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Chemical safety of cereal-based foods: risk management considerations

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REVIEW ARTICLE

Abstract

Cereals are a significant food-source for man and his animals and, as such, are extensively traded on the international market. Given the quantities consumed, even low levels of chemical contamination can have significance both in terms of consumer health and the agri-food economy. In terms of the food-safety aspects of cereals and their products, considerable attention has been paid to the role of chemical contaminants. These can arise both during cultivation and/or when cereals are processed. Contamination can arise as a consequence of natural phenomena (e.g. heavy metals and mycotoxins) or by the direct actions of man himself (e.g. pesticides and food process toxicants). However, even where natural phenomena are the direct cause, the presence of the resulting contaminants can be aggravated or mitigated by agronomic and/or subsequent processing practices. In terms of assuring consumer safety, these issues are being addressed as part of the ongoing development of an international consensus on food-safety in terms of good agricultural and manufacturing practices as well as through the evolution of regulatory limits and codes of practice to achieve them.

Keywords: contaminants, food safety, grains, regulatory

1. Introduction

The domestication and cultivation of grasses (*Poaceae* or *Gramineae*) is considered to be one of the seminal events in the origin of farming. Within the 'Fertile Crescent' of Southwest Asia they have been cultivated since at least 7800 BC (Haard *et al.*, 1999). Cereals are the fruits of cultivated grasses, the species of primary agricultural significance being barley, maize, millets, oats, rice, rye, sorghum, triticale and wheat (Kent and Evers, 1994). The identities of the different species cultivated across the planet are however dependent on both socio-economic and geographic (e.g. climate) factors (Batey, 2010; Kent and Evers, 1994). Cereals are a significant contributor to global human nutrition; on average they account for 50% of dietary energy, a figure which is not expected to change substantially in the foreseeable future (WHO, 2003). They are also an important component of feed for livestock. In terms of quantity, the three most significant cereals grown are wheat, maize and barley, with worldwide production estimated at, 654, 854 and 469 million tonnes respectively (year 2011/2012; World Grains Council, 2013). Although most cereals are usually consumed in the producing country, there is a significant international trade (269 million tonnes in the year 2011/12; World Grains Council, 2013).

In order to obtain the greatest nutritional benefit from any grain, it must undergo some form of processing to increase both digestibility and palatability. Processing is typically physical in nature, involving one or a combination of mechanical (e.g. removal of outer seed coats – threshing and/or size-reduction – milling to convert the grain into a flour of some type) as well as thermal (e.g. boiling or baking) activities. Some of these activities may also result in fractionation of the grain, e.g. removal of bran layers and embryo to essentially leave the endosperm – as in the production of white wheat flour. Compared with many other foods, cereal-based foods have a greater degree of inherent safety (Alldrick, 2010); nevertheless, the supply chain from seed to final product introduces a number of risk factors, which, if improperly managed, make cereal-based foods particularly prone to chemical food-safety hazards. This can be demonstrated through consideration of data from the European Union Rapid Alert System for

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Food and Feed (RASFF; EC, 2013), for the calendar year 2012 (Figure 1). In 2012 there were 172 entries relating to cereal and cereal products, of which 43% directly related to chemical food safety issues. Such hazards may represent contaminants (compounds unintentionally present in food; see Codex Alimentarius Commission, 2012) but also include chemicals added contrary to regulation (e.g. nonpermitted additives). In managing the hazard therefore it is necessary to understand the contributions made by risk-factors made in the seed to food continuum – in other words adopting a 'farm to table' approach (FAO, 2003a).

2. Methodology

This review therefore considers the chemical safety of cereals from a supply chain point of view. Applying the farm to table approach means that the process of cereal food production can be described as beginning with ground tilling and sowing of seed. During cultivation, the seed germinates and the plant grows; it flowers and, following fertilisation, the grain develops. The ripened grain is harvested and subsequently it may have to be dried and then held in storage until required for primary processing. Primary processing may involve simple removal of the outer seed coats or more complicated procedures such as mechanical reduction (milling) or extractive fractionation (e.g. in the production of starch or protein preparations). For reasons of palatability (and also digestibility) the products of primary processing must undergo some form of thermal processing before being consumed. This may simply be boiling either the whole kernel (e.g. rice) or the meal (e.g. millet) as porridge. Alternatively it may involve more complex processes such as those involved in the production of bread, pasta and extruded foods.

