Jinap Selamat · Shahzad Zafar Iqbal
Editors

Food Safety

Basic Concepts, Recent Issues, and Future Challenges

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Preface

We are grateful to edit the first edition of Food Safety: Basic Concepts, Recent Issues, and Future Challenges. With this book on food contaminants, we focus on finding productive, knowledgeable, and well-known authors to help us and provide integrated information on food safety, chemical contaminants in food, and recent challenges together in one text. This striving goal was set for one purpose: to provide readers with the most comprehensive and updated information covering the broad fields within the food contaminants and their toxicity. To create global relevance of food safety, our authors come from a number of countries. We hope that this book captures the current state of this vital and dynamic science from an international perspective. The topics such as basic concepts in food safety, food regulations, and chemical contaminants in food, such as pesticides, mycotoxins, heavy metals, and heterocyclic amines, and future challenges such as food authenticity and climate effect on food toxins will provide detailed and basic information. We hope this book will be a valuable reference for researchers, health professionals, and policy experts in the field of food safety and a useful resource for educators and advanced students of food safety and quality.

Serdang, Selangor, Malaysia

Jinap Selamat
Shahzad Zafar Iqbal

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Part I
Food Safety

Food Safety Systems

Peter Raspor, Mojca Jevšnik, and Mateja Ambrožič

Abstract Throughout the world, major shifts in food consumption at a global and regional level are occurring with considerable health consequences which results in increasing food safety and quality demands and requirements. A food safety management system is a set of interacting elements forming a network to ensure that food presents a minimal risk to consumers and includes good practices, HACCP system, management policies, traceability systems, and standards while considering food safety regulation. The vast numbers of laws, regulations, standards, good practices, and codes make everybody confused, even those who are working in the field on a regular basis and are forced to keep up with the developments. To achieve food-related disease prevention and efficient safe food assurance suitable for working environment from the hygienic-technical point of view, motivated, satisfied, and qualified personnel needs to be assured. Consumers are not connected to food supply chain according to chain principles. However, it has been shown that present maintenance of food safety in food supply chain can be easily broken down, because of different kinds of barriers or simple misunderstanding. Therefore, a new approach called "good nutritional practice" (GNP) was coined to manage food safety. It is important to reconstruct the existent food safety system with GNP which includes consumers and is based on a model that covers subsystems from other good practices through the food supply chain. There is also considerable interest in reducing humankind's impact on the climate and invested effort has focused around the contribution that food makes to global warming such as carbon footprint, wastes, food miles, etc., and promotion of sustainable development. The Consumers Future Food reveals that there is a revolution, which raises ethical concerns all the way from stable to table, from farm to fork, from spring to

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drink. On the dinner tables of tomorrow, consumers may expect a new food icon that is the result of an evolution which is transforming the very nature of the food we eat with a view to create a new breed of future prospects for healthy and safe nutrition.

1 Introduction

Food is the driving force of our lives and eating is our most important daily routine. It is at the same time essential means of providing energy and the basis for social interaction and enjoyment. The production and consumption of food has also a wide range of economic and environmental consequences. The principal daily activity of our forefathers was searching, gathering, hunting, and preparing food. An essential part of all cultures since earliest societies has been gaining knowledge about how to get enough food and how to get it right. Abused or contaminated food can cause illnesses and even death. Food safety has become a major global issue due to recent food scandals, incidents, and scares. Motarjemi et al. (2001) pointed out globalisation aspects which characterised the end of the twentieth century and influences on different levels and aspects of human life including the safety of food supply and consequently human health. Globalisation raises food safety fears and that is why globalisation influences dictate food safety regulation and its harmonisation.

Food safety is the utilisation of resources and strategies to ensure that foods are properly produced, processed, and distributed so they are safe for consumption. Food safety is related to the presence of foodborne hazards like chemical, physical, and biological hazards in food at the point of consumption (Jevšnik et al. 2008a, b). The introduction of food safety hazards can occur at any stage of the food chain and adequate control throughout the food chain is indispensable (Jevšnik et al. 2007, 2008c). Complications in the production of safe food are connected to important changes in food supply and production systems (e.g. globalisation; increased complexity and dynamics of food supply chains and networks; intensification of agriculture on one side and on the other alternative niches like organic production; accelerating technological development and application of mild processing techniques), demographic and social situations, consumption behaviour and lifestyle (e.g. changing food preparation and eating habits like increased consumption of convenience food; changing food ethics) and also environmental conditions (e.g. increased pollution; climate changes) as at the time one of the most important aspects. Despite the fact that food has never been safer, the consumers are more and more uncertain and critical about the safety and quality of food, which resulted in a melting consumer confidence in the safety of food products (Raspor and Jevšnik 2008; Raspor 2008).

