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CHEMICAL HAZARDS IN FOOD

Introduction

The purpose of this review is to give a broad overview of the types of hazardous chemicals (i.e. those that might adversely affect the health of the consumer) that can occur in foodstuffs, and indicate how they arise and how they are measured and controlled. The examples given have been chosen to reflect the whole spectrum of possible hazards - but they are merely examples: it would be impossible to try and cover all possibilities. However, they are representative of the many types of issues that the food industry has to face on a daily basis. They have also mainly been chosen to reflect real hazards - the large area of pesticides has been deliberately omitted because, when correctly used, they are not considered to be a hazard to the food consumer (the primary risks are to the environment and to those who apply them to the crops). In addition, the risks posed by allergens has been omitted, as this is covered by a separate IUFOST Scientific Information Bulletin (http://www.iufost.org/reports_resources/bulletins/).

Origin of chemical hazards in foods

It has been said that 99% of all toxins are naturally occurring, and also that all things are toxic at a high enough concentration. Certainly, many food raw materials contain chemicals which, if consumed in excess, might lead to health problems. Cooking and processing in general can remove or inactivate many chemicals (e.g. protease inhibitors, lectins) that are either directly toxic or inhibit digestion or absorption of nutrients. However, some chemicals have arisen as problems associated with food processing techniques developed in the last 100 years or so, e.g. trans fatty acids resulting from chemical hydrogenation of unsaturated fats, or 3-monochloropropanediol from the chemical hydrolysis of proteins (to form HVP - hydrolysed vegetable protein). One recently discovered example of a process-derived chemical hazard in food is the formation of acrylamide in baked products. Although this has been occurring for centuries (e.g. in home baking of bread, potatoes and other starch-based foods), it was not stumbled upon until 2002. In addition, transfer of packaging material constituents into foods is a potential issue.

Other hazards are contaminants introduced by accident during the production of the food raw materials - sometimes these are unavoidable and sometimes they are to a greater or lesser extent caused by suboptimal growing, post-harvest or processing conditions. Mycotoxins produced by moulds growing on grain or nut products is one example; nitrate accumulation in leafy vegetables, and heavy metal accumulation in seafood are others.

Most difficult to predict or control are the chemical hazards introduced deliberately, either to cause (or threaten to cause) illness in the consumer, or as a consequence of fraudulent or similar malpractice (e.g. use of illegal Sudan dyes to colour spices).

Chemical hazards can thus be divided into four broad categories:

- Inherent ('Natural') toxins
- Natural and environmental contaminants
- Process and storage-derived contaminants
- Deliberately added contaminants

These categories are merely convenient sub-groupings: sometimes, it is debatable which group a particular chemical should be put into. Importantly, the way a chemical is classified has no bearing on how significant a hazard it is.

Examples of chemical hazards

The examples below give a flavour of the many different chemicals that can pose a problem in food from time to time. They are chosen to give a broad picture of their nature, rather than to be exhaustive. Some, such as trans fatty acids, have not been included, as these were discussed in a previous IUFoST Scientific Information Bulletin in 2006 (http://www.iufost.org/reports_resources/bulletins/).

i) Natural toxins

These problem chemicals occur as regular constituents of the food in question (e.g. lectins in kidney beans), or at increased levels as responses of the foodstuff when alive to some sort of stress (e.g. glycoalkaloids in potatoes, an increased production of which can be stimulated when the tuber is exposed to light), and are inherent to the food raw material. There are also some instances of a processing regime potentially releasing a toxin from a non-toxic starting material (as occurs with cyanogenic glycosides in some canned stone fruits). The latter could be considered under the process-derived hazards category, but is essentially 'natural'.

Lectins:

Lectins occur in a wide variety of plants including beans of the *Phaseolus* genus (e.g. kidney beans and lima beans), broad beans, castor beans, soya beans, lentils, peas, field beans, peanuts, potatoes and cereals, as well as a range of non-food plants. In many cases the lectins have no or minimal toxic effect. Others are toxic to a greater or lesser extent, but in most cases normal cooking procedures eliminate this toxicity entirely, and consumption of moderate levels of most types of uncooked beans or peas will have no adverse effect. However, there are some specific exceptions, the most well known and significant of which (because of the way we consume them) is red kidney beans.

Raw kidney beans are significantly toxic and must be cooked adequately before consumption. One form of wording suggested for the labelling of beans for sale is:

"After soaking overnight and throwing away the water, these beans should be boiled briskly for at least 10 minutes and then cooked until soft, otherwise they may cause stomach upsets. Never cook in a small casserole unless the beans have first been soaked and boiled in this way. Do not eat raw beans"

Glycoalkaloids

Potato glycoalkaloids are a good example of naturally occurring toxins that can and have caused problems when consumed in large quantities, but which we have learnt to avoid without too much problem.