Successful hazard management along the supply chain therefore requires both the identification of the particular chemical hazard and the risk factors contributing to it, as well as the steps and processes necessary to protect the consumer. Examples are provided in Table 1.

In terms of consumer protection, the outcome from any hazard management exercise is to ensure not only that residues of contaminants present are at levels which neither immediately compromise consumer health nor give cause for toxicological concern but are also As Low As Reasonably Achievable (ALARA principle; FAO, 1997).

The following section focuses on some of the key groups of contaminants associated with cereals and products

Table 1. Types of chemical contaminants associated with various stages of cereal food production (after Alldrick, 2012).

Stage	Type	Example
Seed sowing and crop cultivation	Inherent toxicants	phytate
	mycotoxins	ergot alkaloids
	heavy metals	arsenic
	agrochemicals	insecticides
Harvest	mycotoxins	zearalenone
Storage (post harvest)	mycotoxins	ochratoxin a
Primary processing	adulterants	melamine
Storage (post primary processing)	fumigants	methyl bromide
Secondary processing	process food toxicants	acrylamide
	non-permitted additives	aluminium salts

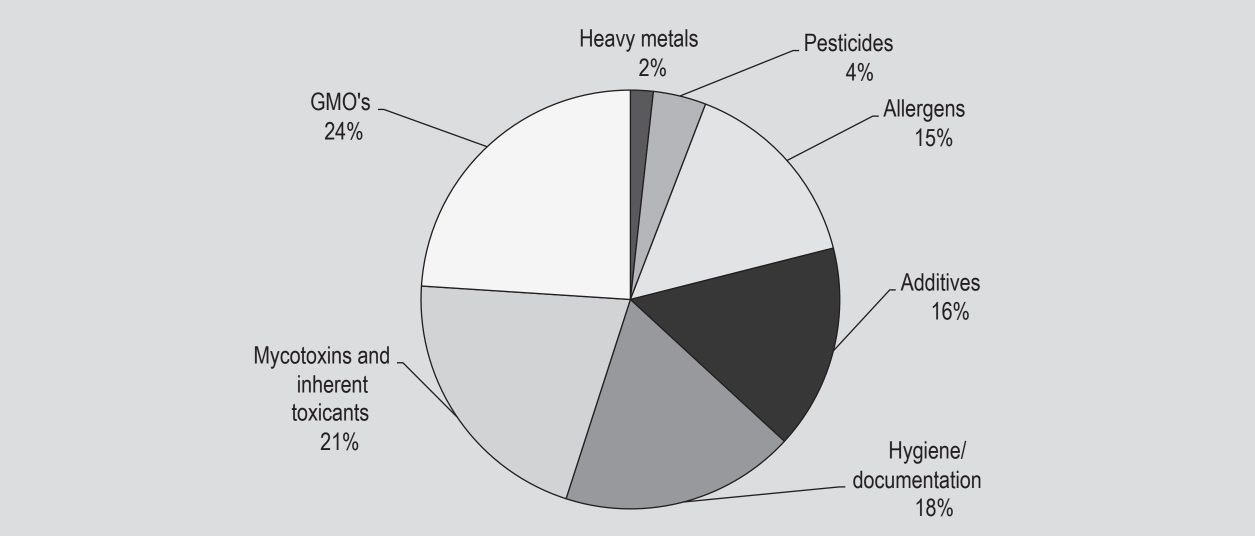

Figure 1. Cereals and cereal-product related entries in the European Union Rapid Alert System for Food and Feed (calendar year 2012).

made from them. It considers where in the supply chain contamination occurs, the implications for consumer health and the mechanisms at both regulatory and food-safety management levels available to ensure that consumer safety is assured.

3. Potential chemical hazards associated with cereals and their products

Inherent toxicants

These are compounds produced by the plant itself and are potentially poisonous to those who eat them. They are a chemically diverse group and include lectins in legumes, glucosolates in brassicas and alkaloids in potatoes and tomatoes (reviewed by D'Mello *et al*., 1991). Cereals generally tend not to contain levels of inherent toxicants at levels significant to the health of man or his livestock; however two compounds which do merit further consideration are phytic acid and tannins.