Globalisation, food trade, and increased urbanisation especially in developing countries influenced the organisation of food supply chains and networks with increasingly complex and dynamic relationships. Globalisation is an historical process that began as early as the first movement of people out of Africa into other parts of the world. Migrants and merchants, who travelled short and gradually longer distances, have always taken their ideas, customs, and products into new lands. The global food supply system has undergone dramatic changes over the past couple of decades and is linked to trade liberalisation, multinational food corporations, retailing, food marketing, and consumers' attitudes and behaviour. The increasing integration of cross-border movement on one side and local food supply chains on the other can be considered as a threat and as a challenge for the food safety at the same time.

Supply chains are understood as transformation processes from inputs through primary production, processing, and marketing to the final consumption (Porter 1990). Food supply chain distinguishes itself from other supply chains due to its purpose to guarantee the provision of safe and healthy products that are fully traceable from farm to fork (Bourlakis and Weightman 2004). The food industry is nowadays solely consumer oriented and needs quick response times to deal with bad publicity and liability due to food scandals and incidents. A food supply chain is a network of food-related business involved in the creation and consumption of food products, where food products move from farm to table (Selvan 2008). Supply chain management is the integrated planning, coordination, and control of all business and activities in the supply chain to deliver superior consumer value at least cost to the supply chain as a whole while satisfying the variable requirements of other stakeholders in the supply chain like government and non-governmental organisations (van der Vorst 2006). In this definition, a supply chain is a series of physical and decision-making activities connected by material and information flows and associated flows of money and property rights that cross organisational boundaries. The supply chain includes all parties who are involved in any operation within food circle from production to consumption. Only one insufficient or truncated information or just simply miscommunication in supply chain can result in unsafe food that is dangerous to health. That is why transparency and traceability along food supply chain is one of the most important elements in food supply chain in order to guarantee product and process integrity, improve consumer trust, and maintain quality and safety standards (Raspor 2008; Aung and Chang 2014; Chen 2015). Growing interest with consumer demands and requirements on food quality and safety emphasises food traceability and food tracking (Trienekens and Zuurbier 2008; Dabbene et al. 2014). Bosona and Gebresenbet (2013) pointed out the benefits such as increase in customer satisfaction, improvement in food crises management, and improvement in food supply chain competence development (for companies), technological and scientific contribution, and contribution to agricultural sustainability.

2 Food Safety Management Systems

The occurrence of intense globalisation and food trade is having a major impact on food systems worldwide. Food systems are changing and are consequently resulting in consistent quality, enhanced safety, greater availability, and diversity of broad assortments throughout the year. Food quality and food safety have become a hot topic in mass media. Consumers have become increasingly concerned and demanding about the quality and safety of food they are eating. The increased demand for safer food has resulted in the development and introduction of quality management systems, which are used to control the quality and safety of products like standards and good practices (Raspor et al. 2013). Food safety requirements with changes in food supply chains, social, health, and demographic situations, lifestyle, and environmental conditions have led to significant efforts in the development of quality management system (QMS) in agribusiness and food industry worldwide. Because quality systems differ in several aspects, they are combined or integrated to assure more aspects of food quality. Quality is divided into aspects of product safety, product quality, and total quality, which embrace product's safety and quality (Raspor and Jevšnik 2008).

The concept of food safety management system (FSMS) consists of "food safety" and "management system" aspects and is based on prevention. However, we will never be able to completely prevent and measure food safety performance, so there is a need to have effective food safety system, which includes integration of various elements within food supply chain whereas communication within circle is crucial (Scott and Chen 2010; Raspor and Ambrožič 2012). An FSMS involves that part of the QMS especially focused on food safety. "Food safety" is defined according to Codex Alimentarius Commission (CAC 2003) as the assurance that food will not harm the consumer when it is prepared and/or eaten according to its intended use, which in reality is not always the case (Jevšnik et al. 2008c). QMS refers to all activities that organisations use to direct, control, and coordinate quality, including formulating a quality policy, setting quality objectives, quality planning, control, assurance, and improvement (ISO 9000 2005). Both aspects contribute to the overall performance of an FSMS (Raspor 2008). Food safety management can be explained from the perspective of government FSMS (horizontal level from farm to fork) or more narrowly from industry point of view (vertical level). Governmental and industry food safety management responsibilities are interactive and interlinked. According to regulatory demand, every operator in food supply chain has to implement a specific FSMS (Regulation 2002; CAC 2003). Kirezieva et al. (2013) clearly elucidate FSMS which is the result of the implementation of available and relevant quality assurance guidelines and standards (like Codex Alimentarius, hygiene legislation, guidelines on good practices, BRC, IFS, etc.). At primary production, these FSMSs are a result of implementing good agricultural and hygienic practices, while, at processing and trade, the FSMS includes good manufacturing and hygienic practices and HACCP-based principles. FSMS comprises the equipment, procedures, programs, tools, organisational measures, and people necessary to execute the control and assurance activities aimed at ensuring chemical and microbial safety of fresh produce (Kirezieva et al. 2013).

