PART I

SPECIFIC TOXICANTS RELATED TO PROCESSING TECHNOLOGY
1

INTRODUCTION TO FOOD PROCESS TOXICANTS

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1.1 HISTORY AND ROLE OF FOOD PROCESSING

Food processing and preservation, the traditional focus of food science and technology, have played, and continue to play, important roles in achieving food sufficiency (availability, quality, and preservation) for the human race. These practices originated in recognition of a need to improve the edibility of many food sources and to maintain food supplies for longer periods of time than their seasonal availability. With the transition from a hunter–gatherer society to life in villages and early agriculture, this need became even greater and emphasis on food preservation became increasingly important. This, of course, was paralleled by the development of processes/processing of animal, vegetable, and marine raw materials into usually more palatable, portable, and nutritionally dense foods. In many cases, if not most, this occurred in a fortuitous, rather than planned, manner as natural causes of food processing and preservation were observed and adapted to human use.

Food processing involves the actions taken from the time a raw product (crop, animal, fish) is harvested, slaughtered, or caught until it is sold to the consumer. By this process, the parts regarded as most valued are separated from by-products or waste. Equally enhanced is the palatability/digestibility
of foods, illustrated in the transformation of baking flour into bread, to maintain or increase quality attributes and to ensure safety. Increasing understanding of the science involved in food loss, deterioration of quality, and means of improving the palatability of foods has resulted in development of the sophisticated methods of food processing and preservation now in use. The work of Pasteur, resulting in identification of the role of microorganisms in food spoilage and development of technology leading to canning by Nicolas Appert in 1809, can be considered initial steps in the development of modern food processing and preservation (1). As the world population continues to grow, resulting in increasing requirements and demands for food availability and safety, new and improved methods of food processing and preservation are needed and in development.

The term “minimal processing” is frequently used to describe foods, such as vegetables, that are harvested, sorted, and washed (or similar minimal invasive procedures) before distribution and sale. This is done to distinguish these more “natural” products from those that undergo more extensive processing procedures. Over the last years the development and distribution of minimally processed foods has been increasing steadily. This trend has been triggered by the demand for fresh and convenient products as well as for more natural products, i.e., less processed or containing less salt, sugar, or preservatives.

Such foods range from fruits and vegetables, which are usually only submitted to washing (with or without biocides), trimming, slicing, or shredding, to prepared foods processed by applying minimal bactericidal treatments in combination with different physicochemical hurdles to ensure their stability and safety. These foods represent certainly a challenge to manufacturers since no or only minimal killing steps are applied, and, at the same time, requirements for more global availability and longer shelf life are increasing. The fact that these challenges are frequently underestimated or not mastered sufficiently is illustrated by the occurrence of numerous incidents linked to a variety of products involving different pathogens. Outbreaks related to minimally processed foods often encompass chilled foods such as sous-vide products, pasteurized vegetables, and baked potatoes, which have frequently been linked to Clostridium botulinum intoxication (2–4).

Early types of processing/preservation evolved from observations of natural processes, e.g., drying, curing (such as salting), smoking, fermentation, and reducing storage temperature (refrigeration or freezing). Salting and smoke processing originated at the beginning of human civilization, mainly employed to preserve meat and fish. In fact, salting, pickling, and drying continued as the primary means of preserving foods until the twentieth century and the advent of mechanical refrigeration (5). More modern means of preservation precluded the use of copious amounts of salt, exemplified by the far reduced concentrations of salt in ham today (<2%) versus that in hams produced in the first half of the twentieth century (>6%). Changes to technologies were also introduced a few decades ago with regard to cured meats and residual nitrite content. Nitrite, used to cure meat, acts as a preservative against
Clostridium botulinum and other spoilage bacteria. However, during the 1970s, concern arose due to the role of nitrates in the formation of carcinogenic nitrosamines (Chapter 4.1), as well as its contribution to the body burden. In modern cured meats, the nitrite amounts have decreased and are typically one-fifth of those found some 30 years ago. Moreover, the use of ascorbate—an effective inhibitor of nitrosamine formation—is an additional mitigation measure introduced in the production of most cured meats.