Phytic acid (myoinositol-1,2,3,5/4,6-hexakis (dihydrogen phosphate); IUPAC and IUB, 1973), is normally found within the kernel as its calcium or calcium-magnesium derivative (phytate). It is considered to be the major source of dietary phosphorous within the grain and its anatomical distribution depends on the cereal being considered (Reddy *et al.*, 1989). Phytate is resistant to the normal digestive processes within the mammalian gut and is therefore considered by some to be an anti-nutrient, either by virtue of it being an unavailable source of dietary phosphorus or as a sequestering agent for nutritionally significant metals (in particular calcium and iron). Phytate sequestration is considered to be a significant issue in terms of complementary foods intended for the relief of malnourished individuals (reviewed by Hurrell, 2003). In contrast, in the affluent populations of the Western World, consumption of phytate (e.g. in products made from 100% extraction flour) is not generally considered to be significant in terms of mineral metabolism (UK Department of Health, 1991).

The second group of compounds to be considered are tannins. The term 'tannin' describes a high molecular weight compound of botanical origin with a sufficiently high number of phenolic hydroxyl groups (1-2 per 100 daltons) to form cross-links with proteins and/or other complex macromolecules (Griffiths, 1991). The amount of tannin present in the kernel varies, depending on the species and ranges (on a 14% moisture basis) from 0.1% in brown rice to 0.4% for wheat and rye (Juliano, 1985) and 5% for certain varieties of sorghum (Collins, 1986). Tannins are considered to be antinutrients by virtue of their ability to inhibit certain digestive enzymes (discussed by Griffiths, 1991). Although not considered to be of significance in terms of Western diets (Bender and Bender, 1996); the case is different where tannin-rich cereals such as sorghum play a role in weaning foods (e.g. parts of Africa; Masha and Svanberg, 1983). There are a number of strategies available for reducing the tannin content of sorghum. These include cultivation of low tannin varieties, characterised by a reduced presence/absence of pigment in the seed coat testa and pericarp (Taylor and Duodu, 2010). Over and above varietal selection, other methods of reducing tannin content in foods containing sorghum include one or a combination of: physical removal (decortication) of the tannin-containing seed coat material prior to milling (Youssef *et al.*, 1988) and malting (Lefyedi and Taylor, 2006).

Mycotoxins

Mycotoxins are the poisonous metabolites of certain fungi and are arguably the single most significant group of chemical contaminants associated with cereals. It has been estimated that approximately 25% of the world's crop production are, to one degree or another contaminated with one or more members of this particular group of contaminants (Charmley *et al.*, 1995).They are a chemically diverse group of compounds with an equally diverse range of both acute and chronic toxic effects. Cereal-related mycotoxicoses in humans have a long history ranging from 'St. Anthony's fire' (chronic ergot alkaloid poisoning) in mediaeval Europe (De Costa, 2002) to acute aflatoxicosis (liver failure) in Kenya in 2004 (Azziz-Baumgartner *et al.*, 2005). Given that a significant proportion of cereals are directed at animal feed, mycotoxicoses are of equal significance to livestock, for example zeralenone exposure and precocious puberty in sows (Mirocha *et al.*, 1967) and feed refusal associated with deoxynivalenol (Young *et al.*, 1983).

Mycotoxins associated with cereals can be broadly classified on the basis of when they are formed in the life of the grain. They are generally referred to as either being of 'field' or 'storage' origin (Miller, 1995). Essentially this reflects whether they are formed by pathogenic (e.g. *Fusarium* spp.) or sarcophagous fungi (*Aspergillus* spp. and *Penicillium* spp.). Such a classification is not absolute and there is evidence to show that some 'field' mycotoxins can be formed postharvest, for example fumonisins (Ono *et al.*, 2003) and zearalenone (Homdork *et al.*, 2000) and *vice versa* (e.g. aflatoxin; Hill *et al.*, 1983). In common with most micro-organisms, mycotoxigenic fungi have evolved to inhabit particular environmental niches. Consequently they are to a degree dependent on the locale where the crop is grown, with climate being a determinate factor (e.g. Cotty and Jaime-Garcia, 2007). As a result, mycotoxins constituting an issue for locally grown crops in one part of the world may not be the same in another. This is something which has to be borne in mind when trading cereals internationally.