Quality assurance is a modern term for describing the control, evaluation, and audit of a food processing system. It consists of the integration of all functions and processes within an organisation in order to achieve continuous improvement of the quality of goods and services (Vasconcellos 2004). To achieve the required standards, quality management throughout all stages of the agro-food chain is very important. The policy of food companies will increasingly be directed towards food safety, ensured by effective quality management (Barendsz 1998; Raspor 2006; Luning et al. 2015; Chen et al. 2015).

Nowadays quality assurance systems such as GMP, HACCP, ISO, BRC, and IFS standards are applied for assuring food safety (van der Spiegel et al. 2003; Konecka-Matyjek et al. 2005). Each quality assurance system is focused on particular one. For example, GMP and HACCP are especially developed to assure food safety (Hoogland et al. 1998; Raspor 2004). Like HACCP, BRC deals with food safety and product quality but evaluates also on management aspects like ISO and facility condition like GMP. Additionally, ISO and Total quality management (TQM) focus more on management aspects, whereas GMP and HACCP focus on technology aspects (Hoogland et al. 1998). Food manufacturers have to decide which quality assurance is most suitable to their situation and how this system should be implemented. Over the last few years, a large number of companies have implemented quality assurance systems and TQM system in order to introduce effective quality systems and consequently produce and distribute high-quality products (Raspor 2008).

To achieve prevention of food-related diseases and efficient safe food assurance suitable for working environment from the hygienic-technical point of view, motivated, satisfied, and qualified personnel needs to be assured. Food hygiene training is fundamentally important (Jevšnik et al. 2007, 2008c). All personnel involved in the process have to be aware of their role and responsibility in protecting food from contamination. Those engaged in food operation who come directly or indirectly in contact with foods should be trained and/or instructed in the control of microbiological hazards to a level appropriate to the operations they are to perform. An important element in the effectiveness of food hygiene training is the support given by managers, both pre- and post-training, to motivate food handlers to enact the safe food handling practices learnt during training (Seaman and Eves 2010). But Seaman and Eves (2010) in their study suggest that many managers do not have sufficient awareness or the correct attitude towards food hygiene training to facilitate an effective learning environment within the workplace. Periodic assessment of the effectiveness of training and instruction programmes should be made as well as routine supervision and checks to ensure that procedures are being carried out effectively. That is why the managers and supervisors of food processes have to have also the necessary knowledge of food hygiene principles and practices. Training and instructions have to be periodically renewed by all food operators and if weaknesses are observed more emphasis on refreshing trainings should be assigned. For this type of activities, it is reasonable to collaborate with outside experts. Public training courses can be organised for consumers too, because consumers have inadequate knowledge about measures needed to prevent foodborne illness in the home. For this reason, the food safety public health campaign to enhance household food safety awareness would be a suitable solution. With this aim, the European Food Information Council (EUFIC 2015) and the Partnership for food safety education in the USA (FightBAC 2015) whose goal is to promote food safety to consumers and educate them how to handle and prepare food safely were established.

3 Food Safety Legislation and Standards

Humanity's quest for food has helped to shape the development of society since human existence. The history of food safety is probably nearly as old as human history itself and may have started with the recognition and subsequent avoidance of foods that were naturally toxic (Griffith 2006). Early humans, probably by trial and error, also started to develop basic forms of food preservation, which possibly also made food safer, e.g. drying, salting, and fermentation. It has influenced population growth and urban expansions, dictated economic and political philosophy and destiny, expanded the commerce from local to the international dimensions, inspired wars, and promoted the discovery of new worlds.

Experiences, tradition, practice, technical, and scientific knowledge helped shape the principles and techniques to achieve acceptable food safety. Even Old Testament contains several instructions on the manner of handling food. Griffith (2006) pointed out that with several thousand years of experience in food safety combined with over 150 years of food microbiology experience including the latest molecular biology techniques, it might be erroneously assumed that problems of food safety would have been resolved. In fact, the opposite is true with increased reports of foodborne disease. The biggest changes in food production occurred during the nineteenth century (Lasztity et al. 2004). Due to industrialisation and rapid urbanisation connected to poor hygiene, food laws like Act of 1860 for "Preventing the Adulteration of Food and Drink" in England and Codex Alimenarius Austriacus (Randell 1995) were created although at that time the knowledge and understanding of the importance of hygiene and the dangers of adulterations were neglected. These laws were not strictly legally enforceable and consequently did not work. The first major federal consumer protection law with respect to food processing was the Pure Food and Drugs Act in 1906, which was also proven to have loopholes. In 1938, the Food, Drug and Cosmetic Act was enforced (FDA 2014).

EU food safety regulation history started after the 1960s. The first EU food hygiene rules which were adopted in 1964 were limited to requirements for fresh meat. Over the decades, further hygiene legislation was developed and implemented for other food groups. The introduction of hygiene rules undoubtedly had an impact on helping to boost the level of food safety in the EU by preventing, eliminating, or reducing contamination of food. Motarjemi et al. (2001) indicate continuous evolution of food safety and its management including the principles for establishing food safety regulation, during the last two decades. Authors determined that key point in this evolution occurred 1991 when was FAO/WHO Conference on Food Standards, Chemicals in Food and Feed Trade, which recommended that the CAC should place greater emphasis on science in its norm-setting work. After that, FAO and WHO organised three conferences where the concept of risk analysis was introduced at the international level.