Smoke processing is still used today to preserve meat, especially in tropical countries. Smoke imparts appealing organoleptic properties, with concomitant preservation of nutrients. However, concern has been raised about the presence of both polycyclic aromatic hydrocarbons (PAHs) and nitrosamines in smoked foods. PAHs are covered in Chapter 2.8, with special attention to their formation, mitigation, and toxicology. Although the exposure risks in modern manufacture of meats and fish are considered minimal, alternatives to traditional smoking have been developed. Liquid smoke flavorings have gained popularity as they provide the same traits, i.e., desirable organoleptic properties, and preservation through antioxidation and bacteriostasis. Additional benefits include increased product consistency and absence of detectable animal carcinogens. In fact, approximately 75% of hot dogs produced in the United States contain aqueous liquid smoke flavorings (5).

Food preservation can be considered part of or an extension of food processing, since it involves the use of procedures to prevent or reduce spoilage of foods. Examples include the inactivation of enzymes and microorganisms by heating or reduction of moisture content, use of antimicrobial compounds, pasteurization (heat or irradiation), freezing, modified atmospheric packaging, and fermentation.

Techniques that have been used in food processing and preservation include:

- Drying/dehydration
- Curing
- Smoking
- Fermentation
- Canning
- Pasteurization (heat or irradiation)
- Freezing and refrigeration
- Additives
- Controlled atmosphere storage
- Aseptic packaging

Until the last quarter of the twentieth century, canning was widely used in homes throughout the rural United States. Inadequate heat treatment during the canning process occasionally resulted in severe illness or death caused by Clostridium botulinum that was not inactivated during the heating process and
resulted in subsequent formation of the toxin. Commercial canning, while having some outbreaks of botulinum poisoning, became used much more widely due to improved quality, safety, and increased urban populations.

1.2 GENERAL APPROACHES TO FOOD PROCESSING

The rapid growth and development of commercial food processing in the twentieth century has continued and now dominates food processing, particularly in developed countries. However, food processing in the home, such as canning, decreased with increasing urbanization. Although some aspects of food processing still occur frequently in home situations, particularly in developing nations. Food preparation/processing in the home is primarily related to heat treatment, which plays an important role in the formation of desirable flavors, colors, aromas, and textures. In fact, exposure of food to heat can be considered the most used processing step in modern society, involving frying, baking, grilling, roasting, toasting, microwaving, and broiling, using ovens (convection, microwave), stoves, toasters, grills (gas, wood, and charcoal), and fat-based fryers.

There are, however, considerable differences between practices in the home and in commercial industrial settings. Home appliances tend to have less accurate temperature controls, resulting in actual oven temperatures differing considerably from what is indicated by the oven setting or temperature gauge. In general, there is also less rigid timing due to interruptions and delays in homes as contrasted to an industrial environment. High-quality standards are pivotal for industrialized processes, and food manufacturers have identified early on the need for quality control tools and stringent targets to achieve consumer preference in terms of nutritional quality, shelf life, and organoleptic properties at all times. Ideally, quality is addressed early on in the product and process design phase, identifying those process steps that impact (key) quality parameters. For this purpose, modern industrial lines are equipped with appropriate measuring systems/sensors (temperature profiles, moisture content, texture, color, pH, etc.) to deal with raw material variability and process complexity.

1.3 CONCERNS ABOUT FOOD SAFETY DURING FOOD PROCESSING

1.3.1 Types of Hazards

The major hazards considered in food safety are allergens, and those that are microbiological, physical, and chemical in nature.

Microbiological contamination with pathogens such as enterohemorrhagic \textit{Escherichia coli} strains, \textit{Listeria monocytogenes}, and \textit{Salmonella} spp. represents a major problem in modern food safety (pathogen identification, control,
and prevention). It is considered the most important aspect of improving food safety globally, displacing the emphasis on chemical contaminants of previous decades. For further reading, various books and reviews on this topic can be consulted (see References 6 and 7).