From a legislative standpoint, mycotoxins are arguably the most heavily regulated naturally occurring food-contaminants in the world. Van Egmond *et al.* (2007) estimated that in 2002, over 100 countries had regulations concerning their occurrence in food – a 30% increase compared with a similar survey performed in 1995. In parallel there has been considerable effort to provide those in the grain supply chain with the tools necessary to ensure that mycotoxin contamination is both as low as reasonably achievable and legally compliant. Although the type of advice very much depends on whether the mycotoxin is of field or storage origin, it is based on the same principle: 'Prevention is better than cure' (Battaglia *et al.*, 1996). Guidance has been produced at international (e.g. Codex Alimentarius Commission, 2003); supranational (e.g. EC, 2006a) and national (e.g. in the UK; Home Grown Cereals Authority, 2013). In some countries (e.g. UK) compliance with such guidance is a pre-requisite for securing certification against specific farm assurance schemes (e.g. Red Tractor Farm Assurance Combinable Crops and Sugar Beet Scheme, 2012); while in turn, farm-certification is often a requirement of trade between vendor and purchaser (National Association of British and Irish Millers, 2013).

Heavy metals

In terms of cereals the heavy metals of concern are arsenic, cadmium and lead. Recent re-evaluations of these metals' dietary toxicological significance (e.g. EFSA, 2009a,b, 2010, 2011), suggest that for the European population at least, cereals and cereal-based foods make a significant contribution to dietary exposure of these metals (Table 2). As will be discussed, the occurrence of these compounds can be determined by the geological conditions where the crops are cultivated and/or the activities of man himself.

Table 2. Average contribution of cereals to dietary heavy metal body burden within the European Community (based on data from EFSA, 2009a,b, 2010).[1]

	Total	Cereal products
Total arsenic	0.94-1.22	0.26-0.32
Inorganic arsenic	0.30-0.43	0.18-0.23
Cadmium	1.9-3.0	0.19-0.67
Lead	0.36-1.24	0.05-0.17

[1] Data represent the range between the lower and upper bound values and are expressed as μg per kg bodyweight per day.

Lead

For Europeans, of the three heavy metals considered here, cereals contribute the lowest proportion to the dietary lead body burden (Table 2), nevertheless as a food-group they are the largest single source of lead in the European diet (EFSA, 2010). Accumulation of this metal in plants appears to be mainly as a consequence of atmospheric deposition and, although some plants have the ability to take up lead through the roots, this does not appear to be significant (US Agency for Toxic Substances and Disease Registry, 2007). Unlike arsenic or cadmium contamination, contamination of cereals with lead is primarily a result of human activities; in particular industrial emissions and the use (now discontinued in many jurisdictions) of leaded petrol (Kabata-Pendias and Mukherjee, 2007). Adoption of more stringent environmental protection regulations (including the use of unleaded automobile fuels) has led to a reduction of levels of lead in the atmosphere (e.g. Central Europe; UN Environment Programme, 2010), which have been associated with a concurrent reduction in the amounts of lead found in plant derived foods such as cereals (Kabata-Pendias and Mukherjee, 2007).

Arsenic

Although arsenic presents itself as a food contaminant in diverse molecular forms (inorganic and organic), inorganic arsenic (in either the As (III) or As (V) state) is considered to be more toxic of the two forms (EFSA, 2009b) and is classified as a category I (known human) carcinogen (IARC, 2012). Consequently most attention has been paid to the inorganic forms of arsenic and a similar approach is used here.

Depending on where in the world one lives, dietary exposure to arsenic (either inorganic or organic) can occur through the drinking of water and/or eating of food. Cereal-based foods can be a significant dietary source of inorganic arsenic. This applies particularly to rice (Agusa *et al.*, 2009; Chatterjee *et al.*, 2010; EFSA, 2009b; Liang *et al.*, 2010), which has a greater propensity than other cereals to accumulate the element (US Environmental Protection Agency, 1982). Arsenic contamination of cereals is effected by uptake through the roots and, in some plants (e.g. rice), contamination is highly dependent on the amount of the metal present in the irrigation water (e.g. Baig *et al.*, 2011). At present reducing the arsenic loading of cereals can only be achieved through processing, for example prewashing and subsequently boiling in large quantities of water (Mihucz *et al.*, 2007). In the future the most effective route of mitigation will probably be to breed varieties with reduced capacities to bioaccumulate arsenic. This presupposes a full understanding of arsenic metabolism within the plant – something, which at the time of writing is incomplete (Tuli *et al.*, 2010).

