as the incident of oranges from Israel, single media releases were retrieved (TIME, 1978). Summary information of the impact of each incident ranging from numbers of humans affected (including deaths), to animals destroyed, information on human health effects, bans on food trade or livestock movement, product recall or increased sample monitoring is shown (Table 1).

The diversity and magnitude of impacts of the selected incidents of unwanted chemicals in food and feeds in terms of economic, environmental, social or political costs are summarized in Table 2.

Currently, no standardized or harmonized approaches exist to calculate the economic costs of incidents, thus the comparability of the given numbers between incidents is limited, but they give an estimate of the magnitude of an impact.

Economic

Analysis monitoring

An immediate impact of a chemical contamination incident is the requirement, and therefore the cost, of additional food sample analyses. Incidents in 1973, 1999 and 2003 incurred the following estimated costs for analytical work during the incident investigation. The 13 000 samples analysed in the 18 months following the 1973 Michigan PBB incident was about €346 500 (Dunckel, 1975), or €1.4 M at current value (http://www.measuringworth.com). The Belgian PCB and dioxin incident of January–June 1999 resulted in more than 55 000 PCB and 500 dioxin analyses (Covaci *et al*., 2008). Based on analytical rates of €130 and €525 for PCB and dioxin analyses, respectively, the estimated cost was €7 M at current value. The more recent German bakery waste incident in 2003 resulted in a total of 339 samples being screened for dioxins within a period of 3 weeks at an estimated cost of €0.3 M (Hoogenboom *et al*., 2004) (R Hoogenboom, personal communication, March 2011).

Product recall/disposal

The economic cost of condemned food resulting from the 1973 Michigan PBB incident, reported in 1979, was €150 M [Office of Technology Assessment (OTA), 1979], – or €450 M in 2009 dollar terms (http://www.measuringworth.com).

The incident of dioxin-contaminated citrus pulp in 1998 resulted in about 92 000 tons of citrus pulp being discarded or destroyed in the European community, worth about €8.75 M. Twelve European Union (EU) Member States were affected (Malisch, 2000).

The Irish dioxin crisis of 2008 resulted in the culling of thousands of cattle and pigs at an estimated cost of more than €4 M (BBC News, 2010).

Further details on product recall costs are included under lost revenue/brand protection.

Health costs

Health costs are those incurred by the consumer whose health has, or potentially can be, adversely affected by the contaminant present in food.

In response to the 2008 Chinese melamine incident, the Chinese government provided free medical treatment to all babies affected, with more than 1600 medical teams and 8000 staff sent to locate sick babies. Within 2 months of the incident being publicly known, almost 300 000 children

Table 1 ncidents and impacts of unwanted chemicals in food or feed

Year	ID	Chemical	Location	Description	Impact	Reference
1888	H	Arsenic	France	Contaminated wine	515 cases including 15 fatalities	(Reynolds, 1901; Dakeishi *et al*., 2006)
1900	H	Arsenic	UK	Contaminated beer, via brewing sugar formed with arsenic contaminated sulphuric acid	6070 cases including 70 deaths	(Reynolds, 1901; Dakeishi *et al*., 2006; Klatsky, 2006)
1910–1945	H	Cadmium	Japan	Mining waste contaminated rice irrigation water	Known as 'Itai-itai' disease ≥20% of women aged over 50 years affected	(Kasuya *et al*., 1992)
1924	H	Arsenic	USA	Contaminated cider	28 cases including 15 deaths	(Dakeishi *et al*., 2006)
1931–1947	H	T-2 and HT-2 toxins (tricothecenes)	Russia	*Fusarium* contamination of over-wintered wheat	Alimentary toxic aleukia High mortality (approximately 80%)	(JECFA, 2001)
1950s	H	Mercury	Minamata Bay, Japan	Seafood contaminated by industrial discharge	By 2010, >14 000 victims had received financial compensation of > € 1400 M. Lost revenue compensation €56 M–63 M Remediation costs ~ €360 M Cultural democratizing effect Lost productivity due to lowered IQ ~ €840 M–12000 M	(George, 2002; Hylander & Goodsite, 2006; The Asahi Shimbun, 2010)
1955	H	Arsenic	Japan	Milk powder inadvertently contaminated with sodium arsenate in the disodium phosphate additive	'Moringa dried milk poisoning' Estimated 13 400 cases by 2002, >100 deaths	(Dakeishi *et al*., 2006)
1957	H	Dioxins	USA	Chicken feed, and thence chickens, contaminated from polychlorophenol-treated cow hides	300 000 chickens died or were destroyed	(Firestone, 1973)
1968	H	Dioxins, polychlorinated biphenyls	Japan	Rice bran oil contaminated at processing,	Known as "Yusho (oil disease) Estimated 2100 cases including 300 deaths at 2003 Victim compensation ~ €90 M	(Yoshimura, 2003)
1971	M	Polychlorinated biphenyls	USA	Detected in ready-to-eat breakfast cereal in total diet study	New food packaging regulations	(Pennington & Gunderson, 1987)
1972	H	Mercury	Iraq	Imported wheat and barley seed grain treated with a mercury fungicide was used for bread making.	6990 cases including >460 fatalities Lost productivity due to lowered IQ ~ €410 M	(Bakir *et al*., 1973) Derived from rationale of (Hylander & Goodsite, 2006)