Physical hazards are considered acute hazards if not adequately addressed and controlled and may pose a serious threat to human health (e.g., glass, hard plastic and metal pieces, bones, wood, stones). There are different sources of physical hazards, and the origins of the potential risks must be clearly understood (raw materials/ingredients or the operations in the manufacturing of food per se may be a source of a physical hazard, e.g., potential glass breakage along a glass filling line). Within the frame of Hazard Analysis Critical Control Points (HACCP), measures are identified that remove or reduce such hazards to an acceptable level in the final product (e.g., filtration, sieving, centrifugation). Procedures must be put in place by the manufacturer to verify that the measures to control such hazards are indeed effective (e.g., metal detectors, X-ray machines).

Food allergens are generally recognized as a serious food safety issue and manufacturers are responsible for controlling them and providing concise information to consumers. Through good manufacturing practice (GMP), identifying possible sources of cross contact, integration of allergen hazards into HACCP studies, and appropriate ingredient labeling, the health risks can be minimized.

The chemical hazards in foods can be multiple, and as depicted in Fig. 1.1 may enter the food and feed supply chain at many different points. Traditionally, the environment has been thought to be the origin of many chemical food hazards, such as heavy metals and persistent organic pollutants (POPs). An increased risk of pathogenic microorganisms may also be attributed to the contamination of the agricultural water supply caused by human and animal waste, and use of manure as fertilizer.

Essentially, the potential chemical contaminants in food can be broadly classified into:

1. natural toxins, e.g., mycotoxins, higher plant toxicants, and marine biotoxins;
2. environmental contaminants, e.g., heavy metals, dioxins, and radionuclides;
3. chemicals used as aids in food manufacture and, in the event of a failure, which may contaminate food, e.g., through leakage, spillage, or misuse of lubricants, cleansing agents, or disinfectants;
4. agrochemical residues, e.g., fungicides, pesticides, and veterinary drugs;
5. packaging migrants, e.g., isopropylthioxanthone, semicarbazide, and styrene;
6. processing toxicants, e.g., heterocyclic aromatic amines, acrylamide, and furan.
The latter class of substances is the focus of this book, and the reader is referred to further sources of information on general chemical risks in food (see References 8 and 9).

1.3.2 Definition of a Process Toxicant

Processing toxicants (process-induced toxicants, process-formed toxicants) as used in this book are defined as those substances present in food as a result of food processing/preparation that are considered to exert adverse physiological (toxicological) effects in humans, i.e., substances that create a potential or real risk to human health. Food in this definition also includes beverages and nonalcoholic drinks such as coffee and tea, and thus both parts of the diet are included.

Ingredients commonly occurring in food formulations (recipes) are excellent substrates for chemical reactions occurring under the conditions encountered in food processing. The reaction products formed depend on the processes and conditions used, such as fermentation, irradiation, and heat processing.
Products from such reactions can have beneficial properties and/or adverse physiological effects on consumers. Examples of the former include compounds such as antioxidants, anticarcinogens, and those resulting in or contributing to nutritional properties, desirable flavor, aroma, texture, and color in food products. Examples of the latter include carcinogens, genotoxins, neurotoxins, anti-nutrients, and undesirable flavors or aromas. Many of these coexist as a result of being formed during common food processing technologies, particularly those involving heating, e.g., toasting, roasting, frying, broiling, baking, grilling and microwaving.

1.3.3 Progress in Technological Developments

The development of new food processing technologies continues at a rapid pace, with some of these, such as high-pressure processing (HPP), already in commercial use (see Chapters 5 and 8). In fact, the application of HPP is not a new concept, and was already described in certain foods in the late nineteenth century (10). The use of HPP is not uncommon in foods such as whole shell oysters, salsa, ready-to-eat (RTE) meats, and jams. New technologies are aimed at delivering products with superior organoleptic quality, minimal changes to nutrients, safety, and shelf life (product life, preservation of quality), and ideally the minimal formation of undesirable compounds. Pulsed electric field, ohmic heating, jet impingement, infrared radiation, and new biotechnological applications are just a few that can be considered new processing techniques. Innovative nonthermal processing technologies (photosensitization, pulsed electric field technologies, high-pressure homogenization, and HPP coupled to packaging under inert atmosphere) to improve the quality and safety of RTE meals are being investigated within the European “HighQ RTE” project, with the goal to improve the safety and quality of three representative categories of European RTE foods, i.e., salads, fluid foods, and vegetable-based meals (11).