Indigenous populations eating home-produced cereals are not the only consumer groups potentially at risk of arsenic exposure. The global nature of the cereals trade (discussed above), means that populations who purchase and import such commodities are also at risk. For example the European Food Safety Authority (EFSA, 2009b), estimated that in the case of high rice consumers (in particular certain ethnic groups), inorganic arsenic exposure could be in the region of 1 μg per kg bodyweight per day. This compares with an index of safe intake (Bench-Mark Dose of 1% extra risk, BMD_{01}) of 0.3-8 μg per kg bodyweight per day. This issue is being addressed by national governments. For example between 2006 and 2009 the United Kingdom Food Standards Agency published the results of surveys to determine the significance (if any) of the presence of heavy metals (including arsenic) in weaning-foods and infant formulae (Food Standards Agency, 2006, 2007) and subsequently rice milk (Food Standards Agency, 2009). Although none of the products contained arsenic at levels which exceeded the then statutory maximum (1 mg/kg), a risk assessment based on consumption data indicated that children consuming such products might be at risk of adverse exposure (Meharg *et al.*, 2008). This was particularly true of rice milk preparations (often used as a substitute in cases of cow's milk intolerance); leading the Agency to advise that, rice milk should not be used as a substitute when feeding babies or young children (Food Standards Agency, 2009).

Cadmium

Cadmium salts occur naturally in the environment as a consequence of erosion, other natural phenomena and the activities of man. Like arsenic, cadmium is considered to be a class I carcinogen (EFSA, 2009). Cadmium exposure can have a number of sequelae including nephrotoxicity and bone demineralisation and in terms of cereals (rice); the metal has been identified as the causative factor of the condition Itai-itai (Kobayashi *et al.*, 2009; Ogawa *et al.*, 2004).

Bioaccumulation within plants is considered to take place particularly within the leaves rather than other tissues of the plant (Alloway *et al.*, 1990). Nevertheless some bioaccumulation in the kernel itself does occur and, as can be seen in Table 2, partly due to the substantial amounts consumed by humans, cereals are a significant dietary source of this metal. In terms of agricultural practice, as in the case of arsenic (discussed above), irrigation is a major contributory factor for the occurrence of cadmium in rice. For example, studies in different countries (Cattani *et al.*, 2008; Hussain *et al.*, 2010) have demonstrated that use of waste water to irrigate rice can result in increased levels of cadmium contamination of the crop. Agronomic factors can further add to the problem, for example by the intensive use of cadmium contaminated phosphorus fertilisers, as seen in rice grown in Sri Lanka (Bandara *et al.*, 2010a). Agronomic practices may also provide a (limited) route of remediation for example through the use of organic fertilisers (Hecl, 2010) and filtration of irrigation water through rice husks (Bandara *et al.*, 2010b). However, as in the case of arsenic (discussed above), in the long-term, development of cereal varieties which do not accumulate the metal into the kernel in the first place will be a significant contributory factor. With regards to rice some progress has been made in identifying those genes responsible for suppressing cadmium bioaccumulation (e.g. Ueno *et al.*, 2010). However translating this into reality may be difficult since rice breeders have found it difficult to maintain yields, while reducing cadmium-loading (Liu *et al.*, 2005). Nevertheless, commercial varieties of other cereals with a lower propensity to bioaccumulate cadmium have already been described (e.g. durum wheat; Clarke *et al.*, 2009).

Pesticides

As defined by the Food and Agriculture Organisation (2003b), the term pesticide embraces a broad spectrum of chemicals used to enhance the cultivation of crops and not only includes those designed to control predators (e.g. insects) and competitors (e.g. weeds) but chemicals applied to the plant for a specific purpose (e.g. plant growth regulators). Since cereal-foods are a significant contributor to the diet, they also have the potential of significantly contributing to the consumer's intake of pesticides. Pesticides are usually tightly regulated (discussed further below) however some carry-over of residues is inevitable. Studies conducted at different times and in different parts of the world, for example the UK (UK Ministry of Agriculture, Fisheries and Food, 1996), Germany (Kersting *et al.*, 1997), Kuwait (Sawaya *et al.*, 2000), all suggest that while overall pesticide intakes are well within the acceptable daily intake and therefore not of toxicological concern, cereal-based products can be a significant source of residual pesticides for some populations. For example, Sawaya *et al.* (2000) estimated that the body burden of organo-phosphorus pesticides in young Kuwaiti men from eating cereals (176 ng per kg bodyweight per day) was higher than for both leafy vegetables (93 ng per kg body weight per day) and fruit (24 ng per kg body weight per day).

