Chapter 2
Foodborne hazards

Biological hazards

The overriding importance of microorganisms in foodborne illness has already been mentioned. Details of individual organisms are presented in Appendix 1. Here we briefly introduce the different types of organism responsible and then consider some general features associated with the transmission of microbial foodborne illnesses, particularly those caused by bacteria.

Parasites

These include protozoa and helminths (worms). Though considerably larger and more complex than other organisms conventionally classified as microorganisms, such as bacteria and viruses, it is often convenient to consider parasites under the same heading. Parasites can cause a variety of illnesses ranging from diarrhoea to liver cancer.

Infection with diarrhoeagenic protozoa such as *Giardia lamblia* and *Entamoeba histolytica* is normally the result of faecal contamination of a food or water source and direct person-to-person spread can occur. These protozoa can be killed by thorough cooking. Other protozoa such as *Toxoplasma gondii* and *Sarcocystis hominis* can infect the tissues of meat animals and be transmitted by undercooked meat.

Parasitic worms have complex life cycles where some time is spent in the tissues of an animal host (Figure 2.1). They do

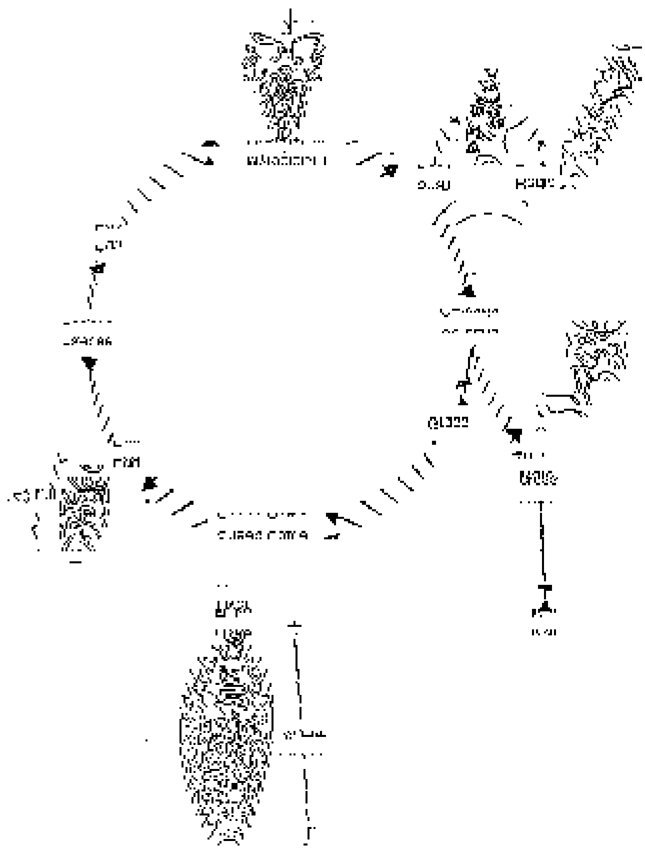


Figure 2.1 ***Life cycle of the liver fluke, Fasciola hepatica***

not show any marked heat resistance and transmission to humans is usually the result of consumption of undercooked fish or meat. Some like the liver fluke *Fasciola hepatica,* however, spend part of their life cycle in a water snail from which it is released to contaminate aquatic plants which may then be eaten by humans. The pork and beef tapeworms *Taenia solium* and *T. saginata* respectively are widely distributed; in the Democratic Republic of Congo, Ethiopia and Kenya, more than 10% of the population are infected with *T. saginata*. In the former Yugoslavia up to 65% of children were found to harbour the organism (5). Foodborne trematode infections are a severe problem the extent of which is only just emerging (Figure 2.2).

Viruses

Viruses are very simple organisms that cannot replicate outside a susceptible host cell and do not therefore multiply in foods. Food and water can, however, be the vehicle for transmission of a number of different viruses that infect humans via the gastrointestinal tract. This is invariably the result of contamination of food by faeces or vomitus from an infected individual, possibly via some intermediary vehicle such as water or equipment.

Poliomyelitis and hepatitis A are the most serious viral diseases that are known to be transmitted by this route; Hepatitis E, which can be waterborne, is a significant cause of infectious hepatitis in Asia and Africa. There are also a number of food and waterborne viruses that cause diarrhoea, most notably the small round-structured viruses or Norwalk-like agents and Rotavirus.