Only very few studies have been performed on the use of alternative or new processing technologies to mitigate process toxicants. Work has recently been reported on the application of infrared radiation to baking with the goal to reduce the amount of acrylamide (12) while maintaining the sensorial properties of the food. Steam baking and steam roasting have also been assessed to reduce acrylamide, and in the case of coffee beans the steam roast had a major impact on the sensorial properties of the coffee, with only a marginal reduction in acrylamide (13).

1.4 FOOD-BORNE PROCESSING TOXICANTS: SETTING PRIORITIES

The processing of ingredients into food products can lead to the formation of a number of chemical compounds having properties desired in the flavor,
INTRODUCTION TO FOOD PROCESS TOXICANTS

aroma, and color of the food. One of the most important sources of these compounds is the Maillard reaction (14). This complex reaction, involving reducing sugars and amino acids, has been, and continues to be, the subject of intensive research for many years due to its importance in the formation of characteristic flavors, aromas, and colors (browning) in foods prepared by heating. A major emphasis has been on the identification of the compounds involved in these attributes as formed during the Maillard cascade and in understanding the chemical pathways involved. The Maillard reaction is known to produce more than 550 volatile compounds of which more than 330 have been identified in the volatiles of cooked foods (15). Many of these contribute to the flavors and aromas in these foods. Nonvolatile products such as the melanoidins contribute to the browning colors.

However, compounds having adverse physiological effects or potential health risks are often formed also. The number of studies involving detection, identification, and measurement of such compounds continues to increase as more sensitive analytical methodologies become available and are applied to foods. One example is the discovery in early 2002 of acrylamide in foodstuffs (16), present in the μg/kg (part per billion) range in a wide variety of common foods that are heated at temperatures >120°C, such as potato chips, French fries, bread, cereal-based products, and coffee (17). Acrylamide has received unprecedented attention since it was first reported in food, with several books and reviews summarizing the research efforts across the disciplines, and reflected by more than 600 research publications to date (15, 18).

Development of new analytical methods to detect and determine acrylamide was required for the very low concentrations encountered in foods. As analytical methodologies continue to become even more sensitive, more of such compounds undoubtedly will be found in foods. When these compounds are determined or known to have adverse effects or potential health risks, toxicological studies can become difficult since these usually are accomplished in animals at concentrations much higher than may be observed in foods. This has become an issue with acrylamide, since definitive toxicological studies are not yet available (anticipated to be complete and reported beginning 2009).

A key question raised by food safety authorities, by academics in the field, and in particular by food producers, is which toxicants are of greatest concern in foods from a dietary health perspective? Numerous compounds have been identified over the past years in foods that show carcinogenic, mutagenic (genotoxic), or neurotoxic properties at high doses in animal studies. Such toxicants can be classified by chemical (structural) type or by the processing methods in which they occur. There will be some overlap in either case. In this book, the issue is approached from the processing method involved and includes (i) thermal treatments, e.g., frying, baking, grilling, roasting, broiling, toasting, and microwaving (Chapter 2); (ii) fermentation (Chapter 3); (iii) preservation (Chapter 4); (iv) high hydrostatic pressure (Chapter 5); and (v) other selected processes such as acid and base treatment (Chapter 6).

When one begins to seek substances that have the potential to be toxic when present in foods, an entirely different set of issues is raised. The HEATOX
Heat-generated Food Toxicants, Identification, Characterization and Risk Minimization project had as one of its emphases identification of heat-formed toxicants, other than acrylamide, in food. Within the frame of this European project, supported within the European Commission’s 6th Framework Programme on research, nearly 800 volatile compounds have been identified and listed in two databases (19), one of which contains approximately 570 formed through the Maillard reaction and the second which contains about 200 compounds from heated lipid systems. Information on toxicity and carcinogenicity of these compounds is scarce, and therefore computer-assisted toxicity prediction systems, i.e., Topkat and Derek, were employed. These make use of molecular attributes to construct quantitative structure–activity relationship (QSAR) models, which are useful tools for prescreening and setting priorities (20, 21). Of the total list, about 50 of these substances were identified as potential carcinogens and mutagens (19).