Food affairs have globally resulted in increased government regulatory activities. Federal and international agencies are acting to encourage better public health protection. One of the principal actions has been the development of HACCP (Hazard Analysis and Critical Control Point)-based regulations or recommendations by federal agencies and the United Nations CAC (Sperber 1998). To control and comprehend safety in the European Union (EU), “White Paper on Food Safety” is an important document that was published in January 2000 (EC 2000). After that, regulation (EC) 178/2002 and decision 97/579/EC were published, which exactly define “European Food Safety Authority”. General Food Law Regulation (EC) No 178/2002 lays down the general principles and requirements of food law and ensures a high level of protection of human life and consumers’ interests in relation to food, while ensuring the effective functioning of the internal market (EC 2015d). It sets outs an overarching and coherent framework for the development of food and feed legislation at both Union and national levels. To this end, it lays down general principles, requirements, and procedures that underpin decision-making in matters of food and feed safety, covering all stages of food and feed production and distribution. It also sets up an independent agency responsible for scientific advice and support, the European Food Safety Authority (EFSA). Moreover, it creates the main procedures and tools for the management of emergencies and crises as well as the Rapid Alert System for Food and Feed (RASFF) (EC 2015a).

The use of HACCP principles at all levels of the food chain is, however, compulsory under EU Directive 93/43/EEC and Regulation 852/2004/EC (EU 1993; EC 2004). The new hygiene rules were adopted in April 2004 by the European Parliament and the Council. They became applicable on 1 January 2006. They are provided for the following key acts:

- Regulation (EC) 852/2004 on the hygiene of foodstuffs, 29 April 2004
- Regulation (EC) 853/2004 laying down specific hygiene rules for food of animal origin, 29 April 2004
- Regulation (EC) 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption, 29 April 2004
- Directive 2004/41/EC repealing certain Directives concerning food hygiene and health conditions for the production and placing on the market of certain products of animal origin intended for human consumption and amending Council Directives 89/662/EEC and 92/118/EEC and Council Decision 95/408/EC, 21 April 2004 (EC 2015a).

It is a responsibility of all included parties in the food chain to ensure food traceability and food safety by internal control in all production phases (Raspor and Jevšnik 2008). Food safety regulations are evolving to performance-based regimes in which firms have greater flexibility and responsibility in adopting effective controls (Cho and Hooker 2009).

The new hygiene rules take particular account of the following principles (EC 2015a):

- Primary responsibility for food safety borne by the food business operator
- Food safety ensured throughout the food chain, starting with primary production
- General implementation of procedures based on the HACCP principles
- Application of basic common hygiene requirements, possibly further specified for certain categories of food
- Registration or approval for certain food establishments
- Development of guides to good practice for hygiene or for the application of HACCP principles as a valuable instrument to aid food business operators at all levels of the food chain to comply with the new rules
- Flexibility provided for food produced in remote areas (high mountains, remote island) and for traditional production and methods

After World War II, activity in international standardisation started to grow intensively. In 1946, a new international organisation named International Organization for Standardization (ISO) with the objective to facilitate the international coordination and unification of industrial standards was founded. Its progression till existing dimension was accelerated during the 1990s when geopolitical changes brought new members from freshly independent states and from developing countries (ISO 2015). ISO is an independent, non-governmental membership organisation made up of 163 member countries. It forms a bridge between the public and private sectors, because many of its member institutes are part of the governmental structure of their countries and others have their roots in the private sector. ISO is the world's largest voluntary standards development organisation and has published more than 19500 International Standards covering almost every industry from technology and food safety to agriculture and health care (ISO 2015). The ISO 22000 family of International Standards contains a number of standards each focusing on different aspects of food safety management (ISO 2015). The Foundation for Food Safety Certification developed Food Safety System Certification 22000 (FSSC 22000 2015), which is a robust, ISO-based, internationally accepted certification scheme for auditing and certification of food safety management in the whole supply chain (FSSC 2200 2015).

As a result of globalisation, many different drivers contribute to food safety like trade of raw materials and end products, exposure to (un)familiar hazards through international trade, introduction of pathogens into new geographical areas, increasing emphasis upon health and well-being, and consumer demands for convenience, freshness, and increased shelf life (Lineback et al. 2009). Growing international competition and increasing food safety incidents led to an ever expanding and confusing system of public and private standards at international as well as at national level. Increased trade between countries with diverging implicit norms on food quality and safety and consequently issues raised by the lengthening of the food supply chains has increased the need to regulate this trade through product standards and regulations. In the past two decades, food standards have sharply increased and now play a central role in global food supply chains (Traill and

Koenig 2010). Food standards first emerged and proliferated in rich countries but are spreading rapidly in developing countries (Swinnen 2005). Standards make things work, because besides ensuring quality, safety, and efficiency they give global specifications for products, services, and systems with the aim of facilitating international trade. Standards take the form of technical specifications, terms and definitions, and principles through which goods are categorised or included in products' grouping (Jones and Hill 1994).