Bacteria

Bacteria are generally considered to be the most important agents of foodborne illness. The individual organisms and the illnesses they cause are described in Appendix 1. Specific aspects of bacterial behaviour and foodborne illness feature prominently in Chapter 3.

Chemical hazards

For many chemical contaminants, a low level of consumption is both unavoidable and harmless. Various national regulatory authorities and international bodies, such as the Joint FAO/WHO Expert Committe on Food Additives (JECFA), have established threshold values for individual additives and contaminants below which there is no appreciable risk. These levels of acceptable daily intake (ADI) or provisional tolerable daily (or weekly) intake are expressed as the number of milligrammes of the chemical which may be safely consumed by a human for each kilogramme of the consumer's body weight. They are usually derived from experiments in animals which determine the level at which the chemical has no adverse effect on the animal. This is known as the no-observed-adverse-effect level (NOAEL). The NOAEL for the most sensitive animal species is then divided by a safety factor, usually 100, to arrive at the ADI. Bodies such as the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) evaluate pesticide residues and recommend ADIs and maximum residue levels. Since its inception in 1962 the Joint FAO/WHO Codex Alimentarius Commission has adopted more than 3200 maximum residue levels for various pesticide/commodity combinations. Maximum residue levels are also prescribed for a number of veterinary drugs.

Chemical hazards in foods can arise from a number of different sources.