Potatoes contain two main glycoalkaloids: solanine and chaconine, with chaconine being the more biologically active. Symptoms of acute poisoning can range from abdominal pain, vomiting and

diarrhoea (similar to bacterial food poisoning) to confusion, fever, hallucination, paralysis, convulsions and occasionally death. There is an unofficial, but widely accepted safety limit of 200 mg glycoalkaloid/kg fresh potato. Levels of glycoalkaloids in modern varieties are usually well below this value, but they can exceed the limit under certain circumstances. The associated bitterness that accompanies these increases means that the chances of ingesting a toxic dose are small unless the bitterness has been masked with other highly flavoured ingredients.

Thus, although the chances of someone eating potatoes with high levels of glycoalkaloids are small, the possibility does exist, and the food industry must take precautions to eliminate the risk as far as is possible. Glycoalkaloids can only be made by the living potato tissue, and therefore will be halted by cooking and any other process that kills the tissue. However, they are heat stable and therefore preformed toxin will remain after processing. Glycoalkaloid levels in potatoes are highest in the flowers and in the sprouts on the tubers. Within the mass of the tuber itself, they are concentrated in the outer 2mm, so that unpeeled potato products are a higher risk than flesh-only products. Levels vary from one variety to another, and are generally higher in early varieties than in main crop varieties. Smaller potatoes tend to have higher levels than large potatoes, largely as a consequence of the increased surface area/volume ratio.

Increased levels arise through various stress factors, such as pest and disease damage, drought, water-logging, and extremes of temperature. During post-harvest handling, bruising, abrasion and other types of mechanical damage can all cause increases in levels, as can peeling (although the act of peeling will remove much of the glycoalkaloid content unless the peel is added back into the product). Light can also induce glycoalkaloid formation. Light also induces chlorophyll formation, causing the potatoes to turn green on the surface.

Oxalates

Oxalic acid and oxalates are widely distributed in plant foods, highest levels being found in spinach (0.3-1.2%), rhubarb (0.2-1.3%), tea (0.3-2.0%) and cocoa (0.5-0.9%). Although there is no question that the ingestion of sufficient oxalic acid as crystals or in solution can be fatal, there is considerable debate as to whether serious food poisoning from oxalate is usually due to food.

The eating of rhubarb leaves has been a well-known cause of illness for centuries. Rhubarb leaves contain high amounts of oxalate. However, the levels of oxalate in rhubarb stalks are sufficiently high that consumption of normal levels of rhubarb stalks will result in at least as much oxalate intake as from small to moderate amounts of leaves.

There is some debate as to whether it is the oxalate in rhubarb leaves that is responsible for toxicity. Whatever the toxic principle, consumer perception is, correctly, that rhubarb leaves are toxic and consumer complaints about small fragments of leaves in canned rhubarb are well-known.

Phytates

Phytic acid and the phytates have the ability to chelate (bind) divalent and trivalent metal ions such as calcium, magnesium, zinc and copper. As such, they have the potential to interfere with the absorption of these ions in the gut. Levels of phytate vary greatly with the stage of maturity of the plant and the portion of the plant that is consumed, but cereals, nuts and legumes have relatively high levels, and potatoes, sweet potatoes, artichokes, blackberries, strawberries and figs contain small to moderate amounts.

Whether or not high levels of consumption of phytate-containing foods will result in mineral deficiency will depend on what else is being consumed. In areas of the world where cereal proteins are a major and predominant dietary factor, the associated phytate intake is a cause for concern.

Enzyme inhibitors

After ingestion, proteins are denatured by the acid in the stomach and subsequently hydrolysed by a number of enzymes in the small intestine to yield a mixture of amino acids and small peptides which can be absorbed. Inhibitors to most of these enzymes have been isolated, but it is trypsin that is by far the mostly widely affected, and this enzyme has also been the most closely studied.

Many constituents of plant foodstuffs are known to contain enzyme inhibitors. Seeds are the most common part of the plant to contain protease inhibitors (they help the seed survive in the gastrointestinal tract as part of their dispersal strategy), but they can be found in virtually any part, such as in the tubers of potatoes and sweet potatoes. All of the protease inhibitors that have been isolated to date have proved to be proteins. The nutritional significance of these inhibitors is that they are often associated with foods that are important sources of dietary protein, and they can potentially prevent the utilisation of this protein.

The best known trypsin inhibitor occurs in soya beans. It has long been known that soya needs to be cooked in order for it to support growth in experimental animals. It was found that, in the case of soya, supplementing raw soya with methionine or cysteine (the limiting amino acids in soya) had the same effect, nutritionally, as cooking the soya. However, rather than being a specific effect on the absorption of these amino acids, it is believed that the inhibitor has a more general role of preventing or slowing protein digestion so that insufficient quantities of the limiting amino acids (whatever they happen to be) are absorbed.