The HEATOX inventories for Maillard and heated lipid reaction products are in a spreadsheet format and list compounds that may be formed in model systems and/or are known to occur in food, the latter also featuring the food where the concentration has been reported to be higher than 1 mg/kg (different literature sources).

A key question, however, is the ranking of these compounds in terms of risk level. One approach that is employed to help prioritize risks of food-borne genotoxic carcinogens is the margin of exposure (MoE). The MoE is usually calculated as a range, taking in most cases the BMDL\textsubscript{10} value (the lower confidence limit on the benchmark dose associated with a 10% cancer incidence) and the upper- and lower-bound human exposure estimate. Table 1.1 illustrates the principle, and shows selected food-borne toxicants and an approach to estimate the margin of safety or MoE. A MoE band \( >10,000 \) is interpreted as unlikely to be of concern. Such a procedure would provide a first indication of the degree of risk. However, the interpretation of any MoE is complex and comparisons are not straightforward without knowledge of the methodologies used to analyze the data and data quality (for both the animal carcinogenicity data and dietary exposure estimates).

For a majority of the compounds, however, toxicity data may simply be lacking. In this case, a first screening will be required using existing data (considering also the limitations and uncertainties of the predictive toxicity models), and preferably probabilistic modeling, followed where warranted by in-depth research including method development, analytical measurement, and chronic animal studies. Other databases such as the carcinogenicity potency database (CPDB), which contains information on the toxicity of more than 1400 chemicals, some of which are naturally present in foods such as coffee, may also be a useful source of data (22). This, combined with occurrence databases or other published data on amounts of the selected chemicals in food, may allow a first ranking based on the margin of safety, provided that the compounds are retrievable in the database.

When considering process-induced toxicants and their potential health risks, a number of additional factors come into play in establishing the context.
within which concerns are raised and decisions made, particularly those relating to risk analysis. In this book, these are included in Part II: General Considerations. One of the most commonly used approaches to food safety during food processing is the HACCP concept. Some countries mandate application of this approach, which recognizes that safety should be built into a product during the early development phase, rather than depending on final product testing to detect safety defects. This subject is presented in Chapter 7. A pivotal factor in food processing, including development of new process technologies, is the impact of the processing technology on nutritional aspects (gain/loss during processing, bioavailability, formation of allergens). Chapter 9 deals with this very important area.

In recent years it has become apparent that decisions, particularly those involving regulatory action, need to be risk-based. This is often encompassed in the concept that the amount of regulation should be in direct proportion to the health risk in the food product. As a result, risk analysis (risk assessment, risk communication, risk management) is playing an increasingly important role in this general area. Importance of risk communication is addressed in

### TABLE 1.1 Risk assessment of selected food-borne toxicants.

<table>
<thead>
<tr>
<th>Food-borne toxicant</th>
<th>Estimated dietary uptake, ng/kg bw/d*</th>
<th>Tox. dose: point of departure, ng/kg bw/d</th>
<th>MoE/Safety factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,3-DCP/2,3-DCP (**)</td>
<td>3–200</td>
<td>6,300,000§</td>
<td>2,100,000–32,000</td>
</tr>
<tr>
<td>Heterocyclic aromatic amines (PhIP)</td>
<td>4.8–7.6 (***))</td>
<td>1,250,000¶</td>
<td>260,000–164,000</td>
</tr>
<tr>
<td>Polyaromatic hydrocarbons [Benzo(a)pyrene]</td>
<td>4(a)–10(b)</td>
<td>100,000§</td>
<td>25,000–10,000</td>
</tr>
<tr>
<td>N-nitrosamines (NDMA)</td>
<td>3.3–5.0</td>
<td>60,000§</td>
<td>18,200–12,000</td>
</tr>
<tr>
<td>Ethylcarbamate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furan</td>
<td>33(c)–55(d)</td>
<td>300,000§</td>
<td>9,000–5,460</td>
</tr>
<tr>
<td>3-MCPD(g)</td>
<td>260(e)–610(f)</td>
<td>1,000,000§</td>
<td>3,900–1,600</td>
</tr>
<tr>
<td>Acrylamide</td>
<td>360(b)–1,380(i)</td>
<td>1,100,000§</td>
<td>3,055–800</td>
</tr>
<tr>
<td></td>
<td>1,000(j)–4,000(k)</td>
<td>300,000§</td>
<td>300–75</td>
</tr>
</tbody>
</table>