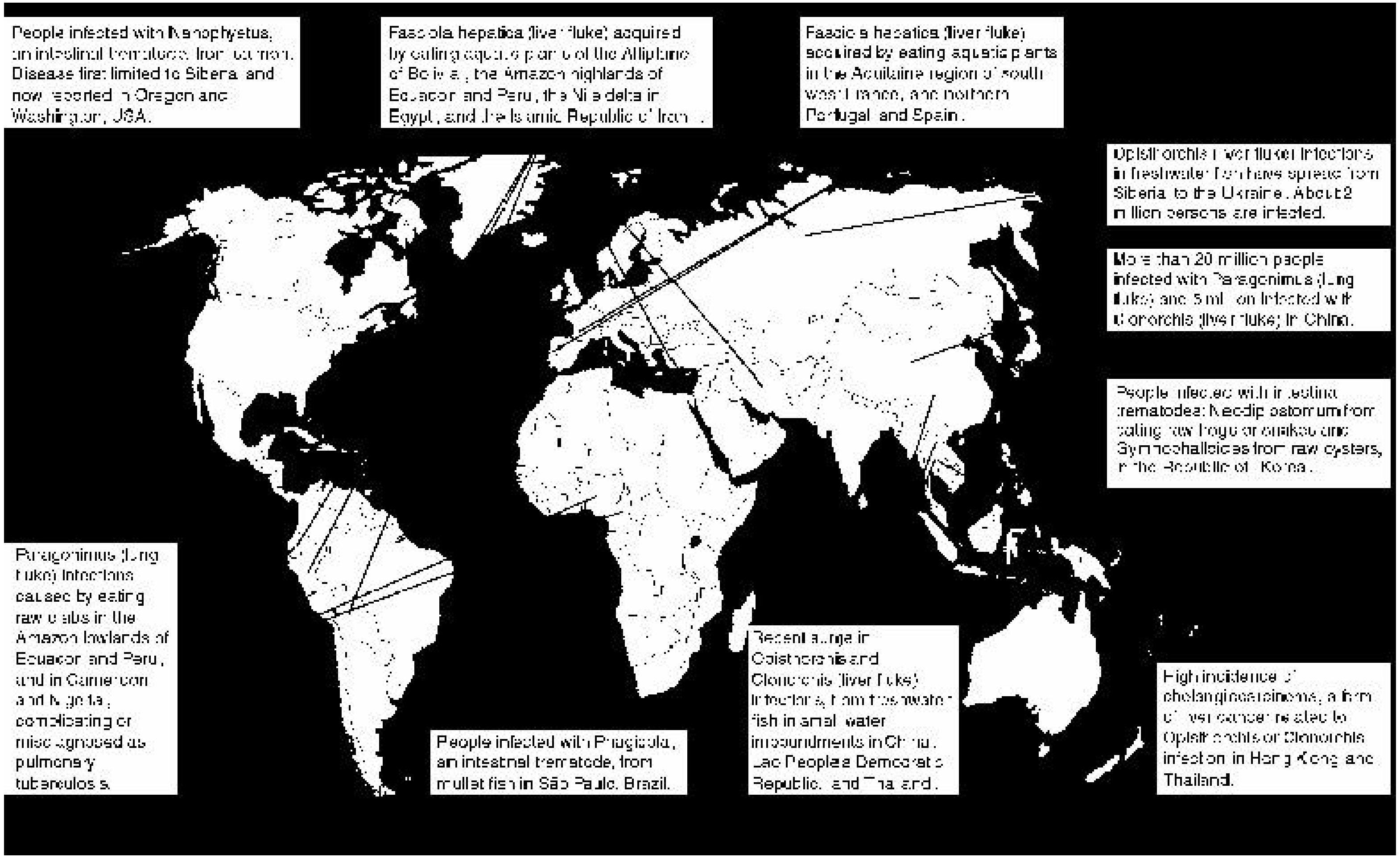


Figure 2.2 ***Foodborne trematode infections: the global distribution is changing with the environment and human behaviour***

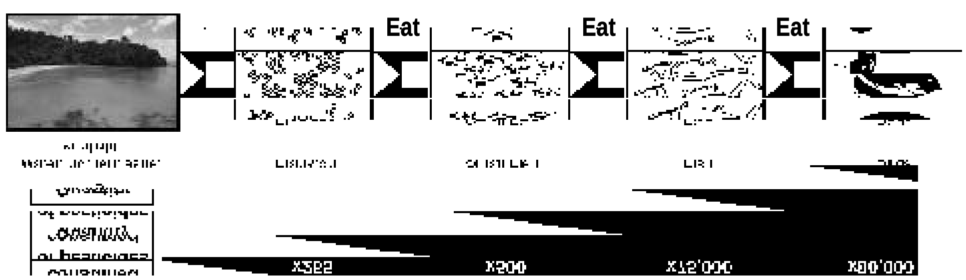
Industrial pollution of the environment

Modern industry produces huge numbers of chemical products and by-products. These can contaminate the environment and food chains, ultimately contaminating the human food supply itself. Most attention in this area has focused on heavy metals such as mercury, cadmium and lead, and organics such as polychlorinated biphenyls (PCBs). All are now widespread in the environment though their concentrations are usually low, except in cases of industrial accidents and environmental disasters.

Mercury, for example, has numerous industrial applications but also has toxic effects on animals and human beings, particularly pregnant women, nursing mothers and children. The most toxic form of mercury is methylmercury which damages the central nervous system. It is often found in fish since industrial effluents containing mercury are discharged into rivers or seas where the mercury is converted into methylmercury by bacteria. It then moves up the food chain and concentrates in the bodies of fish. The ability of contaminants or toxins to concentrate as they pass up the food chain is seen in numerous other instances. Pesticide accumulation is illustrated in Figure 2.3.

The most serious outbreak of mercury intoxication where industrial wastes contaminated fish occurred at Minimata Bay in Japan some years ago. Over 20,000 people are thought to have been poisoned since the outbreak was first recognized in 1956. Thirteen years later, fish in the bay still contained 50mg Hg/kg body weight compared with the Codex recommended limit of 0.5mg Hg/kg. In the Minimata case, contamination came from a single source but large quantities of mercury are also released from fossil fuel combustion, smelters and incinerators that can contaminate aquatic systems via the air. One example of this was when fish in lakes in northern Wisconsin in the USA were found to contain levels higher than 0.5mg/kg though they were remote from obvious sources of contamination.

Lead is a cumulative poison that affects the blood-forming tissues and the nervous and renal systems. Children are most susceptible and adverse effects on intelligence and behaviour have been seen with only very low levels of lead in the blood. Lead can be introduced into the environment by industry or in exhaust fumes from vehicles using leaded fuel. Sometimes the chemistry of the soil itself can give rise to contamination problems. A local cooking salt used by some villagers in Nigeria was found to contain very high levels of lead



Source: Hegarty, V Nutrition, Food and the Environment
St Paul Minnesota USA, Eagan Press, 1992: p. 33

Figure 2.3 ***Bioconcentration of environmental chemicals in the food chain***

(437 μg/kg) and manganese (2340 μg/kg) compared to common salt (1 μg lead/kg and 8.7 μg manganese/kg). Lead, silver and iron had been mined in the region and it was thought that the local geology led to high levels of these elements in the natural spring from which the salt was recovered (*6*).