1973	H	Polybrominated biphenyls	Michigan, USA	Fire retardant was inadvertently mixed into animal feed	No human cases to date 29 400 cattle, 400 sheep and 2 000 000 chickens destroyed Monitoring analysis ~ €1.4 M Food disposal ~ €450 M Information on toxicity and human health effects Regulatory limits established	(Dunckel, 1975; Fries, 1985)
1974	H	Aflatoxin	India	Contaminated maize	397 people developed acute hepatitis and 108 died	(Tandon *et al*., 1978)
1975	H	Ergot (alkaloids)	India	Contaminated pearl millet	78 cases from 21 villages with gastrointestinal symptoms	(Krishnamachari & Bhat, 1976)
1976	H	Dioxins	Seveso, Italy	Atmospheric contamination from a manufacturing plant explosion	Unknown contribution from contaminated food Led to information on toxicity and human health effects	(Mocarelli, 2001)
1978	H	Mercury	The Netherlands	Adulterated oranges from Israel	4 children affected Imports halted	(TIME, 1978)
1978	H	Ergot (alkaloids)	Ethiopia	Contamination of barley with ergot containing oats	140 cases of gangrenous ergotism, including 47 fatalities	(Demeke *et al*., 1979)
1979	H	Dioxins, polychlorinated biphenyls	Taiwan	Contaminated rice oil	Estimated 2093 cases including 32 deaths	(Hsu *et al*., 1985)
1979	H	Solanine (glycoalkaloid)	UK	Spoiled potatoes	78 schoolboys affected, all recovered	(McMillan & Thompson, 1979)
1983	H	Solanine (glycoalkaloid)	Alberta, Canada	Spoiled potatoes	61 schoolchildren and staff became ill	(JECFA, 1993)
1987	H	Deoxynivalenol, nivalenol, T-2 toxin (tricothecenes)	Kashmir valley, India	Bread contaminated by mouldy wheat	Approximately 50 000 people with gastrointestinal symptoms	(Bhat *et al*., 1989)
1989	H	Lead	UK	Animal feed containing imported, lead-contaminated rice bran	Ban on stock and produce movement for approximately 1800 farms	(Crews *et al*., 1992)
1993	H	T-2 toxin (tricothecene)	China	Heavy rainfall during harvest resulted in contaminated rice	97 cases of mainly gastrointestinal symptoms	(Wang *et al*., 1993)
1995	H	Fumonisin	India	Contaminated sorghum and maize	1424 cases, in 27 villages, of mainly gastrointestinal symptoms	(Bhat *et al*., 1997)
1998	H	Arsenic	Wakayama, Japan	Adulteration of curry	67 cases including 4 deaths	(Uede & Furukawa, 2003)
1998	M	Dioxins	Germany, The Netherlands	Meat and milk contaminated by citrus pulp used in feed	92 000 tons of citrus pulp discarded or destroyed ~ €9 M Tolerance level set by EC Collapse of citrus pulp market in some EC countries	(Malisch, 2000)