Standards can be divided regarding:

- Purpose (objective, aim) (i.e. private and public)
- Level of application (i.e. national, regional, international)
- Product and process characterisation (e.g. quality standards, sanitary measures, traceability regulations)

Many public and private standards (Henson 2006) on food safety and quality have been established since the 1990s as a result of market internationalism. Public standards have the ultimate role of protecting consumers, while private standards are designed to protect their own business (Trienekens and Zuurbier 2008).

Private standards (Henson and Reardon 2005; Henson and Humphrey 2009), also called private voluntary or just voluntary standards, have emerged as an important mode of market governance in many developed countries as well as developing countries. Private standards have become the basis for product differentiation in markets and are increasingly driven by quality-based competition. Private standards often consider food hazards as well as environmental, ethical, occupational health issues and other social responsibility issues. The key factors driving private standards are brand protection, the promotion of business improvement and efficiency, and assistance in response to consumer concerns. Private standards are driven by the food industry, retail buyers, buyers' organisation, commodity groups, non-governmental organisation, and others. Although private standards are not legally binding, they become an obligation for suppliers. Private standards also function as instruments for the coordination of supply chains by standardising product requirements over suppliers, which may cover wide geographical regions that cut across national boundaries.

In the last two decades, substantial growth in voluntary and national certification schemes for agricultural products and foodstuffs was observed. In 2010, more than 440 different schemes for agricultural products and foodstuffs marketed in the EU were observed (EC 2015b). Certification schemes in the EU for agricultural products and foodstuffs provide assurance through a certification mechanism. They cover a wide range of different public and private initiatives that function at different stages of the food supply chain. They can operate at the business-to-business level or at the business-to-consumer level. EU schemes operate in the market alongside an increasing number of voluntary certification schemes. While certification schemes by definition employ third-party audit, there are also other schemes in the market which operate on the basis of a label or logo without involving any certification mechanism. Adherence to these schemes is done by self-declaration or through selection by the scheme owner (EC 2015b).

Certification schemes can bring benefits to (EC 2015b):

- Intermediate actors in the food supply chain, by assuring standards for protecting liability and reputation for product and label claims
- Producers, by increasing market access, market share, and product margins for certified products and also, potentially, by increasing efficiency and reducing transaction costs
- Consumers, by providing reliable and trustworthy information on product and process attributes

Some stakeholders have argued that certification schemes can also have drawbacks (EC 2015b):

- Threats to the market
- Questions relating to the transparency of scheme requirements and the credibility of claims particularly for schemes that certify compliance with baseline requirements
- Potential for misleading consumers
- Costs and burdens on farmers, particularly where they have to join several schemes to meet demands from their buyers
- Risk of rejection from the market of producers not participating in key certification schemes
- Impacts on international trade, especially with developing countries

Demands regarding private standards are best presented by global forum The Global Food Safety Initiative (GFSI 2015), which is facilitated by The Consumer Goods Forum, which is the only independent global network for consumer goods retailers and manufacturers worldwide. This forum (GFSI 2015) is an industry-driven initiative providing thought leadership and guidance on food safety management systems necessary for safety along the supply chain with motto “once certified, accepted everywhere”. This work is accomplished through collaboration between the world’s leading food safety experts from retail, manufacturing, and food service companies, as well as international organisations, governments, academia, and service providers to the global food industry. The GFSI was launched in the year 2000 to harmonise international food safety standards and to reduce the need for multiple supplier audits. The food safety schemes currently benchmarked by GFSI (GFSI 2015) are Food Safety System Certification (FSSC) 22000; the British Retail Consortium and the Institute of Packaging (BRC/IoP) Global Standard for Food Safety; BRC/IoP Global Standard for Packaging and Packaging Materials; International Featured Standard (IFS) Food Standard; IFS Logistics; IFS PACsecure; Global Good Agricultural Practice (GLOBALG.A.P.); Integrated Farm Assurance Scheme; GLOBALG.A.P. Produce Safety Standard; Canada Good Agricultural Practice (CanadaGAP) Scheme; CanadaGAP Program Management; the Global Aquaculture Alliance (GAA)Best Aquaculture Practices (BAP) Seafod Processing Standard; Global Red Meat Standard (GRMS); Primus Global Food Safety Initiative Scheme (primusGFS); Standard and Safe Quality Food Institute (SQF) Code.

Concerns about the impact of the food that people consume on their own health, as well as the social and environmental consequences that it entails, have led to major changes in food consumption patterns and consumer behaviour and consequently on food supply chains. Green market trends are on the rise and are based on third-party certification and private eco-branding (Chkanikova and Lehner 2015). Eco-branding aims to capture higher market shares through means of product differentiation based on sustainability attributes (Orsato 2009) and certification provides a guarantee of product and process adherence to certain environmental, social, and ethical standards at different stages in the value chain (Vorley et al. 2010). Making agriculture greener, more efficient, and fairer are the goals also of the European Common Agricultural Policy. Wherever today's consumers choose to buy or eat organic products, they should be able to have confidence that these comply with strict EU rules. Products that do not meet these standards may not be referred to as organic or bear the EU's organic logo or a national equivalent (EC 2015b).