PCBs were manufactured for industrial applications such as use in hydraulic systems, transformers and heat exchangers though their production has been drastically reduced in many countries since the 1970s. Contamination of edible oil with PCB has caused large-scale poisonings in Japan and Taiwan and exposure to PCB in the workplace has been associated with an increased risk of cancer. Exposure of women to PCBs during pregnancy appears to have a long-term impact on the intellectual function of their children (*7*). Fish generally contain higher levels of PCBs than other types of food. Information on dietary exposure to PCBs is almost exclusively from industrialized countries but the basic trend has been downwards since the 1970s.

Agricultural practices

Foods can also carry residues of pesticides and veterinary drugs. Organochlorine pesticides such as DDT, aldrin and dieldrin were identified in the early 1970s as a particular problem since they persist in the environment, accumulate in the fatty tissues and increase in concentration as they pass up the food chain (Figure 2.3). Contamination is particularly associated with foods such as milk, animal fats, fish and eggs. As a result of concerns over their potential carcinogenicity and harm to the environment, the use of organochlorine pesticides has been restricted in many countries and residue levels in foods have shown a decline over recent years. They do however remain important in many developing countries, where DDT for instance is still widely used in the fight against malaria. Residue levels in foods from developing countries are generally higher, but data are not available from many countries.

Organochlorine pesticides have increasingly been replaced by organophosphorus compounds. These do not persist in the environment or animal tissues for long periods and survey data have shown that they are seldom present in foods. However, they pose a serious health risk when ingested at high concentrations.

In a study of 63 outbreaks of intoxication due to pesticides (*8*) four causes of food contamination were identified:

- *Contamination during transport or storage*

  Typical cases involved powders such as sugar or flour which were transported or stored with a pesticide or in a place previously contaminated with pesticide.

- *Ingestion of seed dressed for sowing*

  Mainly associated with organic mercury fungicides, such outbreaks occurred particularly during times of food shortage when treated seeds were distributed after farmers had already sown their own grain. Local people were unable to read the warning label on the bags or mistakenly believed that washing off the dye also removed the pesticide.

- *Mistaken use in food preparation*

  This occurs when pesticides are mistaken for food materials such as sugar, salt and flour.

- *Misuse in agriculture*

  Pesticides have been found in food or water due to misuse near harvesting time, misuse of containers, contamination of ground water and use of excessively high doses in agriculture.

Residues of veterinary drugs such as antibiotics can also find their way into milk or meat. In many cases the long-term effects of these on human health are not known but they can, for example, provoke strong allergic reactions in sensitive people. They can also encourage the spread of antibiotic resistance in bacteria, making treatment of human infection more difficult, and for this reason it has been recommended that antibiotics used in human medicine should not be used in animals. Antibiotic residues in milk that is used to produce fermented products can interfere with the fermentation process by inhibiting the desirable lactic acid bacteria. Normally this is just a technical problem resulting in economic loss but, when it occurs, pathogens present in the milk may grow and pose a health hazard later. For these reasons many countries have regulations prohibiting the sale of milk from cows being treated for mastitis and milk is routinely tested for the presence of antibiotic residues.

A few hormonal agents are used for growth promotion in farm animals (e.g. bovine somatotropin hormone, or BST). Minute residues of these drugs do not pose a risk for consumers, although there are different opinions on the acceptability of these drugs and monitoring is necessary to ensure that permitted limits are not exceeded.

Food processing

Chemical contaminants can sometimes be introduced as a result of food processing and storage. Drinking water can be contaminated from lead used in water storage tanks and piping and this has on occasion caused cases of lead poisoning in children (*9*). Lead-based solder used in certain types of can is the major source of lead in canned foods, and processors in many countries have now adopted non-soldered cans as a simple remedy for this problem. Lead can also leach into foods stored in inadequately glazed earthenware pots. When pots are glazed at temperatures below 1200°C, much of the lead in the glaze will remain soluble and if the pots are used to store acidic foods such as pickles or fruit juices then the product can become contaminated. Apple juice that caused a fatal case of lead poisoning contained 1300 mg/l lead after three days storage in such a jar (*10*).