Table 1 Continued

Year	ID	Chemical	Location	Description	Impact	Reference
1999	H	Dioxins, polychlorinated biphenyls	Belgium	Animal feed contaminated with transformer oil	More than 2500 poultry and pig farms affected 40–8000 estimated cancer cases Monitoring analysis ~ €7 M Maximum residue levels set and harmonised across the EU National monitoring established Federal food safety agency created Loss to Belgium economy €1500–2000 M Consumer confidence and political rating threatened	(Covaci *et al*., 2008) (Van Larebeke *et al*., 2001)
2001	M	Polycyclic aromatic hydrocarbons	Spain	Contaminated olive pomace oil	Product recall	(FSA, 2001; GovernmentNews, 2001)
2002	M	Chloramphenicol	UK and Canada	Honey from China contaminated with the antibiotic chloramphenicol	Product recall of Chinese and blended honey on sale in UK and Canada	(FSA, 2002a; Health-Canada, 2004)
2002	M	Nitrofurans	UK	16/77 samples of prawns and shrimps imported from SE Asia (Thailand, Vietnam, Indonesia, India, Bangladesh), contaminated with banned veterinary antibiotic	Withdrawal and destruction of affected batches	(FSA, 2002c)
2002	M	Nitrofurans	Northern Ireland	5/45 samples of chicken, imported from Thailand and Brazil contaminated with banned veterinary antibiotic	Product in cold storage withdrawn and destroyed	(FSA, 2002b)
2003	M	Dioxins	Germany	Animal feed contaminated with bakery waste dried by firing waste wood	339 samples of animal feed and bakery waste screened in a 3-week period Monitoring analysis ~ €0.3 M	(Hoogenboom *et al*., 2004) Hoogenboom personnal communication, 2011
2003	M	Nitrofurans	Portugal	Contaminated chicken	Poultry from 43 farms destroyed	(Food Production Daily, 2003; FSA, 2003)
2004	H	Aflatoxin	Kenya	Contaminated maize	317 cases of hepatic failure and 125 deaths	(Azziz-Baumgartner *et al*., 2005)
2004	M	Lead	New Zealand	Cornflour and products contaminated during shipping of bulk corn by a 'prior cargo'	4 products recalled 3 countries affected (New Zealand, Fiji and Australia)	(New Zealand Food Safety Authority, 2004b)
2004	M	Iodine	New Zealand	Soy milk manufactured with added kelp led to high iodine levels	5 cases of hyperactive thyroids Product recall and reformulation	(New Zealand Food Safety Authority, 2004a; O'Connell *et al*., 2005)
2004	M	Chloramphenicol	Canada	Honey contaminated with antibiotic	Voluntary product recall	(Health-Canada, 2004)
2004	M	Nitrofuran	Northern Ireland	Organic free-range chicken	Voluntary product recall Consumers advised to destroy any affected chickens	(FSA, 2004)

2005	M	Malachite green	British Colombia, Canada	Farmed salmon contaminated with banned fungicide	54 tons fish recalled, 36 tons reached consumers Lost revenue €2–11 M	(Dipietro and Fiorillo, 2005; Friends of Clayoquot Sound, 2005)
2005	M	Sudan I dye	UK	Imported adulterated chilli powder used to manufacture Worcester sauce, that was used as an ingredient in a wide range of products	576 food products recalled Food industry cost ~ €120–200 M Legal sentencing costs ~ €5600	(BBC News, 2006; FSA, 2005a, 2005b, 2006; Murray-West, 2005; William Reed, 2005)
2008	H	Melamine	China	Milk powder adulterated with melamine to raise apparent protein level	300 000 babies affected, 51 900 hospitalizations, 6 deaths Lost revenue compensation ~€30 M Bankruptcy, industry loss ~€90 M Food and feed limits established in several countries 68 countries imposed trade restrictions with China At least 60 arrests, 2 executions, 1 life sentence Consumer confidence targeted with testing regime	(Gossner *et al.*, 2009; Yang *et al.*, 2009)
2008	M	Dioxins, polychlorinated biphenyls	Ireland	Animal feed derived from waste food contaminated by dioxins in oil fired to dry the feed Feed supplied to 7 pork producers and 38 cattle farms	All Irish pork and pork products exported to 23 countries was traced and much was recalled Cattle and pig culling >€4 M Lost revenue compensation €200 M	(BBC News, 2010; FSAI, 2009; Matthews, 2009
2009	H	Iodine	Australia	Soy milk enriched with 'Kombu' seaweed resulted in high levels of iodine	48 cases of thyroid problems, Product voluntarily recalled	(Crawford *et al.*, 2010; The Australian, 2010)
2011	M	Dioxins	Germany	Meat, eggs and egg products contaminated from animal feed made with contaminated fat	4 700 German farms affected 8 000 hens and hundreds of pigs culled Imports from Germany to China banned	(Harrington, 2011)

EC, European Community.
>, greater than; H, incident identified from human or animal health effects; M, incident identified through monitoring or surveillance.