Ecocert (2015) is an inspection and certification body established in France in 1991 by agronomists aware of the need to develop environmentally friendly agriculture and of the importance of offering some form of recognition to those committed to this method of production. From its creation, Ecocert is specialised in the certification of organic agricultural products. Ecocert contributed to the expansion of organic farming in the 1990s by helping to draw up French and European regulations. Still very involved in promoting organic farming, Ecocert today works with French and international institutions in supporting project development. By winning the confidence of professionals and consumers, Ecocert has become a benchmark in organic certification worldwide.

The vast numbers of laws, regulations, standards, good practices, and codes make everybody confused, even those who are working in the field on a regular basis and are forced to keep up with the developments (Ambrožič et al. 2010). The challenge for the food supply chain is to satisfy and meet consumer needs, wants, and even their desires. The food supply chain embraces a wide range of disciplines. The creation, operation, and evaluation of food supply chains are key dimensions in food safety management.

4 Good Practices in Food Supply Chain

Today we manage food safety through good practices at different levels of production, processing, and consumption within food supply chain. Good practices are described in several different Codes of Practice designed by producers' organisations, importers and retailer's consortia, and government bodies representing consumers. In general, good practice presents activity of the quality assurance which ensures that food products and food-related processes are consistent and controlled to assure quality procedures in food systems (Raspor 2008). They define the production, processing, manufacturing, transport, and storage practices for individual foods or groups of foods that are considered essential to ensure the safety and suitability of food for consumption. Codex Alimentarius codes of practice are a collection of internationally adopted food standards presented in a uniform manner. Raspor (2008) pointed out that today we master food safety with different good practices which are the consequence of human culture, history, and lifestyle. If we analyse good practices in the broad spectre of food area we could arrange them into three categories. First category of good practices is directly connected with food technology (i.e. good manufacturing practice—GMP). Second category is indirectly connected with food issues (i.e. good research practice—GRP, good educational practice—GEP, good training practice—GTrP). Third category deals with all the activities regarding consumers' food handling (good housekeeping practice—GHKP). Consumers are not connected to food supply chain according to chain principles. Consumer behaviour and attitudes towards food safety have shown that the levels of understanding, motivation, and trust need to be further cultivated. It has been shown that present maintenance of food safety in food supply chain can be easily broken down, because of different kind of barriers or simple misunderstanding. Therefore, a new approach called "good nutritional practice" (GNP) was coined to manage food safety. It is important to reconstruct the existent food safety system with GNP which includes consumers and is based on a model that covers subsystems from other good practices. Food safety point of view should be focused on knowledge, constant education, and exchange of information. "From farm to table" approach is a philosophy with an important goal: safe and healthy food for all consumers. With this aspect in mind, we are building the foundation for Good Life Practice (Raspor and Jevšnik 2008; Raspor 2008; Raspor et al. 2013).

The first published good practice was good housekeeping practice in 1885, which is nowadays frequently disregarded and even ignored. In 1885, Clark W. Bryan published the first edition of Magazine Good Housekeeping with a mission to produce and ensure perfection as may be obtained in the household (Good Housekeeping Magazine 2011).

The first good practice for industry was GMP in manufacture, processing, packaging, and holding of drugs in the year 1963 (U.S. Federal Register 1963), which was in the next few years translated in GMP for processing facilities and proposed in the year 1968 (FDA 2014). The first Codex code of practice General Principles of Food Hygiene was adopted in 1969 and was representing a firm foundation for ensuring food hygiene. GLP was published in 1976 for assuring study's validity (Baldeshwiler 2003). GAP was first presented to the FAO Committee on Agriculture in 2003 (FAO 2008).

Good practices are described in several different Codes of Practice designed by producers' organisations (e.g. Europe/AfricaeCaribbeanePacific Liaison Committee—COLEACP), importers and retailers' consortia (e.g. British Retail Consortium—BRC, Food Policy Council—FPC, Commission for Instruments and Methods of Observation—CIMO, Euro-Retailer Produce Working Group—EUREP), and Government bodies representing consumers (e.g. UK Food Standards Agency). In general, good practice means activity of the quality assurance which ensures that food products and food-related processes are consistent and controlled to assure quality procedures in food systems (Raspor 2008).

With development of public and private standards, good practices started to grow intensively and also consequently intensively proliferated. The proliferation of existing best practice and technology at all stages of the food chain is a result of a complexity within food supply chain and integration of various stakeholders into different consortia, organisations, and associations. Each guild has own rules of engagement and consequently their own derivative of good practices. Proliferation led to the confusion and vagueness in the field of implementing good practices even for professionals in the field of food safety.