Chemicals have been deliberately added to foods since the earliest times. Before the advent of accurate analytical methods this was largely uncontrolled and open to abuse, but nowadays their use is subject to much closer regulation. Food additives can serve a number of purposes, such as preservative, antioxidant, acidity regulator, emulsifier, colour, flavour or processing aid. The health implications of additives is constantly under review by national regulators and international bodies such as JECFA who recommend ADI levels on the basis of data from toxicological studies. Additives such as some food colourings have occasionally been banned as a result of such studies. Where additives are allowed, permitted levels of use are prescribed for specified foods. Occasional problems may arise, however, with unscrupulous or ill-informed food processors who use non-permitted additives such as boric acid or excessive levels of permitted ones.

Nitrates and nitrites occur naturally in the environment and are also deliberately added to some processed foods as a preservative and colour fixative. They are, for example, particularly important for controlling the growth of *Clostridium botulinum* in cured meats. Under suitable conditions, the presence of nitrate/nitrite can lead to the formation of nitrosamines which are known to cause cancer in mammals. Studies have shown that food preparation techniques such as malting grain, smoking, drying and broiling of meat and fish and the frying of cured meats can, under certain conditions, promote the formation of nitrosamines.

To reduce exposure to these compounds, good manufacturing practices are recommended which include addition to foods of the minimum amounts of nitrates/nitrites necessary to achieve their functional purpose and the use of nitrosation inhibitors such as ascorbate.

Natural toxicants in foods

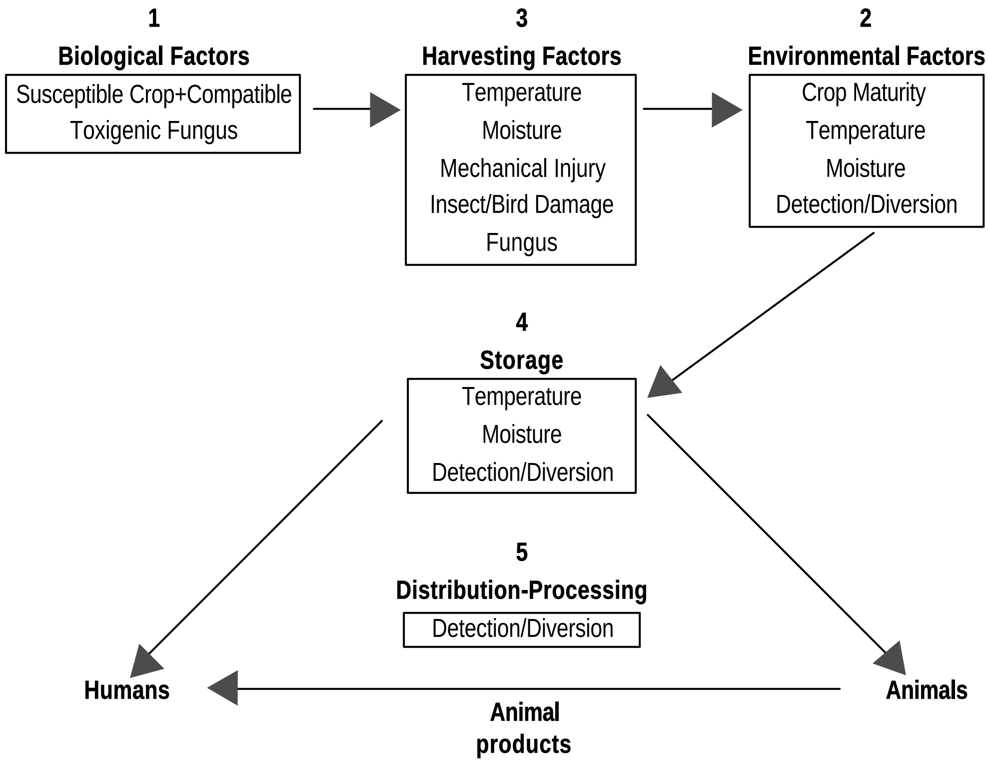
Many plants that serve as staple human foods often contain a range of secondary compounds that are produced to deter predators (Table 1.3). Over the years, selective plant breeding has to some extent reduced the level of these protective factors, though this of course increases the plant's vulnerability to pests and disease. Human ingenuity has also developed processing procedures that eliminate or at least reduce the hazard. Cooking of legumes, for example, can be important in destroying protease inhibitors and haemagglutinins (lectins) which, if ingested, can inhibit growth and sometimes cause illness.