Table 2 Range of estimated economic, environmental, social or political impact of incidents of unwanted chemicals in food or feeds

Impact type	Parameter assessed	Cost range
Economical	Analysis, monitoring	€0.3–7 M
	Damage to country's reputation/tourism	NA
	Health costs (compensation)	€1400 M
	Legislative costs (criminal, civil, regulatory)	€35 M
	Lost productivity	NA
	Lost revenue/Brand protection or damage	€30– 2000 M
	Product recall and/or disposal	€4–450 M
Environmental	Remediation	€6–360 M
Social	Burden of disease (morbidity and mortality)	0–300 000 affected, 900 deaths
	Consumer confidence	€1300 M
	Cultural change	NA
	Mental trauma	Democratizing affect
		NA
Political	Political party survival/rating	Loss of political power

NA, no data retrieved.

were reported as suffering from kidney and urinary problems, with 51 900 receiving hospital treatment (Gossner *et al*., 2009; Yang *et al*., 2009).

The economic compensation to victims poisoned with methyl mercury in Minamata, Japan, was reported as nearly €1050 M in current values, from the 1950s until October 2004 (Hylander & Goodsite, 2006). The payment of an additional €15900, plus monthly medical allowances, to 2123 previously unrecognized victims was agreed in 2010, paving the way for almost 40 000 more victims to be compensated – more than 50 years after the event. The total compensation, paid by the Chisso Corporation, central and Kumamoto prefectural governments, was therefore in excess of €1400 M (The Asahi Shimbun, 2010).

Legislative costs (criminal, civil, regulatory)

One criminal and seven civil suits were filed in connection with the 1968 Japanese 'Yusho' incident. In the criminal lawsuit, the factory manager was found guilty of ignorance and sentenced to 3 years' imprisonment while the company president was found not guilty. With regard to the civil suits, dispute over the cause of the contamination eventuated in a compromise settlement for compensation to victims some 20 years after the incident, with most of the reparations, in the order of €90 M, paid by the company that manufactured the chemical (Kuratsune *et al*., 1996).

In 2006, the Essex County Council prosecuted the food wholesaler, East Anglian Food Ingredients, for selling curry powder containing the illegal dye Sudan1. East Anglian Food Ingredients was fined £2000 and ordered to pay £3000 costs – a total of approximately €5600 (BBC News, 2006; FSA, 2006).

There were at least 60 arrests, resulting in two executions and one sentence of life imprisonment, as a result of the melamine incident in China (Editorial, 2009).

Voluntary or mandatory food recall directives require (effect based) regulatory limits for regulators to uphold. Any food with contaminant concentrations above such limits is condemned and either destroyed or restricted from market (OTA, 1979). In the early incidents, for example the PBB Michigan incident, this information was lacking and establishing a limit was an important first step in managing that incident (Fries, 1985). A number of the incidents led to new food regulations.

In the 1971 US Total Diet Study, PCB residues were found in a ready-to-eat breakfast cereal. Follow-up investigations revealed the contamination to have occurred from migration of PCBs from the packing which was manufactured from recycled paper. The recycled paper included so-called carbonless copy paper that contained PCB-filled pressure-sensitive capsules as the ink release agent. This finding eventually led to regulations limiting the PCB content of paperboard packaging intended for food contact use (Pennington & Gunderson, 1987).

Tolerances for PBB in milk, meat, eggs and feed were established by the US Food and Drug Administration (US FDA) in May 1974 following the Michigan PBB incident in 1973. These were subsequently revised downwards (Dunckel, 1975). Soon after the incident, the US FDA established a temporary guideline for PBB in milk and tissue fat, which was subsequently lowered in 1977 (Act 77) (Fries, 1985).

The European Community regarded the high contamination of citrus pulp from Brazil and its use as feed material as a possible risk to human health and therefore set a tolerance for dioxins in citrus pulp (Malisch, 2000).

The 1999 Belgian PCB/dioxin crisis led to the introduction of national maximum residue levels for PCBs in feed and foods, the establishment of a national monitoring programme for food of animal origin, and the creation of a Federal Agency for Food Safety in Belgium. In addition, the levels of dioxins in animal feed and food of animal origin were harmonized across the EU (Covaci *et al*., 2008).