From an industrial point of view, knowledge of the antinutritional characteristics of soya and other legumes is important in product design. Whilst many raw beans may not be intrinsically toxic, they may have reduced available protein levels compared with their cooked counterparts.

Cyanogenic glycosides

Many fruits and other plant foods contain compounds that have the potential to release cyanide. These compounds are usually glycosides - i.e. they consist of a sugar molecule linked to a cyanide group, usually indirectly through another component. The release of cyanide from these compounds occurs by enzymic hydrolysis, usually when the plant tissue is crushed or otherwise disrupted (allowing the active enzyme to reach the substrate), but it can also occur in the digestive system after the food has been eaten. Some plants are toxic because of their high levels of these compounds. Other foods we still consume, despite their having moderate levels. The most well-known of these compounds is amygdalin, a cyanogenic glycoside first identified in bitter almonds, which on hydrolysis by an enzyme complex known as emulsin yields glucose, benzaldehyde and hydrogen cyanide.

Cassava or manioc is a major basic food for large numbers of the world's population. It is the world's seventh largest food crop in terms of production area. The toxic potential of cassava has been known of for hundreds of years, and traditional methods of food preparation from cassava have been developed to reduce cyanide content. These include leaching out the linamarin precursor, washing in running water before cooking (bruising of the cassava root during harvesting often results in considerable cyanide release), and boiling in uncovered pots, so that the cyanide can evaporate. Fermentation steps also significantly reduce cyanogenic potential. The risk of food poisoning from cassava can be reduced by avoiding bruised or non-fresh material, and avoiding roots known to be bitter.

ii) Natural and Environmental Contaminants

All plants and animals during their lifetime will accumulate various chemicals from their environment that are not specifically required by them and become assimilated more or less by accident. Some of these chemicals, if they are accumulated in high enough amounts, might be of toxicological significance to us when we eat the food. Specific examples that are of concern at the moment are nitrates in leafy vegetables; heavy metals in various systems, and specific toxins in shellfish. In many cases, the best way to control levels of these unwanted substances is to control the environment in which the food is produced. However, this is generally a long-term control measure and more immediate steps have to be taken to protect human health. As most of the toxins can not always be 'processed out', the short term controls are usually based around the setting of maximum permitted levels, and the removal from the supply chain of food that does not meet the required standard. These contaminants are divided below into 'natural' (of biological origin) and 'environmental', but they are linked in that the food plant or animal acquires them from its surroundings during its growth.

'Natural' Contaminants

Mycotoxins

Mycotoxins are a chemically diverse group of harmful compounds with a correspondingly diverse range of physiological effects. Members of a number of different fungal genera produce mycotoxins, including *Aspergillus*, *Fusarium* and *Penicillium*, in a range of commodities, including nuts, dried fruits and cereals. Until recently most of the human health issues have focussed on the so-called 'storage mycotoxins' principally, the aflatoxins and ochratoxin A. These are produced mainly as a result of the growth of the mould on the commodity when it is stored incorrectly - usually at too high moisture levels. Aflatoxin can also be a problem in milk if contaminated grain is fed to dairy cattle.

More recently attention has begun to focus on toxins produced by *Fusarium* spp., e.g. the fumonisins and tricothecenes (deoxynivalenol, nivalenol). In cereals these appear to be produced mostly while the grain is developing in the field, in contrast to the 'storage mycotoxins'. Another mycotoxin that has received recent attention is patulin. This mycotoxin is formed by some strains of the mould *Penicillium expansum*, which occurs naturally on some fruit and vegetables, but most notably apples. The major dietary source of patulin is apple juice. The Institute of Food Science and Technology website contains information statements on mycotoxins (see www.ifst.org/uploadedfiles/cms/store/attachments/mycotoxins.pdf).

Shellfish toxins

There are several types of shellfish poisoning - neurotoxic (NSP), diarrhetic (DSP), paralytic (PSP), amnesic (ASP), and ciguatera fish poisoning (CFP). Shellfish toxins are not produced by the shellfish themselves, but are accumulated through their diet, in which planktonic dinoflagellate algae are a component. The term shellfish generally refers to both marine crustaceans (lobsters, crab, shrimp etc), and molluscs. However, it is the bivalve molluscs – oysters, muscles, clams and scallops - which accumulate these algae by filter feeding, that are the major areas of concern. See Garthwait (2000) for a review of these different types.