Historically acute toxicoses relating to dietary exposure of pesticides have related to improper storage of bulk pesticides together with grain or misuse of pesticides during food preparation – rather than as a consequence of agricultural practice itself (discussed by Alldrick, 2012). As already alluded to; many jurisdictions have enacted legislation which enables the regulation of pesticides using a farm to table approach. Such regulations not only specify which pesticides are permitted to be used on which crops and for what purpose but also set maximum limits for their presence in crops and products, once they enter the food chain. It should also be borne in mind that there is also an economic incentive for primary producers in most countries to apply pesticides correctly in terms of quantity. Misapplication generally results in financial loss, either through reduced yields due to too little pesticide being applied or any increases in yield being insufficient to justify the associated cost of high levels of pesticide application. Advice on application is therefore often provided to the farmer by the pesticide company and consultant agronomists. Consequently, pesticide treatments are designed not only to achieve the appropriate level of crop-protection but also to ensure that any residues are below the maxima set in local legislation. Although such advice might be provided, a second consideration is whether or not it will actually be taken up by the end-user. Many good agricultural practice standards (e.g. Red Tractor Farm Assurance Combinable Crops and Sugar Beet Scheme, 2012); require those certified to them to apply pesticides in an appropriate manner. Furthermore, examples exist where purchasers of grain use supplier certification as part of their supplier quality assurance programme (e.g. National Association of British and Irish Millers, 2013).

Food process toxicants

Processing of foods generally, and thermal processing in particular, can lead to the production of potentially poisonous compounds. Generically these have been referred to as food process toxicants (discussed by Lineback and Stadler, 2009). In terms of cereals and the foods made from them, four compounds or groups of compounds are considered here: acrylamide, chloropropanols, dioxins and polyaromatic hydrocarbons (PAH). In terms of where in the food chain these compounds arise; dioxin and PAH contamination are usually associated with handling of the grain itself, while contamination due to either acrylamide or chloropropanols is associated with the processes involved in the manufacture of the finished food.

Poly-aromatic hydrocarbons

These are compounds containing two or more fused aromatic rings, a number of which, most notably benzo[a] pyrene, are known carcinogens (reviewed by Park and Penning, 2009). In its assessment of dietary exposure to PAH by European Union inhabitants, the EFSA (2008a) considered exposure to 8 PAH with demonstrable oral carcinogenicity. The Authority determined that that the principal sources of PAH in the diet were cereal-based products and fish and that while levels of contamination were generally low, levels of intake in some of the highest centile groups of consumers might exceed the index of safe exposure.

Contamination of cereal grains appears to be as a result either as a consequence of deposition through atmospheric pollution (Dennis *et al.*, 1983, 1991) and/or as a result of use of inappropriate fuel in grain drying or oven-processes, leading to incomplete combustion and consequent PAH production/contamination (El-Samahy *et al.*, 2000; Hellweg, 1994). In terms of risk management therefore, maintaining low levels of PAH contamination of cereal foods is achieved not only through the control of the temperatures used to dry and process cereal foods but also in the choice of the most appropriate sources of energy to generate the necessary heat to achieve the desired end-product (Home Grown Cereals Authority, 2011).

Dioxins

'Dioxin' is the trivial name for 2,3,7,8-tetrachlorodibenzo para dioxin; while the term 'dioxins' refers to a series of structurally related compounds (WHO, 2010a). Dioxins are ubiquitous, low level pollutants and, although usually man-made, can also occur as a result of natural causes. They are highly toxic to humans. Short term, high level exposure can lead to skin lesions (e.g. chloracne) while longer, chronic exposure has been shown to include effects on the immune and endocrine systems as well as adversely affecting foetal and child development (World Health Organization, 2010b). In terms of their food-safety significance, dioxins are of concern since they concentrate by bioaccumulation in the food chain. Thus providing livestock with feed contaminated with low levels of dioxins results in animal products intended for human consumption (meat, milk, eggs, etc.) having far higher levels. One route by which they can be introduced into the food chain in this manner is through the use of inappropriate fuels in direct flame drying systems for cereals and cereal-based foods (Codex Alimentarius Commission, 2006). The significance of this route of contamination was highlighted in 2008 in the Irish Pork recall incident where approximately 10% of the national herd were fed a dioxin contaminated feed prepared from waste bread. Subsequent investigation showed that the source of the dioxin contamination was as a result of the bread being dried in a direct-flame drier, fuelled with polychlorinated biphenyl contaminated recovered oil (Irish Department of Agriculture, Fisheries and Food, 2009).