Several countries established limits for melamine in food and feed (e.g. Australia, Canada, China, EU, Malaysia, New Zealand and United States), following the 2008 melamine incident in China (Gossner *et al*., 2009; Yang *et al*., 2009).

With the exception of the Sudan dye prosecution in 2005, the financial cost to conduct these criminal and civil cases, or to establish food regulations, was not retrieved.

Lost revenue/brand protection

According to Hylander and Goodsite, compensation paid to fishermen for lost revenue from the Minamata Bay incident was between €56 and €63 M (Hylander & Goodsite, 2006; The Asahi Shimbun, 2010).

The 1999 PCB/dioxin crisis cost the Belgium economy €1500–2000 M, with several food-producing companies being bankrupted and thousands of jobs lost (Covaci *et al*., 2008). For many months, consumers avoided Belgian products and some even avoided all animal products from the EU.

The citrus pulp market in some European Community countries collapsed as a result of the Brazilian-sourced citrus pulp incident in 1999. The total market for citrus pulp as animal feed in Europe at the time was worth an estimated €70–105 M (Malisch, 2000).

The incident of Sudan 1 dye in Worcestershire sauce that occurred in the UK in 2005 resulting in the recall of 580 food products reportedly cost the food industry in the order of €120–200 M for sales loss, recall, management time, public relations and brand impact (William Reed, 2005; Murray-West, 2005 FSA, 2005b).

As a result of the 2008 Irish dioxin incident, €200 M was paid to compensate Irish pork producers and processors for lost income. The total cost of this recall for the Irish industry and/or the Irish (and EU) taxpayers was estimated at €100–200 M (Heatley, 2008; Matthews, 2009; BBC News, 2010).

The Sanlu group, the milk powder processors responsible for the 2008 melamine incident in China, were bankrupted by the pressure of recalling more than 10 000 tons of milk powder and claims for compensation. China's biggest liquid-milk producer, the Mengniu Group, claimed losses of 900 million yuan (€90 M). Chinese dairy and related exports dropped by 92% compared with the year prior. About 20% of dairy farmers were still inoperable 2 months after the incident. The Chinese government set aside 300 million yuan (€30 M) to compensate farmers who lost money and farmers were also to receive a feed subsidy of 500 yuan (€50) per cow (Yang *et al*., 2009). Some of those identified as responsible were found guilty and paid with their life.

Lost productivity

Two major incidents of mercury contamination are included in Table 1 (the Minamata Bay incident in the 1950s, and the grain seed incident in Iraq of 1972). While productivity costs, derived from lost productivity, were not estimated for either of these incidents, productivity cost in Greenland was estimated at €40 M for lost IQ due to methyl mercury toxicity of 703 children. This calculation assumed 1.5 IQ points lost for each doubling of mercury (Hg) concentration above 5.8 μg Hg per litre of blood and that each IQ point reduction resulted in a 2.6% decrease in lifetime earnings (Hylander & Goodsite, 2006). For 14 000 victims who received full or partial compensation from the Minamata Bay incident (or approximately 200 000 persons who may have been affected) (in Hylander & Goodsite, 2006) and almost 7000 Iraqis in 1972 (Bakir *et al*., 1973), lost productivity due to lowered IQ may also have been in the order of €840 M (or €12000 M) and €410 M, respectively, assuming a similar decrease in lifetime earnings. Given that arsenic also impairs mental development, lost productivity from the 13 400 victims of the 'Moringa' incident (1955) (Dakeishi *et al*., 2006) was also likely to have been substantial.

Environmental

Remediation

Planning for remediation of Minamata Bay started in 1971 and was completed in 1990 by dredging and burial below fabric and a layer of soil at an estimated cost of €360 M (Hylander & Goodsite, 2006).

Social

Burden of disease (mortality and morbidity)

A conservative estimate of deaths attributed wholly, or in part, to mercury contamination of Minamata Bay in the 1950s is 900, although 14 000 victims have been compensated and there may have been as many as 200 000 people affected (Hylander & Goodsite, 2006). If a human life is valued at €1.4 M based on the willingness to pay for safer roads (Scott *et al*., 2000; Hylander & Goodsite, 2006), the economic burden of this incident is conservatively estimated at €1260 M.