The most significant toxins in PSP are saxitoxin and its derivatives. The exact composition differs amongst algal species and amongst regions of occurrence. Generally the population density of such algae is not high enough to cause problems. However, on occasion when environmental conditions (nutrients, temperature, sunlight etc) are favourable, population explosions called algal blooms occur. Problems can arise if the algal bloom is of a species which produces toxins, such as the *Alexandrium* genus. Such toxins can accumulate within the flesh of the filter-feeding bivalve at levels which cause disorder in humans after consumption. The toxins can persist within shellfish at dangerous levels for weeks or months after the algae are no longer present in the waters. Seafood containing saxitoxin looks and tastes normal, and cooking or steaming only partially destroys toxins. Therefore one of the most effective methods in preventing outbreaks of PSP is the detection of the toxins before the shellfish are harvested.

Amnesic shellfish poisoning is also algae in the diet of shellfish; domoic acid is the principal toxin and is produced by various species, but the diatom *Pseudo-nitzschia* is the primary source. It can work its way up through the food chain, so illness can result from consumption of other contaminated seafood. As with PSP, decontamination of foodstuffs is not particularly effective and detection of areas where the contamination exists is the best method of preventing problems.

'Environmental' contaminants

Dioxins/Polychlorinated biphenyls (PCBs)

PCBs and dioxins are long-lasting environmental contaminants. They are by-products of fires and some manufacturing processes. The latter are subject to strict environmental controls. Their widespread environmental occurrence means that PCBs and dioxins are present in all foods and food contributes 95% of all human exposure to these chemicals. The highest concentrations are in fatty foods such as oily fish. The main sources of dioxins in the diet are meat and milk.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of compounds comprising two or more fused aromatic rings. Over 100 individual PAHs exist, the most simple of which is naphthalene. A variety of toxic effects have been related to PAH exposure. Varying degrees of carcinogenicity have been reported for many PAHs, of which benzo(a)pyrene is considered to be one of the most potent. Consequently the carcinogenic potency of individual PAHs is frequently expressed relative to that of benzo(a)pyrene.

PAHs are found in petroleum and coal, and can also be formed by the incomplete combustion of these and other organic materials. These compounds have been detected in air, water, soil and foods. Foods may become contaminated through direct environmental exposure, migration from packaging material or during thermal processing of food, e.g., baking, grilling, frying and smoking.

The occurrence of PAHs in fruit, vegetables and cereals is primarily due to soil and air exposure. Although levels detected in foods of animal origin tend to be low, high levels have been recorded in smoked meats and animals farmed on contaminated land. Shellfish can accumulate PAHs from oils spilt by grounded tankers or from waste oils which have been incorrectly disposed of. PAHs can also be formed during the heating and drying processes which allow combustion products to come into contact with the food substance. Direct fire-drying and heating processes used during the production of food oils can result in high levels of PAHs.

Heavy metals

Heavy metals are metals which have a high atomic mass, including, for example, mercury, cadmium, arsenic, lead. Heavy metals are usually toxic in low amounts and are therefore a potential health hazard. Metals can occur in a variety of foodstuffs of plant and animal origin. Mostly, they arise indirectly in foodstuffs from the environment – e.g. they are in soil that the crop is grown in, or on the grass that a cow is eating or in the water in which a fish is living. As such, once they become incorporated into the food they cannot be removed. Control of raw materials is, therefore, the only mechanism for ensuring that levels do not become unsafe.

There is a risk to crops and animals themselves from metals in the environment (e.g. they can kill plants and reduce yields) and to humans from eating crop and livestock products. Metals which can be particularly harmful to animals and man include lead, cadmium, arsenic, mercury, copper, selenium and molybdenum. These elements can accumulate in primary products that are otherwise growing satisfactorily, but still affect animals and man. Although not a metal, fluorine is another element which can accumulate in raw materials and pose a risk to man.

Of particular relevance to crop products as food raw materials are lead and cadmium. Lead is a widespread environmental pollutant, deriving from such human activities as lead mining, smelting and processing, and burning of fossil fuels. The main route of crop contamination is via uptake from the soil. Soil contamination with both lead and cadmium is primarily from aerial deposition.

Nitrates

In general nitrates in agriculture are considered more of a hazard to the environment and water than in foods. However, nitrate intake from water and food has received considerable publicity because of its role in methaemoglobinaemia in infants and its reported implication in various types of cancer. Methaemoglobinaemia is caused by nitrate being reduced, under the conditions found in the infant stomach, to nitrite, which then combines with haemoglobin in the bloodstream. Methaemoglobinaemia, sometimes known as the "blue baby syndrome", can be fatal.

The possible involvement of nitrate in cancer is via its role in the generation of nitrosamines. Nitrosamines are known to be very potent carcinogens and are produced by the reaction of nitrate, when reduced to nitrite, with certain nitrogenous compounds found in proteinaceous substrates. Whilst nitrosamines can be formed in the body, the link between high nitrate exposure and the incidence of cancer is often not clear.