* Data sources vary and are shown here for illustrative purposes only; a = mean intake; b = high-level intake; c = lower-bound mean; d = upper-bound mean; e = mean for 2+-year-old children; f = 90th percentile for 2+-year-old children; g = non-genotoxic mode of action; h = highest mean of participating country for adult population (23); i = highest 95th percentile of participating country for adult population (23); j = average intake for general population; k = high consumers. ** (24). *** (25). § LOAEL.

DCP = dichloropropanol; NDMA = N-nitrosodimethylamine; PhIP = 2-Amino-1-methyl-6-phenylimidazo-[4,5-b]pyridine.

TABLE 1.1 Risk assessment of selected food-borne toxicants.
Chapter 10 and the concepts of risk–risk and risk–benefit are presented in Chapter 11.

1.5 ISSUES OF PROCESS TOXICANTS PRESENT IN SMALL AMOUNTS IN FOODS

As analytical methodologies increase in sensitivity, allowing detection and determination of process toxicants formed during food processing, an increasing number of significant issues will arise. The analytical instrumentation required for accurate determination of these toxicants will become more costly, prohibitively so in many cases. Already, this has been encountered in the case of acrylamide, for which the preferred analytical procedures for determining the content in foods involve mass spectrometry combined with other techniques, such as liquid chromatography-tandem mass spectrometry (LC-MS/MS). The analytical instrumentation for measurement has been beyond affordability in many institutions, particularly in developing countries.

As a result, this has limited accurate determination of acrylamide in the food supply in many countries, resulting in an inadequacy of data needed for a quantitative risk assessment (26) of potential health implications from its consumption in the diet. Also, this results in an inadequate amount of data to determine exposures to acrylamide in different countries, data also required for risk assessments. Lacking the data needed for quantitative risk assessment, how does one make judgments concerning the reality of a potential public health risk from the chemical involved?

Large amounts of resources have been committed to acrylamide investigations worldwide. The requisite information/data needed to make public health decisions is, however, still not available six years after the announcement of finding it in foods common to diets globally. This raises an important question: Are there criteria that can be established to enable a relatively rapid decision to be made regarding whether a large investment of resources should occur for further investigation of any new toxicant identified at the low concentrations observed for acrylamide, perhaps even when adverse effects have been noted in animal studies?

1.5.1 Risk Assessment Strategies for Food-Borne Toxicants

A risk assessment is a scientific evaluation of a chemical substance and is used to determine whether a particular chemical poses a significant risk to human health and/or the environment. Chemical risk assessments follow a set paradigm comprised of four steps, i.e.:

1. **Hazard identification**: reviews research into any potential problems that the chemical may cause.
(2) *Hazard characterization:* describes and evaluates dose–response and dose–effect, mode of action, extrapolation of animal to man with ideally an acceptable daily intake (ADI) or tolerable daily intake (TDI) established.

(3) *Exposure assessment:* the amount in food, duration, and pattern of exposure are estimated, encompassing average, medium, and maximum figures for intake.

(4) *Risk characterization:* assesses the risk for the substance to cause cancer or other illnesses in a given population as well as the seriousness of any health risk.