Like standards, good practices can also be divided regarding their purpose into private and public good practices due to the convenience. Like standards, public good practices have the ultimate role of protecting consumers, while private are not designed just to protect consumer but also protect brand reputation and consequently remunerative business. Into group of public good practices can be classified good practices developed by CAC as the most important international reference point for developments associated with food on a global level like code of hygiene practice, which lay a firm foundation for ensuring food hygiene. Private good practices embrace good practices, which are in majority based on the principles of Codex Alimentarius good practices but are tailored for the specific requirements for various branches, products, processes, consortia associations, etc. (Raspor 2008).

On a global level, the Food and Agricultural Organization (FAO), the World Health Organization (WHO), and the World Trade organization (WTO) deal with food safety issues. Motarjemi et al. (2001) described the creation of CAC in the period from 1961 to 1963. The aim of the Codex is to protect public health and to support balanced trade relationships in food with developing harmonised international food standards, guidelines, and codes of practice to protect the health of the consumers and ensure fair trade practices in the food trade.

Good practices are described in several different Codes of Practice designed by producers' organisations, importers and retailer's consortia, and Government bodies representing consumers. In general, good practice means activity of the quality assurance which ensures that food products and food-related processes are consistent and controlled to assure quality procedures in food systems. Producers in the past started to think about integrity control of individual stage and activity in production chain (Raspor et al. 2013).

Positive experiences have developed and today we call it "good manufacturing practice" (GMP). From its first rules and principles in the year 1986, the World Health Organization set the course about meaning of enacting standard procedures dealing with personal, building, equipment, documentation, production, and quality control (Zschaler 1989). Nowadays, food processing includes several practices: GMP, good laboratory practice (GLP), good catering practice (GCP), good retail practice (GRP), and good hygiene practice (GHP) that are intertwined with each other practices (Raspor and Jevšnik 2008; Raspor 2008; Raspor et al. 2013). Today we master food safety via Good Agricultural Practice (GAP), Good Manufacturing

Practice (GMP), Good Transport Practice (GTP), Good Warehouse Practice (GWP), Good Selling Practice (GSP), Good Catering Practice (GCP), as well as Good Laboratory Practice (GLP) and Good Hygiene Practice (GHP) which can be involved in all practices mentioned but can be also independently applied. Precise analyses of good practices showed that they are introverted and they are limited within their own frame of activity and they do not generally show intention to be fused with neighbouring or related good practice. Raspor (2008) stressed that all good practices have intention to provide consumers with safe and quality products, but Good Housekeeping Practice (GKP) is still not part of any food safety system. Consumer should be integral part of food safety system, because it is a vital link between retail and home (Raspor 2008; Raspor and Jevšnik 2008; Raspor et al. 2013).

In the context of food production, GAP is clearly the most important good practice for the next steps of food supply chain in terms of hazards which are transported through chain. GAP address environmental, economic, and social sustainability for processes on farm and result in safe and quality food and non-food agricultural products and were first presented to the FAO Committee on Agriculture in 2003 (FAO 2008).

GLP deals with the organisation, process, and conditions under which laboratory studies are planned, performed, monitored, recorded, and reported. GLP practices are intended to promote the quality and validity of test data. The formal regulatory concept of GLP originated in the USA, because of concerns about the validity of non-clinical safety data submitted to the Food and Drug Administration (FDA) in the context of new drug applications (WHO 2009).

GCP consists of practical procedures in catering. The Guidelines concentrate on the essential steps needed to ensure that the food served is always safe and wholesome. GRP consists of practical procedures and processes that ensure the right products are delivered to the right addressee within a satisfactory time period and at required conditions. A tracing system should enable any faulty product to be found and there should be an effective recall procedure. GHP consists of practical procedures and processes that return the processing environment to its original condition (disinfection or sanitation programmes); keep building and equipment in efficient operation (maintenance programme); and control cross-contamination during manufacture (usually related to people, surfaces, the air, and the segregation of raw and processed product) (Raspor 2008; Raspor and Jevšnik 2008).

The next stage in food supply chain is storage and distribution. GSP consists of practical procedures and processes that ensure appropriate handling of foods, regarding implementation and control of product storage in accordance with a defined regime prior to their use. GTP consists of practical procedures and processes that ensure a qualitative system governing the organisation, implementation, and control of transport of food products from the producer to the final user. The last step in the food supply chain is consumption. Consumers must also respect the principles of food safety at home. GHKP is selection of the principles and techniques of food storage and food preparation at home (Raspor 2008; Raspor and Jevšnik 2008; Raspor et al. 2013).

The main purpose of all good practices in food safety circle is to provide consumers with safe, healthy, and quality food. In all good practices are the HACCP elements that compose HACCP system as main system in food practice today. All practices are partial and not connected in comprehensive system. GHKP is of the last importance for connecting food system chain into food safety circle. GHKP is according to considerable number of FBD occurring in domestic food preparation still neglected (Jevšnik et al. 2008b; Raspor 2008; Raspor et al. 2013).