Nitrates in food might, therefore, have some adverse health effect, but the levels in most crops are not generally considered a food safety hazard. However, green leafy vegetables usually contain higher levels of nitrate than most other foods, and maximum levels have been set in the EU and by Codex for nitrates in spinach and fresh lettuce (2000-4500ppm). There are a number of factors which affect the levels of nitrates in these crops, including nitrate availability in the soil, seasonal variations and environmental influences.

iii) Process-derived contaminants

The production of problem chemicals in foodstuffs through processing is relatively unusual. However, the first three examples below serve as good examples of how unexpected contaminants may arise. In addition, the contamination of food with chemicals from packaging or from pesticide applications could loosely be described as process-derived.

Acrylamide

In 2002, Swedish scientists linked acrylamide contamination with food when they were carrying out a study into occupational acrylamide exposure. As part of the study, people who were not believed to have been exposed to acrylamide were included and were found to also have been also exposed to acrylamide; further research determined that this unknown source was food. Although acrylamide is a known carcinogen, it is still unclear whether it has any major effect on health when consumed in food.

Acrylamide is formed in food by traditional cooking methods such as baking, frying and roasting (i.e. high temperatures), but the temperature involved in boiling food does not lead to significant amounts. The level of acrylamide formed varies widely among different products and between production batches of the same foods.

High-carbohydrate foods are principally at risk from acrylamide formation:

- Potato products such as crisps, chips
- Coffee
- Savoury snacks such as crackers
- Toasted cereal products
- Bread and bakery products

A process in excess of 120degC is required, and the chemical precursors of acylamide are asparagine and a reducing sugar (e.g. glucose). Acrylamide levels also increase with the duration of

heating. As a result the main steps being taken by the food industry are to reduce asparagine and glucose levels in food ingredients, and also to reduce cooking time and temperature.

The acrylamide infonet at <http://www.acrylamide-food.org> has further information, as does the Institute of Food Science and Technology website at www.ifst.org/site/cms/contentviewarticle.sap?article=545.

3-MCPD

3-Monochloropropane-1,2-diol (MCPD) can occur in foods and food ingredients at low levels as a result of processing, migration from packaging materials during storage, or domestic cooking. It has been found in a variety of foods, such as cooked/cured meats and fish, cheese, bread and toast, malt extracts and beaked products, as well as in teabag paper, tissue and sausage casings, but the main area of concern is its occurrence following the acid hydrolysis of proteins. Hydrolysed vegetable proteins are widely used ingredients and are a major factor in soy sauce production, itself an ingredient in many products. In laboratory animal studies it has been shown that 3-MCPD is a carcinogen; it was originally classified as a genotoxic carcinogen, but more recent studies suggest that there is a lack of evidence of in vivo genotoxicity. However, the issue with 3-MCPD has meant that industry has looked to use enzymic methods of producing HVP rather than acid hydrolysis.

Furans

Furan is a colorless, volatile liquid used in some chemical manufacturing industries, which was occasionally found in foods. Recently, it has been discovered that furan is formed in some foods more commonly than previously thought. This discovery is probably a result of our ability to detect compounds at exceedingly low levels rather than a change in the presence of furan. It is believed that furan forms in food during traditional heat treatment techniques, such as cooking, bottling, and canning. Furan has been found in such canned or bottled foods as soups, sauces, beans, pasta meals, and baby foods.

Packaging migrants

There is a risk with any packaging material that its components may be transferred in some way to the food that it is surrounding. In most cases, the level of transfer is extremely slight and the components transferred are innocuous. However, there are instances where a realistic hazard exists and must be controlled. There are no official internationally agreed guidelines, but in the EU there is a general requirement that food packaging components must not be transferred into food during its normal shelf-life to the detriment of the food (i.e. to pose a health risk, or to adversely affect the quality of the food - its flavour, texture or appearance).

Transfer of monomers and additives such as plasticizers in plastic packaging materials are the major area of concern. In the EU, there is a list of approved monomers and of additives that can be used in food contact plastic materials (this covers all contact with food, not just packaging materials) and also limits for the migration of these constituents into food. The general limit for containers and sealing devices is 60mg per kg of food. For other contact materials it is 10mg/dm². To determine whether a particular plastic formulation meets these criteria, there are four model simulants that are used in laboratory trials to assess the plastic's properties. These are: distilled water; a 3% aqueous solution of acetic acid; 10% ethanol in water solution (or greater, if the alcoholic beverage in question has a higher alcohol content); and rectified olive oil. The regulations specify which simulants should be used for each category of food. In general, there are no simulants listed for dried foods, which can be considered to not take up plastics constituents from contact materials.