Applying the same rationale to the more than 460 lives lost as a result of the mercury poisoning in Iraq in the early 1970s (Bakir *et al*., 1973), the burden of that incident might be conservatively estimated to be in excess of €640 M. This estimate does not include the 6500 victims non-fatally affected.

At the time of the 1955 'Moringa' arsenic incident, there were more than 100 infant deaths. At March 2002, some 47 years after the incident, the total number of victims was reported as 13 420 (Dakeishi *et al*., 2006). While the cost of the deaths may be estimated in the order of €140 M, to our knowledge, the magnitude of the economic burden of the victims has not been assessed.

Estimates of the total number of cancers resulting form the Belgian PCB and dioxin incident of January–June 1999 was 40–8000, based on a simple model in which an episodically high dose was converted to an average daily dose over a lifetime (70 years) (Van Larebeke *et al*., 2001). Given additional non-cancer effects in neonates, infants and children, these authors concluded that this incident had a significant impact on the body burden of most Belgian citizens and probably doubled or tripled the body burdens of highly exposed subpopulations (Van Larebeke *et al*., 2001).

Consumer confidence

Consumer confidence was threatened at the time of the 1999 Belgian PCB and dioxin incident because of controversy and some exaggerated risks of the possible health consequences, in sections of both the media and the scientific community. In addition, Belgian authorities were accused of having deliberately served the economic interests of farmers' unions and meat industry instead of protecting public health (Covaci *et al*., 2008).

The 2008 Irish dioxin crisis was heavily reported by the media. The FSA of Ireland (FSAI) fielded 3725 calls and 700 media enquiries in 6 days. Over 30 FSAI staff members and volunteers manned advice lines. As the media coverage evolved, the FSAI worked to maintain consumer confidence with a repeated message not to consume the contaminated product and not to be overly concerned about the health risks of short-term exposure to elevated levels of contaminants (FSAI, 2009).

As a result of the 2008 melamine incident, the Chinese government required all dairy products to be tested, inspected and labelled 'QS' to protect consumer rights. Only products labelled 'QS' could be sold in the market (Yang *et al*., 2009).

Cultural change

The protests of victims seeking compensation from the Minamata Bay disaster from the 1950s to the present day are claimed to have had a democratizing effect in Japan. Initially disease victims, fishing families and company employees were excluded from discussions, but with media coverage and ongoing protests, these people were eventually allowed to discuss the issue. As a result, it is considered that post-war Japan became more democratic (George, 2002).

Political

The Centre-left Christian-Democrat/Socialist coalition that had been in power for 12 years in Belgium, and that was in favour beforehand, was voted out of power and a contributing factor assigned by many was the preceeding PCB/dioxin crisis of 1999 (Covaci *et al*., 2008).

Discussion

The aim of this paper is to present a compilation of global incidents of unwanted chemicals in food or feed and to report the diversity and magnitude of socio-economic impacts of these incidents as far as these are available.

The list of incidents presented here is not exhaustive. In the first instance, the task of defining a chemical incident is subjective, and begs the question as to whether in fact all product recalls and Rapid Alert System for Food and Feed (RASFF) alerts are incidents. Further debate of this may be valuable. There will be events that have been missed because they were not retrieved in our literature searches or were not reported in the accessible literature. Alert systems, for example, may not report incidents that never crossed a border. Indeed, we plan to make this initial list openly available for others to augment.

A review of the 44 incidents shows a noticeable progression from incidents that were apparent because of adverse human health effects (H), in some cases hundreds of deaths, to the likely prevention of disasters because of product recalls based on monitoring and surveillance activities (M) (Table 1). From 1888 to 1979, there was an increasing

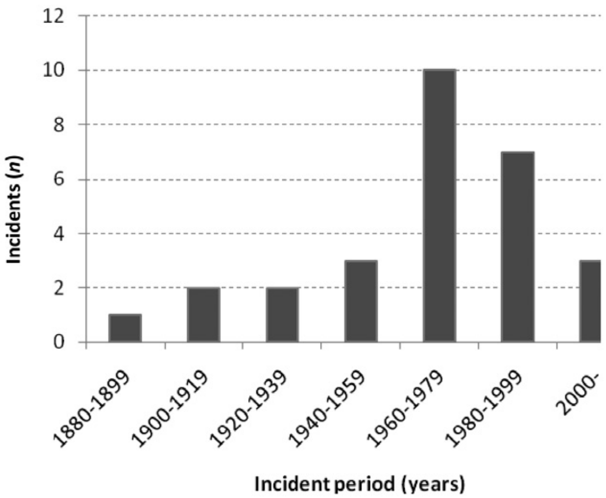

Figure 1 Numbers of incidents identified from adverse human health effects over 20-year periods from 1888 to 2011.

occurrence of adverse health-related incidents, which since 1980 has declined (Figure 1). Over 50% of the incidents listed occurred since the 1990s. This, together with only four incidents resulting in adverse health effects since 1999, substantiates the efficacy of monitoring systems in public health protection.