Chloropropanols

While dioxin and PAH contamination of cereal-based foods occur as a result of external factors, the formation of compounds such as chloropropanols and acrylamide (discussed below) are the result of chemical reactions between ingredients within the food itself. The presence of chloropropanols (e.g. monochloro-1,2-dichloropropane-1,2-diol; 3-MCPD) as food contaminants was first reported in hydrolysed vegetable protein preparations by Velíšek *et al.* (1978). Subsequent research demonstrated the potential of these compounds to act as rodent carcinogens (Lynch *et al.*, 1998). Regulatory limits for the presence of these compounds in hydrolysed vegetable protein preparations and similar products (e.g. soy sauces) have been set in a number of jurisdictions including the European Community (EC, 2006b). Subsequently, far lower concentrations of 3-MCPD have also been detected in other foods, including bread. In these cases, the levels of 3-MCPD were seen to rise (to still low levels) when the bread was toasted (Breitling-Utzmann *et al.*, 2003). Although observed, the levels found in bread were not considered to present a hazard to the consumer (UK Food Standards Agency, 2001).

Acrylamide

Acrylamide is an important industrial compound used in the manufacture of polymers (polyacrylamides). Evaluations relating to its industrial safety have shown that it is both a dermal irritant and neurotoxin (UK Health and Safety Executive, 1987). The compound has been shown to be carcinogenic in rodents and is considered to be a probable human carcinogen (IARC, 1997). The issue of acrylamide as a dietary contaminant arose as a result of work undertaken in Sweden at the beginning of the century (Törnqvist and Ehrenberg, 2001). The major sources of dietary acrylamide appear to be foods with a relatively high carbohydrate content that had been prepared at high temperatures. Typically, these include coffee, baked farinaceous foods and fried potato products (Svensson *et al.*, 2003). Initial estimates (i.e. before the introduction of mitigation strategies – discussed below) of dietary exposure suggested that acrylamide intakes may be cause for concern in some consumer groups (e.g. Food Standards Agency, 2005). The situation is under continuous review at national, supra-national and international levels (e.g. EFSA, 2012).

Considerable effort has been expended on developing good manufacturing practices (GMP) to enable food manufacturers to produce foods with lower acrylamide loadings. Development of such guidance has been complicated by the fact that acrylamide formation in foods occurs due to Maillard-type reactions involving asparagine and glucose (Stadler *et al.*, 2002) – the same type of reactions involved in the production of other sensorial attributes (e.g. flavour and colour). Arguably one of the best examples of such guidance is the Food Drink Europe 'Acrylamide Tool Box' (Food Drink Europe, 2011). The tool box adopts a field to fork approach in identifying routes by which acrylamide formation can be mitigated. The guidelines emphasise that not all of the steps may be applicable to a particular manufacturing unit and that introduction of such practices has to be done with care to avoid adverse effects on other desired product attributes (e.g. colour and flavour). Adoption of such guidance has implications for food-safety management systems where consideration needs to be given to their impact on both GMP programmes and Hazard Analysis Critical Control Point (HACCP) plans. For example two approaches suggested in the tool box in connection with biscuit baking are replacement of ammonium bicarbonate with other chemical leavening agents and modification of the oven time/temperature profile. Restrictions on the use of leavening agents would fall within the GMP programme while the baking step (in terms of time and temperature) might be considered to be a critical control point, managed through the business' HACCP system. Caution must also be employed to ensure that steps to reduce levels of acrylamide do not result in increased concentrations of other food process toxicants and *vice versa*. For example in bread production, increasing the initial dough pH value towards the alkaline leads to a reduction in levels of 3-MCPD in the final product however it also leads to a concomitant increase in acrylamide formation (Hamlet and Sadd, 2009).