Tin

Tin can be considered to be a specific type of packaging-derived contaminant. Although there is no evidence that excess tin intake has any long-term health effects, some studies have shown that intake of high concentrations (above about 250ppm) may cause short-term gastrointestinal problems. For

most foods, this is of no significance, but for foods packed in cans with some unlacquered tinplate, high levels can sometimes occur. Tin dissolution in unlacquered tinplate cans is essential in that it confers electrochemical protection to the iron, which makes up the structural component of the can and so maintains the can's integrity. Without it, the can would quickly become corroded by the contents of the can; this could cause serious discoloration and off-flavours in the product and swelling of the can. Tin is also involved in maintaining product quality (it helps prevent undesirable colour changes amongst other things, by mopping up any residual oxygen left in the headspace), so there is an advantage in some products of having some exposed (i.e. unlacquered) tinplate. As tin dissolution tends to be accelerated by oxygen, for products where exposed tin is considered to be beneficial, the base, lid and ends of the can may be lacquered, with the rest being unlacquered.

Tin pick-up is normally relatively slow and does not give rise to excessive levels in the product within its shelf-life. However, certain natural variations within the product can cause problems.

iv) Deliberately added contaminants

There is no limit to what chemical contaminants might be deliberately added to foods during manufacture in order to cause harm to the consumer. In most cases, however, the aim is not to cause harm, but to defraud for financial gain. However, potential harm can still result, as evidenced from two of the examples given below.

Sudan dyes

The Sudan I-IV group of chemicals are synthetic azo dyes which have been historically used in industry to colour products such as shoe polish, automotive paints and petroleum derivatives. They are not permitted food colours.

During the summer of 2003 it became apparent that chilli powder and related products in the European market, and originating from India, were contaminated with Sudan I-IV at levels between 2.8 and 3500mg/kg.

Although the Sudan dyes were deemed to be toxic, the levels at which they were found were probably not a major health concern. However, the dyes are not permitted for use and they were being incorporated into the chilli powder in order to make it appear to be of better quality than it actually was. The chilli powder was incorporated into various sauces, which were themselves then used as ingredients in a range of ready meals. With the significant dilution effect of this, analysing the final food for Sudan dyes became a problem, as the levels involved were now very small. Instead a major traceability program had to be launched in order to identify and remove all affected products. This involved the withdrawal of over 1000 products, at a significant cost to the food industry.

Melamine

Melamine has no nutritional value but because it is high in nitrogen, it makes food that uses it as an ingredient appear to have more protein than it actually does and so meet required contractual obligations.

Melamine is an industrial chemical found in plastics and was found to have been fraudulently added to wheat gluten and rice protein from China, which was subsequently used in pet foods. This was a particular problem in the USA in 2007, when a pet food recall was initiated by manufacturers who had found their products had been contaminated. Further vegetable protein imported from China was later implicated. It was claimed that some of the animals that had eaten the contaminated food had become ill, although melamine was not previously believed to have been significantly toxic at low doses.

In September 2008, it was discovered that melamine was present in infant milk powder produced in China. At least four infants are believed to have died as a result, and over 54,000 were receiving

medical treatment at the time of writing. Traces of melamine were subsequently found in other dairy-based products in the region.

Spanish Toxic Oil Syndrome

There are occasions, thankfully rare, when an act of adulteration or substitution is not just fraudulent but jeopardises food safety, sometimes with extremely serious consequences. Perhaps the most serious such incident is that which resulted in Spanish Toxic Oil Syndrome. The incident started as a deliberate act of fraudulent adulteration. A large volume of rapeseed oil had been treated with aniline to downgrade it for industrial use. Some unscrupulous traders decided to refine, decolourise and deodorise this oil, mix it with other oils, package and label it as olive oil, and then illegally introduced it on to the Spanish market. Unfortunately, the oil contained a highly toxic substance formed in a reaction between the aniline and fatty acids in the oil.

Over 20,000 people suffered health problems – many with symptoms as severe as respiratory failure and muscle wasting – and as many as 600 people are believed to have died as a result of consuming the oil. The evidence linking the outbreak to the oil was initially epidemiological, and it was only after several years of extensive investigation, involving sophisticated chemical analysis (including GC-MS) that the causative agent was reliably confirmed. A full account of the incident can be found in Wood et al. (1994).

How are maximum limits set?

As can be seen from the above examples, there is a variety of chemical hazards that could enter food. Some of these are unpredictable (e.g. those that are deliberately added), but most can be and are controlled. The main route for this is good manufacturing practice and monitoring of environmental conditions and the quality of incoming ingredients and raw materials. However, part of the control at a national or international level may be in the form of the setting of maximum legal limits. What these limits are and how they are determined may vary from one part of the world to another, depending on specific circumstances, but in general three main areas are taken into consideration.