Socio-economic impacts were stated as reported. As many were from unverified media clips, the reader is cautioned to be mindful of exaggeration for enhanced effect. In most cases, the derivation of the reported costs was not stated. There is nothing systematic about these impacts, but rather they illustrate a diversity and magnitude of possible impacts resulting from a chemical incident. Some of the sources have a vested interest and may estimate costs with some degree of bias. It is easy to put a 'slant' on how a figure is weighted – for example, the value may be maximized if it is made in relation to compensation payments, or minimized if brand protection is the primary objective. Also, there are various differences in the figures that are given which can relate to direct costs involving product recalls and destruction of affected food; others will include consequent changes in production and clean up. Few may estimate damage to brand and others may still add on damage to associated brands – for example, all food from Belgium (and even Europe) took a downturn in sales after the 1999 dioxins incident even though only poultry and pork products originating from Belgium were affected. Even these situations have to be considered carefully. For example, if one brand or if one country suffers, another may benefit from increased sales of the same or alternative food products. So the true cost to 'the economy' or to 'society' is not clear.

Costs of additional monitoring or tighter legislation that are put into place as a result of an incident are rarely included in cost estimates, although this can be considered as part of the brand protection and recovery process and hence pays for itself. It is very difficult to include estimates for such brand influence with all the other 'noise' and confounders that influence these figures. It is even more difficult to estimate health costs and attribute causal association with exposure to chemicals in the diet when carcinogens, or compounds with other long-term effects such as those that have an impact on reproductive capacity (and can impact on subsequent generations), or where chemicals such as lead have an impact on brain function or learning ability, are concerned.

While some incidents, in particular the mercury discharge into Minamata Bay in Japan in the 1950s and the 1999 PCB/dioxin incident (Covaci *et al*., 2008), have been evaluated in terms of various impacts, comprehensive assessments of combined impacts of individual incidents are rarely available. The cost of some historical events were relatively recently evaluated; for example, the remediation cost of Minamata Bay (Hylander & Goodsite, 2006) and the human health effects of exposure to brominated flame retardant in Michigan in 1973. Although the latter incident occurred almost 40 years ago, studies of long-term health effects were more recently undertaken with six human epidemiological studies published in the past 4 years (Hoffman *et al*., 2007; Small *et al*., 2007; Sweeney & Symanski, 2007; Terrell *et al*., 2008, 2009; Joseph *et al*., 2009).

Analysis of costs and impacts of these incidents is fragmentary but emerging. In purely economic terms, the highest costs of the cited incidents relate to compensation to mercury-poisoned victims at Minimata Bay (in the order of €1400 M) (The Asahi Shimbun, 2010) and the estimated loss to the Belgian economy of €1500–2000 M as a result of the 1999 dioxin/PCB contaminated animal feed incident (Covaci *et al*., 2008). These are very approximate as it remains unclear how many victims were affected (and compensated) by mercury in Minamata Bay, and the rationale behind the Belgian estimate. If a life is valued at €1.4 M, the social burden of the lives lost as a result of the Minamata Bay incident is in the order €1300 M for 900 deaths (Scott *et al*., 2000; Hylander & Goodsite, 2006). Perhaps higher yet may be the cost of mental impairment from mercury exposure – €800–12000 M on the basis of rationale applied by Hylander & Goodsite (2006).

While these incidents have been tragic and costly, positive outcomes have also arisen. A number of incidents, including mercury into Minamata Bay, the 'Moringa' arsenic poisoning, the 'Yusho' incident of PCBs in rice oil, the mercury-treated seed in Iraq, the 1973 Michigan PBB event and the incident of trichothecene mycotoxins in India in 1987, led to new scientific knowledge about the chemicals and their health effects. This knowledge has resulted in food regulations and monitoring and surveillance systems to protect consumers. An incidental benefit of the 1999 PCB event in Belgium was the attribution of campylobacteriosis to poultry (Vellinga and Van Loock, 2002).