Failure to recognize the significance of certain traditional food processing procedures can also lead to food safety problems. One good example of this is cassava which serves as the major source of dietary energy for about 500 million people worldwide. All cassava cultivars contain the cyanogenic glucosides, linamarin and lotaustralin. When the plant tissues are damaged, these compounds are attacked by the enzyme linamarase which degrades them to cyanohydrins which then decompose to release hydrogen cyanide. Processing of cassava which involves extended crushing and soaking of the roots maximizes conversion of the bound cyanide to its free form which is much easier to remove.

Konzo is a tropical myelopathy, characterized by the onset of spastic paraparesis, which occurs as epidemics in rural areas of Africa as a result of consuming insufficiently processed cassava. It can arise when rapidly growing populations experience declining agricultural yields and resort to cultivating high-yielding bitter cassava with high cyanogen levels, though other factors have also been shown to contribute. For example, in the Bandundu region of the Democratic Republic of Congo, construction of a new road improved transport to the capital and made cassava an important cash crop. To meet the higher demand, the women who were processing cassava reduced the soaking time from three days to one, resulting in higher cyanogen levels in the product. This led to outbreaks of konzo in the dry season when the diet tends to lack supplementary foods containing sulfur-amino acids which are essential for cyanide detoxification. Villages where the traditional three days soaking was retained did not report any konzo cases (*11*).

Glucosinolates are sulfur-containing compounds produced from amino acids. They occur particularly in cruciferous plants such as mustard, cabbage, broccoli, turnip and water cress where they contribute a pungency to the product's flavour. Cooking can reduce levels by up to 60%. In some cases, glucosinolates have been associated with hypothyroidism, endemic goitre, but problems with their toxicity appear to have been mostly associated with the growth impairment of farm animals. In contrast, a number of epidemiological studies have indicated that consumption of cruciferous vegetables is associated with a lower risk of tumour formation in the human digestive tract, suggesting that they exert a protective effect against carcinogenesis (*12*).

Favism is an acute haemolytic reaction found primarily around the Mediterranean



Mycotoxins in human nutrition and health 1994,
adapted from J.E.Smith, G.L.Solomons, C.W.Lewis & J.G. Anderson, European Commission DGXII

Figure 2.4 ***Factors influencing the production of mycotoxins in foods***

and in the Middle East in people with an inherited deficiency of the enzyme glucose-6-phosphate dehydrogenase. It is triggered by exposure to fava beans (*Vicia fava*) and is thought to be caused by alkaloids such as vicine which occur in the skin of the bean.

Lathyrism, a condition characterized by a spastic paralysis of the legs, is associated with consumption of the pulse *Lathyrus sativus* in North Africa and Asia. It is caused by a neurotoxin which can be removed from the pulse by prolonged boiling in water. Its toxicity is well known but the plant is hardy and survives adverse conditions well. Outbreaks of illness are particularly associated with times of severe food scarcity when it can form a major part of the diet.

Solanine is a glycoalkaloid found in potatoes. Concentrations are highest in the sprouts and skin (especially when green) and it is not destroyed by cooking. It is an inhibitor of the enzyme cholinesterase and has been implicated in cases of human illness where the symptoms involve gastrointestinal upset and neurological disorders.

Biological sources

Mycotoxins

Some moulds have the ability to produce toxic metabolites, known as mycotoxins, which can produce a range of disorders from gastroenteritis to cancer. More than 300 mycotoxins have been identified but only a relatively small number have been shown to occur in foods and feeds at levels sufficient to cause concern. A list of these and some of their characteristics is presented as Table 2.1.