- toxicity evidence - how toxic is the contaminant believed to be and how sound is the evidence for this belief
- good manufacturing practice - what is technologically achievable and how costly is it?
- analytical capability - what are the limits of detection or quantification

In all instances, safety is the primary concern, and maximum limits are usually set at about 100 times below the level at which a toxic effect is noted. However, maximum limits to control contaminant levels are only meaningful if they can be monitored by analysis (see below). In addition, even if a contaminant is only mildly toxic, it may be possible to reduce levels to well below the toxicity/100 threshold by good manufacturing practice. This approach is taken with many pesticides, where good agricultural practice (including correct application regimes and suitable intervals between application and harvesting) will result in no remaining residues. Maximum levels are therefore set at the 'limit of detection' or 'limit of quantification'.

The maximum limit for a chemical will often be different for different food types - and there may well be a limited number of foods for which a maximum limit is set. It may be unnecessary to specify a maximum limit in cases where the chemical would not be expected to be found in the food. In contrast, it may be very difficult to limit a chemical in some food types, and so higher limits are set, based on what is realistically achievable (bearing in mind that safety is still the over-riding factor). Nitrates provide a good example of this. In Europe, high nitrate levels are only a significant issue in leafy vegetables (spinach and lettuce), and it is these products for which limits have been set. However, levels will vary depending on growing conditions and season, and so different maxima have been set for different situations. These are typically in the range 2000-3000ppm.

The Codex Alimentarius Commission (Codex, 2007)

(www.codexalimentarius.net/download/standards/17/CXS_193e.pdf.) has set maximum and guideline levels for the following chemical hazards that are an inherent risk in certain foods. The figures given are typical but may vary in some cases depending on product type and whether consumed raw or further processed. In particular the levels set for foods for infants and young children are often much lower than those for the general population. The figures given are merely for illustration; for any individual contaminant in a particular foodstuff, the original text should be consulted.

Mycotoxins

Aflatoxins (15µg/kg in peanuts; 0.5µg/kg Aflatoxin M1 in milk)

Patulin (50µg/kg in apple juice)

Heavy metals

Arsenic (typically 0.1mg/kg)

Cadmium (typically 0.05-0.2mg/kg)

Lead (typically 0.1-1mg/kg)

Mercury (0.001mg/kg in natural mineral water; 0.1mg/kg in food grade salt)

Methylmercury (0.5mg/kg in fish - 1mg/kg in predatory fish)

Tin (150mg/kg in canned beverages; 250mg/kg in canned fruit and vegetables)

Radionuclides (1-10,000Bq/kg, depending on individual radionuclide - generally 10-fold lower in infant foods)

Others

Plastic monomers (typically 60mg/kg of food or 10mg/dm² of package surface)

Acrylonitrile (0.02mg/kg)

Vinylchloride monomer (0.01mg/kg)

As a comparison, in the EU, the following have been set (see <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:364:0005:0024:EN:PDF>):

Nitrates (typically 2000-4500mg/kg)

Mycotoxins

Aflatoxins (typically 4-15µg/kg in total; 0.05µg/kg M1 in milk)

Ochratoxin A (typically 2-10 µg/kg)

Patulin (50 µg/kg in apple juice; 25 µg/kg in solid apple products)

Deoxynivalenol (typically 500-1750µg/kg)

Zearalenone (typically 50-200 µg/kg)

Fumonisin (200-2000 µg/kg)

Metals

<i>Lead</i>	<i>(0.02-1.5mg/kg)</i>
<i>Cadmium</i>	<i>(0.05-1mg/kg)</i>
<i>Mercury</i>	<i>(0.5-1mg/kg)</i>
<i>Tin</i>	<i>(100mg/kg in canned beverages; 200mg/kg in other canned foods)</i>
3-MCPD	<i>(20 µg/kg in HVP and soy sauce)</i>
Dioxins and PCBs	(usually picogram levels per gram of fat)
Polycyclic aromatic hydrocarbons	
	<i>Benzo[a]pyrene (1-10 µg/kg)</i>

In addition, there are limits for many components of plastic packaging materials.

Analytical approaches

As mentioned above, robust analytical methods are essential if the occurrence of chemical hazards in food is to be monitored and controlled. The type of method used will depend primarily on the chemical concerned, as well as the levels likely to be present and the food matrix.

Analysts have at their disposal a wider range of analytical techniques than ever before, and the sophistication of many of these would have been almost unimaginable just a few decades ago. This means that the analyst can now measure lower levels of a wide range of compounds in many different sample types. But it also means that the analyst has to be careful about the approach taken. Getting the right result requires the correct approach – and this includes using the right method of analysis.