As described by Tritscher (27), traditionally for chemicals in food two approaches to risk assessment are discerned depending on the presumed mode of action of the compound. For non-genotoxic substances, a threshold of action is assumed, from which a no-effect level can be extrapolated experimentally (NOEL or NOAEL). From this safe level, a TDI or reference dose (RfD) can be derived for humans by applying safety factors to the equation. For genotoxic carcinogens, the assumption taken is a non-threshold mechanism and hence no safe level of intake can be derived. In the case of food-borne contaminants, it will be difficult or almost impossible to conduct formal risk assessments for each compound, and regulators may apply the ALARA (as low as reasonably achievable) or ALARP (as low as reasonably practicable) principle aimed at reducing exposures as far as possible. This leaves the decision to the risk managers on the extent of reduction that is technologically and financially practicable and justifiable. However, ALARA does not give a quantitative dimension on which to prioritize the risk. Moreover, the number of undesired substances to be assessed in foods is very high and more compounds are continuously added to the list as detection techniques achieve better performance, setting immense constraints on the limited resources at hand.

One pragmatic approach that is being investigated and discussed, particularly in Europe and North America, is the threshold of toxicological concern (TTC). The TTC is a concept that a threshold of human exposure can be established for all chemicals such that there would be no appreciable risk to health below this value (28, 29). This is an interesting concept, with considerable interest and potential, particularly as an initial screening tool. Regulators undoubtedly will find considerable difficulty with the concept that a threshold can be set for all chemicals below which no appreciable health risk will exist. The possibility is much higher that some criteria can be developed to guide the decisions required for different compounds in a timely manner.

The question as to whether criteria can be established to allow rapid initial decision making, particularly commitment of resources, is being actively discussed. A workshop was held (30) in the United States (i) to develop recommendations on approaches or criteria useful for prioritizing potential risks of chemical and microbial contaminants in foods, as potential tools for resource allocation and decision making; and (ii) to develop recommendations on next steps to advance the use of prioritization tools, including identification of criti-
cal knowledge gaps and research needs. Several common themes and conclusions were identified during the workshop with a publication to be prepared on the risk prioritization framework concepts that emerged from the workshop discussions. A second workshop was held (November 2008) to bring together experts who are working on tools for dietary exposure estimates to discuss approaches and develop recommendations for using exposure estimates in a framework for prioritizing risks associated with chemical and microbial contaminants in food.

The outcomes of these efforts and discussions will be of critical importance to how the results of detecting and determining very low concentrations (i.e., ppb and less) of process contaminants in foods will be interpreted in terms of risks to human health and how they are potentially regulated. It must be remembered that just because a toxicant is present in low amounts in foods does not mean that it will not be a significant contributor to exposure in an individual’s diet. As an example, acrylamide is present in low amounts in coffee or bread. However, since both of these are consumed in significant amounts in the daily diet of many individuals in some countries, they end up being in the top five or so foods/drinks in terms of daily sources of exposure to (intake of) acrylamide in those nations.

1.5.2 Risk–Benefit Considerations

A further important aspect to be considered also in the mitigation of process toxicants is risk–benefit. Changes made to the nutritional profile of a product may negatively impact the inherent beneficial properties of the food. For example, the removal of whole grain accepted to deliver a nutritional benefit will result in a product with relatively lower amounts of acrylamide. However, the current assessment of such measures is mainly subjective, and lacking is an appropriate risk–benefit framework that allows legitimate comparisons to be made. As noted by the European Food Safety Authority (EFSA), a risk–benefit analysis should not be performed as a routine procedure but only applied in those cases where an impact on public health outcomes can be expected (31). Such an activity has been started by ILSI Europe and models have already been established, comparing for example, the benefits of eating fish that are rich in omega-3-polyunsaturated fatty acids (associated with a lower risk of coronary heart disease and a beneficial role in inflammatory conditions such as arthritis) versus dioxin and methylmercury that may accumulate in certain fish (associated with risk of cancer development and developmental changes in the fetus) (32). Similarly, a recent project comparing the benefits associated with the heat processing of foods (reduced microbial spoilage, extended product shelf life) versus the risks (formation of acrylamide and other process toxicants) has been initiated within the frame of the BRAFO project (Benefit-Risk Analysis of Foods). The main goal is to develop a framework that quantitatively compares human health risks and benefits of foods and food components, using common scales of measurement such as the indices Disability Adjusted Life Years (DALYs) or Quality Adjusted Life
INTRODUCTION TO FOOD PROCESS TOXICANTS

Years (QUALYs) (see Chapter 11). Recently, a case study on risk–benefit considerations of mitigation measures of acrylamide in potatoes, cereals, and coffee has been completed and published (33). Such studies have the ultimate goal of facilitating the decision-making process in public health nutrition.