The aflatoxins are probably the most extensively studied mycotoxins. They were discovered in the United Kingdom in the early 1960s following the death of thousands of turkey poults which had con-

Table 2.1 ***Toxicity and biological effects of some major mycotoxins found in foods***

Mycotoxin	Major Foods	Common producing spp.	Biological activity	LD_{50}(mg kg^{-1})
Aflatoxins	Maize, groundnuts, figs, tree nuts (Aflatoxin M_1 (secreted by cow after metabolism of Afl B_1) Milk, milk products)	*Aspergillus flavus* *Aspergillus parasiticus*	Hepatotoxic,carcinogenic	0.5 (dog), 9.0 (mouse)
Cyclopiazonic acid	Cheese, maize, groundnuts, Rodo millet	*Aspergillus flavus* *Penicillium aurantiogriseum*	Convulsions	36 (rat)
Deoxynivalenol	Cereals	*Fusarium graminearum* *Fusarium culmorum*	Vomiting, feed refusal	70 (mouse)
T-2 toxin	Cereals	*Fusarium sporotrichioides*	Alimentary toxic aleukia	4 (rat)
Ergotamine	Rye	*Claviceps purpurea*	Neurotoxin	-
Fumonisin	Maize	*Fusarium moniliforme*	Equine encephalomalacia pulmonary oedema in pigs oesophageal carcinoma	?
Ochratoxin	Maize, cereals, coffee beans	*Penicillium verrucosum* *Aspergillus ochraceus*	Nephrotoxic	20–30 (rat)
Patulin	Apple juice, damaged pomme fruits	*Penicillium expansum*	Oedema, haemorrhage possibly carcinogenic	35 (mouse)
Penitrem A	Walnuts	*Penicillium aurantiogriseum*	Tremorgen	1.05 (mouse)
Sterigmatocystin	Cereals, coffee beans, cheese	*Aspergillus versicolor*	Hepatotoxic, carcinogenic	166 (rat)
Tenuazonic acid	Tomato paste	*Alternaria tenuis*	Convulsions, haemorrhage	81 (female mouse) 186 (male mouse)
Zearalenone	Maize, barley, wheat	*Fusarium graminearum*	Oestrogenic	not acutely toxic

sumed feed containing groundnut meal contaminated by the mould *Aspergillus flavus*. Since the fungi producing aflatoxins are prevalent in areas of high humidity and temperature, crops in tropical and subtropical regions are more subject to contamination.

Aflatoxins are acutely toxic and have been shown to be carcinogenic for some animals. Their toxicity varies between different species but data from a large outbreak of poisoning in India in 1974, which involved mouldy maize and in which nearly 100 people died, suggests that the toxicity of aflatoxin B_1 for humans lies somewhere between that for the dog and that for the rat. The involvement of aflatoxins with human cancer is more complex and remains to be defined. For example, the risk of liver cancer is believed to increase with the prevalence of hepatitis B in the population (*13*).

The FAO has estimated that up to 25% of the world's foods are significantly contaminated with mycotoxins (*14*). They are produced by moulds infecting agricultural crops, particularly cereals and oilseeds, during both growth and post-harvest storage and their occurrence is the result of complex interactions between the toxinogenic organism, the host plant and a range of environmental factors (Figure 2.4). Mycotoxins can also occur in milk, meat and their products as a result of animals consuming mycotoxin-contaminated feed. Aflatoxin M_1 is a metabolite of aflatoxin B_1 which is itself thought to be carcinogenic and can be isolated from a cow's milk 12 hours after consumption of the aflatoxin B_1. It is unaffected by pasteurization treatments and will persist into products such as yoghurt, cheese and cream. It can also be isolated from human breast milk. However, it is thought to be considerably less potent than aflatoxin B_1.

Mycotoxins differ in their chemical and physical properties but most can be considered relatively stable to heat and other processes normally applied in the production and preparation of food. A number of countries have established limits for mycotoxins in particularly susceptible foods (Table 2.2).

Algal toxins

A number of algae can produce heat-resistant toxins which are not destroyed when the alga is eaten by a predator. The toxin can then be passed up the food chain and accumulated by other organisms which are eaten by people. Ciguatera poisoning, a sometimes fatal condition characterized by nausea, vomiting, diarrhoea and sometimes neurosensory disturbances, convulsions and paralysis, is the most common example with thousands of cases occurring each year in tropical and subtropical regions. Details of the etiology of ciguetera poisoning are described in Chapter 3.