A method of analysis typically involves several stages, and can involve a combination of techniques. Following sample receipt and the associated administrative requirements, the sample may need to be pretreated (e.g. ground or blended), before the analyte is extracted (e.g. by solvent extraction). This latter stage may involve an initial crude extraction, followed by a purification stage (e.g. on an affinity chromatography column). Only then can the analyte be measured. Following analysis, the results have to be correctly interpreted and reported. In many cases, the extraction and/or purification stages are combined with the actual analytical stages, as happens with liquid or gas chromatography techniques linked with mass spectrometry.

Given the breadth of chemical hazards that might be present in food, the variability in their nature, and the many different types of food matrices, it is impossible to describe in any detail the types of analytical techniques that could be used. Some of the many generic techniques available are described in Jones (2005).

In some cases it is possible to analyse many related chemicals in one sweep - screening. This is possible for a wide range of pesticides, for example, and for some of the Sudan dyes. In many other cases targeted analysis is required, i.e. a specific procedure for an individual chemical.

When looking to analyse any chemical hazard in food (or indeed any chemical), there are a few basic points to note:

- Purpose of the analysis - it is important for those commissioning the analysis to be clear about the reasons for the analysis and how the result is to be used
- Sampling - samples should be representative of the product being analysed. Once taken, the samples should be handled, stored and prepared properly, so that they are not altered in any way that would affect the analysis
- Method suitability - the analytical method has to be fit for purpose - even if a method has been devised for the specific hazard in question, it may have to be adapted or modified for a

particular foodstuff or to take into account other chemicals present that may interfere with the analysis

- Validation - following on from the above, the method, if it is new or modified, will have to be validated - i.e. tested to show that it works
- Quality control and standardisation - although the method itself has been shown to be fit for purpose, there needs to be evidence that it can produce consistent results over a period of time and in the hands of different analysts.
- Measurement uncertainty - no method will ever give exactly the right result all the time - in fact, in any analysis the result obtained will only ever be an approximation (adequately close, if the method is suitable) to the 'true' answer. It is important to understand where the potential sources of error might arise, and which are the most significant, when interpreting the results.

Preventing chemical safety breakdowns in the food chain

HACCP

The most effective and efficient way of minimising the chances of chemical (and any other) safety issues arising in the food chain is through the use of HACCP (Hazard Analysis and Critical Control Points) systems. In the EU, it is a requirement throughout the industry to use HACCP-based systems to ensure food safety. In essence this means identifying what chemicals may be a problem in a particular food, and the measures to limit (or eliminate) their occurrence or remove them. It is then a case of monitoring and documenting what is being done and sampling the final product from time to time to ensure that the protocol is working.

The HACCP approach is based on seven internationally recognized simple principles:

Conduct a hazard analysis: prepare a flow diagram of the steps in the process; identify and list the hazards associated with the process and specify how they are going to be controlled.

Determine the critical control points (CCPs), i.e. those stages at which hazard control is essential for the production of a safe end-product.

Establish critical limits for each hazard at each CCP, i.e. the levels for each individual hazard that must not be exceeded if a safe product is going to be achieved. This may, for example, be a requirement to boil red kidney beans vigorously for 10 minutes in order to eliminate haemagglutinin (lectin) activity.

Set up a system to monitor control of each CCP by scheduled testing and observations, to ensure that the hazard remains within critical limits.

Establish what corrective action needs to be taken if monitoring indicates that a particular CCP is not under control *or is moving out of control*, i.e. is going beyond critical limits – this means stopping something going wrong before it happens, if at all possible.

Set up procedures to make sure that the overall HACCP plan is working as desired; this may include some end-product testing and a regular review of the system.

Establish thorough documentation of the system, process and procedures, and of all measurements taken relating to the monitoring of the process.

Surveillance

General monitoring of levels of specific chemicals in foods is part of the HACCP process, but in addition to this there are general government-initiated surveillance programmes for specific chemicals. These may be long-term studies to determine trends in levels of well-known hazards in the environment, such as dioxins or nitrates, or may be as a result of a specific problems that arise.

As an example, both the UK's Food Standards Agency (FSA) and the EU's European Food Safety Authority (EFSA) publish reports of surveillance exercises. In addition, there are also systems in place to inform the industry of specific incidents as they arise. The latest EFSA Annual Report on the Rapid Alert system is available at http://ec.europa.eu/food/food/rapidalert/report2007_en.pdf. The FSA's Annual Report of Incidents for 2007 is available at <http://www.food.gov.uk/multimedia/pdfs/incidents07.pdf>.

Further reading

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The International Union of Food Science and Technology (IUFoST) is the global scientific organisation representing over 200,000 food scientists and technologists from more than 60 countries. It is a voluntary, non-profit association of national food science organisations linking the world's food scientists and technologists.

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