1.6 OUTLOOK

1.6.1 Research Needs

Research needs in process toxicants were recently highlighted in several international scientific meetings. Worthwhile mentioning is the symposium organized by the German DFG (Deutsche Forschungsgemeinschaft, German Research Foundation) Senate Commission on Food Safety (SKLM) in September 2005 on the potential health benefits and risks of thermal processing of foods, which summarized the major research needs. The SKLM emphasized the importance of further study of the risk–benefits of foods as well as specific needs related to the substances per se. In this context, four compounds or compound classes were selected, i.e., acrylamide, heterocyclic aromatic amines, furan, and 3-MCPD (34).

Similarly, the UK Food Standards Agency convened a stakeholder meeting to discuss the research commissioned by the Agency on food process contaminants in April 2005 (35) and to share the progress made in the different projects on surveys and minimization of risk. The substances of concern were chloropropanols (including 3-MCPD), ethyl carbamate, and acrylamide. Recently, EC-DG SANCO and the CIAA (European Food and Drink Federation) organized a joint workshop on acrylamide in March 2006, pulling together the latest findings from academic and industry research (36), and integrating this into the CIAA “Acrylamide Toolbox,” which is the reference for the most promising avenues and achievements to reduce acrylamide in the main concerned food categories (37). Soon thereafter, a joint workshop on “furan in food” was hosted by the EC-DG SANCO/EFSA/DG JRC to update the latest knowledge pertaining to analysis and formation/mitigation of furan in food (36). Research in all these areas is progressing at a rapid pace and these selected examples show that process toxicants have in the past few years gained significant attention on a global scale in terms of potential human health risk.

1.6.2 Interdisciplinary Efforts of All Stakeholders

To effectively address food chemical toxicants, the pooling and coordination of knowledge coming from a variety of disciplines and areas of expertise is crucial (agronomy, toxicology, epidemiology, analytical chemistry, food chemistry, food technology, nutrition, consumer research), as well as committed efforts of all stakeholders. Hence, interdisciplinary research projects and partnerships are a more effective means of improving the science–policy inter-
face and ensuring that the work has both scientific and societal relevance. This requires a strategic assessment of research trends in food safety, encompassing the complete chains of food and feed production. Food safety networks have been established at the European level, such as the European Association for Food Safety (SAFE consortium). Its member organizations work together to develop and promote interdisciplinary research projects and partnerships. The output of the consortium as a whole can be consulting activities, larger projects within the Framework Programmes, and participation in the ERA Net Scheme (38) and in Technology Platforms such as the European Technology Platform (ETP) “Food for Life,” which consists of more than 90 projects (ongoing or completed) that are related to food safety (39). Cost Action 927 is a further endeavor to coordinate research and foster exchange of scientists working primarily on the health effects of thermally processed foods. The initiatives of the Action are reported on their website and updated on a regular basis (40).

The occurrence of processing toxicants in low amounts in foods will continue to be of increasing concern in the human diet. Many are not new risks, but the occurrence in the diet has raised concern, e.g., furan in baby foods in jars (Chapter 2.4), acrylamide in food (Chapter 2.1), and 3-MCPD esters in refined oils (Chapter 2.6).

That many of these will have adverse toxicological properties/effects will draw attention from consumers and regulators. The fact that it will not be possible to reduce or remove many of these to a significant extent from certain foods, without changing taste, odor, texture, nutrient profiles, or forming other compounds that may increase safety concerns, will have to be carefully and fully explained to consumers in a manner they can understand and accept. Thus, responsible risk communication and management are highly important factors in these issues. Aspects of food processing and preservation, with the attendant potential relationships to adverse effects on public health, are the subject of this book.

REFERENCES


23. European Commission (2004). Report of experts participating in Task 3.2.9. Collection and collation of data on levels of 3-monochloropropanediol (3-MCPD) and
REFERENCES