Transmission of algal toxins to humans is often associated with the consumption

Table 2.2a ***The range of regulatory limits for mycotoxins***

Mycotoxin	Reg. Limit (µg kg^{-1})	Number of Countries
Aflatoxins in foods	0*	48
Aflatoxin M_1 in milk	0*–1	17
Deoxynivalenol in wheat	1000–4000	5
Ochratoxin A in foods	1–300	6
Patulin in apple juice	20–50	10
T-2 Toxin	100	2
Zearalenone	30–1000	4

* Limit of determination

Table 2.2b ***Maximum acceptable levels for aflatoxin for a selection of countries (Aflatoxin B, unless otherwise stated)***

Country	Limit (µg kg^{-1})	Foods
United Kingdom	2	Nuts, dried figs and their products
	5	As above but intended for further processing
United States	20	Total aflatoxins in all foods
	0.5	Aflatoxins M_1 in whole milk, low fat milk and skim milk
Australia	5	All foods except peanut products
	15	Peanut products
India	30	All foods
Japan	10	All foods
China	50	Rice, peanuts, maize, sorghum, beans, wheat, barley, oats

Table 2.3 ***Principal algal intoxications associated with shellfish***

Syndrome	Symptoms	Toxin	Algal species
Amnesic shellfish poisoning	choking, vomiting, diarrhoea, incapacitating headaches, seizure and short-term memory loss	domoic acid	*Pseudonitzschia pungens*
Diarrhetic shellfish poisoning	diarrhoea, vomiting, abdominal pain, nausea (may persist for several days)	okadaic acid dinophysistoxin	*Dynophysis acuta* *Dynophysis acuminata* *Dynophysis fortii*
Neurotoxic shellfish poisoning	paresthesia, reversal of hot and cold temperature sensitivity myalgia and vertigo (generally mild)	brevetoxins	*Ptychodiscus brevis (Gymnodium breve)*
Paralytic shellfish poisoning	tingling, numbness in fingertips and lips, giddiness, staggering, incoherent speech, respiratory paralysis (high mortality rate)	saxitoxin gonyautoxin	*Alexandrium (Gonyaulax) catenella* *Alexandrium tamarensis*

of shellfish. More widespread than ciguatera intoxication, cases have been reported from locations all over the world. Four distinct syndromes are recognized and some of their features are described in Table 2.3.

For sufficient toxin to accumulate it is usually necessary for there to be a sudden increase or bloom of toxigenic algal species in a locality. This is usually a result of a combination of climatic conditions, light, salinity and nutrient supply and when it occurs the only preventive measure is to ban the harvesting and consumption of shellfish from these areas.

Physical hazards

At almost any stage in its production, food can be contaminated with foreign material that could be a physical hazard to the consumer. Physical hazards are very diverse and difficult to categorize since it is possible to conceive circumstances in which almost any foreign object could cause harm. Some, such as pieces of glass, pose an obvious risk of cutting the consumer's mouth or doing even greater damage if swallowed. For this reason, food manufacturers take great care to reduce the risk of this happening by restricting the use of glass in equipment and sheathing light fittings to prevent glass dropping into food in the event of a bulb or tube breaking. Often, of course, glass is the packing material of choice for foods and great care must be taken to avoid breakage or damage to containers that could result in slivers of glass being packed with the food. Sharp stones, pieces of metal, bone or wood can cause similar problems.

Any hard object can damage teeth and an even wider range of other, often apparently innocuous, objects can cause choking when swallowed. These often pose a particular risk for young children. To minimize such risks, commercial food manufacturers go to great lengths, installing devices such as metal detectors and X-ray machines to detect foreign objects in food, and controlling the quality of their raw materials and the production environment. Such measures are inappropriate to domestic food preparation where care and vigilance are the best ways to avoid physical hazards.

KEY POINTS

- Foodborne hazards can be classified as biological, chemical or physical.
- Biological hazards can be posed by parasites, viruses or bacteria.
- Chemical contaminants in foods can come from industrial and agricultural sources, from food processing or from the food itself.
- Toxic chemicals also come from biological sources such as moulds and algae.
- Foreign objects present in food could constitute a physical hazard to the consumer.