Food additives

In its standard, the Codex Alimentarius Commission (2013) defined a food additive as:

> Any substance not normally consumed as a food by itself and not normally used as a typical ingredient of the food, whether or not it has nutritive value, the intentional addition of which to food is for a technological (including organoleptic) purpose...

The use of food additives is usually governed by local legislation and is therefore subject to considerable variation across the world. Irrespective of jurisdiction, food-additive legislation shares some common features, in particular, that for any permitted additive it will specify the purpose(s) for which the additive can be used and in which foods. The legislation will go on to specify limits for the amount of residues that are allowed to remain in the finished product. It is important to note that the use of a food additive in one jurisdiction might be more limited or even prohibited in another. This is particularly the case with regard to cereal-based foods.

Two examples to highlight this point are potassium bromate and aluminium-based additives (e.g. aluminium sulphate).

Potassium bromate

This compound is used as a flour treatment/dough conditioning agent; its use improves dough-handling properties contributing to improved loaf volume and texture (American Baker's Association and American Institute of Baking, 2008). Potassium bromate had been identified as a genotoxic carcinogen by Kurokawa *et al.* (1983); however it has been argued that when used under controlled conditions all of the bromate is reduced to bromide during the baking process. Nevertheless surveillance studies in the UK during the 1980's suggested the contrary with the presence of bromate being detected and the consequent prohibition of its use (discussed by UK Ministry of Agriculture Fisheries and Food, 1993). However its use continues to be permitted in other parts of the world (e.g. USA).

Aluminium salts

The toxicology of aluminium was recently reviewed by the EFSA. Chronic aluminium exposure can lead to neurotoxicity, embryotoxicity and damage to the male reproductive system (EFSA, 2008b). In its assessment, the EFSA expressed concern that some groups of the population might consume the metal in amounts greater than the tolerable weekly intake. In response to this, the use of aluminium containing food additives was further restricted by legislation (EC, 2012). In parallel, concern was being raised over elevated levels of aluminium being found in imported noodles from the Far East, probably due to the use of potassium aluminium sulphate or ammonium aluminium sulphate as leavening agents (Laboratory of the Government Chemist, 2011). This led to a *de facto* limit of 10 mg/kg being established (EC, 2010). Consideration of Figure 1 indicates that 16% of all RASFF entries (n=172) related to food additives, of which 16 (over half of the additive related entries) concerned aluminium in imported noodles.

4. Discussion

It can be argued that cereal-based foods do not present the same degree of immediate food-safety hazard as many other types of foods (discussed by Alldrick, 2010). Paracelsus' (1493-1541) dictum states that 'All things are poison and nothing is without poison; only the dose makes that a thing is no poison' (http://toxipedia.org/display/toxipedia/Paracelsus). Given the sheer quantity of cereals and cereal-based foods, consumed by man, his livestock and pets, it can be argued that, even with low levels of contamination, cereal-based foods have the potential of being a source of chemical-safety issues. Even now, failure to manage the issue can have demonstrable consequences in terms of both acute and chronic toxicoses, as exemplified by acute aflatoxicosis in Kenya and Itai-itai in Japan.

The risk factors which contribute to the hazard occurring are many and various, reflecting one or a combination of environmental, biological or human factors. Establishing an appropriate risk management regime therefore requires an approach based on farm to table principles. Once the risk factors have been identified, it is possible to develop appropriate codes of practice, guidance and standards to establish mitigation practices. Depending on the chemical of concern, mitigation is currently effected at one or more of the levels of agronomy, raw material processing and food manufacture.

This review has been restricted to chemical food safety issues arising as a result of natural phenomena or activities during agriculture and food-processing. Criminally motivated chemical hazards such as food-fraud and malicious contamination have not been discussed in any detail. These can however be significant at both local and international levels. For example melamine contamination (to give elevated nitrogen and consequently apparently increased protein levels) of imported wheat gluten into North America, which was used as a pet-food ingredient. As a result, within the US, there were 38 product recalls between March and September 2007 and over 18,000 consumer complaints concerning pet illness or death (US Department of Health and Human Services, 2009). The topic is also one that continues to evolve, one contributory factor being climate change, which some (e.g. Miraglia *et al.*, 2009) have identified as a factor contributing to the altered incidence of many of the contaminants considered here. Consequently research into mitigation strategies will have to be continued and reinforced in the light of ever changing circumstances of supply.

Conflicts of interest

No conflicts of interest arise.

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