Any crisis offers the opportunity for change and improved identification and management of risks. New food safety regulations and improved monitoring and surveillance programmes are often the result of lessons learned in crises. Admittedly, the assurance of food safety comes at a price, considering the necessary research to develop methods to identify and quantify chemical contaminants, socio-economic costs to draft and implement new or better regulations, and finally systems and tools to monitor and alert for potential risks. However, the investment must be balanced against the possible costs associated with an incident.

Following the European food crises of the 1990s (such as BSE and dioxins), the EU passed a regulation defining the general principles and requirements of food law (Regulation 178/2002). This led to a variety of measures (legislative and otherwise) to assure a high level of food safety, animal health, animal welfare and plant health within the EU. One of these is a pan-European Database, RASFF, which provides a system for capturing and disseminating information on a wide range of food risks between network members (RASFF, 2011).

As many of the identified events were accidentally discovered through *ad hoc* monitoring, how many incidents go undetected and how can the consumer be reassured of the safety of the global food supply? If safety is the responsibility of the food producer, might we heed the lessons from past events to inform and improve HACCP? Where in the supply chain is risk from chemical contamination best assessed? With respect to dioxin-related incidents, a high proportion of these incidents originated from contaminated animal feed – a critical control point to target. What level of monitoring is appropriate and what is society's or a country's willingness to pay the price? Monitoring comes at a high price. Some countries do not have routine monitoring schemes and only a traceability and post-incident response. These countries may be viewed by some as having a free ride on those countries with more extensive and more expensive monitoring programmes. The EU pays a high price for regulatory monitoring schemes in all Member States and still the melamine incident happened. Absolute safety is not possible, and one is surprised by the ingenuity of fraud.

International initiatives such as the WHO Global Burden of Foodborne Disease Project will improve current socio-economic impact assessments, and food safety. That project aims, in part, to quantify the burden of foodborne disease, including disease caused by chemicals in food, in monetary costs. This will help inform appropriate allocation of resources to prevention and control efforts, the development of new food safety standards, monitoring and evaluation of food safety measures, and assessment of the cost-effectiveness of interventions. Aflatoxin, a cyanide originating from cassava, peanut allergens, dioxins, lead and cadmium, is a priority chemical hazard for this programme (World Health Organization, 2010).

In addition, the MoniQA consortium has developed a toolbox for assessing socio-economic impact of regulations on food safety and quality in terms of efficiency, effectiveness and consistency, and administrative costs as well as international trade among stakeholders (e.g. consumers, industry, regulatory and control bodies) at different levels (i.e. micro vs. macro) (Poms & Astley, 2011; Ragona *et al*., 2011). The toolbox provides a transparent, iterative, system for all stakeholders to participate in the assessment. The spread of outcomes from different stakeholders is a measure of the variability of the impact assessment. Ultimately, decisions on food regulations are made by politicians, advised but not dominated by expert assessors, therefore socio-political-economic implications are paramount.

Conclusions

Since the end of the 19th century, multiple incidents of unwanted chemicals in food or feed, which affected the lives of people in various parts of the globe, have been documented and reported. The unwanted chemicals, including environmental contaminants, food ingredients, heavy metals, mycotoxins, natural toxins, processing contaminants and veterinary medicines, resulted from poor harvesting or storage of grain to human error, use of banned veterinary products, industrial discharges, inadvertent contamination through processing or food adulteration.

An evolution is apparent from evidence of adverse human health effects to the prevention of adverse human health effects through the development and implementation of effective monitoring and surveillance programmes.

The impact on society of incidents of unwanted chemicals in food or feed may be economic, environmental, social and/or political. Impact assessments are fragmentary but provide evidence of substantial costs. In purely economic terms, the highest costs of the cited incidents related to victim compensation, in the order of €1400 M, from mercury discharge into Minamata Bay in the 1950s and loss to the Belgian economy of €1500–2000 M as a result of the 1999 dioxin/PCB contaminated animal feed incident.

Initiatives are in progress that will improve current socio-economic impact assessments of unwanted chemicals in food.

An apparent increase of incidents in recent years is due in part to legislative changes, a wider definition of food incident and increased incident reporting. Regular incident reviews help ensure we learn from incidents and assure safe foods.

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