Food business operators shall ensure that foodstuffs comply with the relevant microbiological criteria. Even more, they should decide themselves the necessary sampling and testing frequencies as part of their procedures based on HACCP principles and other hygiene control procedures (EC 2005). For most small and medium-sized enterprises (SMEs), even if they could be motivated to change, their progress would be severely hindered by a lack of information as to how to apply HACCP principles and other food safety requirements into their businesses. It is obvious that high-quality food safety training must be widely available, at an appropriate cost, to all SMEs. While the principles remain the same for all food operations, their application needs skilled interpretation, especially for SMEs (Taylor 2001; Taylor and Kane 2005; Jevšnik et al. 2008c).

When applying the principles of FSMS, risk managers should seek input from risk assessors, affected industry, and consumers to reach a consensus on the acceptable level of risk. Risk is an estimate of the probability and severity of the adverse health effects in exposed populations which may result from a hazard in a food. The acceptable level of risk is the level adopted following consideration of public health impact, technological feasibility, economic implications, and that which a society regards as reasonable in the context of and in comparison with other risks in everyday life (Van Schothorst 1998). It is well known that the public's perception of risk and their trust in information on food risks (Banati and Lakner 2006) may be important determinants of consumer reactions (Rosati and Saba 2004). Banati and Lakner (2006) emphasised that consumers are not sufficiently aware of the concept of biotechnology and often misunderstand it. Understanding risk and perceptions of reliability could lead to more effective food policies aimed at maintaining consumer confidence in food safety (Rosati and Saba 2004).

Regulatory tools are giving support to all included in food chain. On one side HACCP (EC 2002, 2004), good practices (CAC 2003; EC 2004), Codex Alimentarius (2003), etc., underpin technological tools and on the other serve as basis for efficient control and management. For that reason, we should develop and implement system approach which will congregate systemic tools to reduce risk in food safety. Together regulatory standards and the increased reporting of food contamination have pushed companies to put a higher priority on food safety. This is in accordance with globalisation of food trade and the recognition that "emerging hazards" are a significant issue. The modern food industry, based on international market, long shelf-life products, and ready to eat food, raises new microbial safety problems and demands. Consequently, pathogenic microorganism detection and identification have become major objectives over the past decade in food and water microbiology (Danin-Poleg et al. 2006). The ability to manage microbial food safety risks has clearly benefited greatly from ready access to the wealth of knowledge pertaining to the types of pathogens found in foods and the effect of environmental conditions on the behaviour of those organisms at the population level (McMeekin et al. 2006). HACCP as a regulatory tool therefore play an increasingly important role in the facilitation of food safety supply chain.

5 Consumer's and Food Handlers the Weakest Link in the Food Supply Chain

Food safety is of crucial importance to the consumer, food industry, and economy. Despite significant investment, the incidence of food-derived diseases still increases. Our inability to effectively improve the situation is a matter of major concern in spite of the very significant resources allocated to the problem of foodborne diseases (Raspor 2008).

Foodborne diseases as a growing public health problem (EFSA 2015) encompass a wide spectrum of illnesses. Foodborne diseases not only significantly affect people health and well-being, but they also have economic consequences for individuals, families, communities, business, and countries. The cases of foodborne illness occur daily in developed and also developing countries. Outbreaks of foodborne illness attract media attention and raise consumer concern. Unsafe food causes many acute and lifelong diseases, ranging from diarrhoeal diseases to various forms of cancer. WHO estimates that foodborne and waterborne diarrhoeal diseases taken together kill an estimated two million people annually, including many children and particularly in developing countries (WHO 2014). Despite significant efforts by all involved parties, there is still a considerable burden of foodborne illness, in which microorganisms play a prominent role. Microbes can enter the food chain at different steps, are highly proficient, and can adapt to the environment allowing survival, growth, and production of toxic compounds.

In 2013 (EFSA 2015), a total of 5196 foodborne and waterborne outbreaks were reported in the European Union, causing 43,183 human cases, 5946 hospitalisations, and 11 deaths. Most of the reported outbreaks were caused by Salmonella (22.5 %), viruses (18.1 %), bacterial toxins (16.1 %), and Campylobacter (8.0 %). In 28.9 % of all outbreaks, the causative agent was unknown. 38.5 % of reported foodborne outbreaks are caused by improper handling of food at households followed by restaurants, cafes, bars and hotels (22.2 %), and schools and kindergartens (8.3 %). Only a minor part of foodborne illnesses are reported so the true dimension of the problem is unknown and efforts to secure the resources and support necessary for the identification and implementation of effective solutions often are not effective.

Consumers and other stakeholders are increasingly concerned about the continuing sequence of food scandals and incidents. The occurrence of various national and international food safety issues over the last few decades has arguably resulted in a decline in public trust in food safety regulation and management inside and outside Europe (Houghton et al. 2008). Implemented food safety guidelines are not purposely designed for informing the consumers, although the studies in the last years highlighted gaps in food safety knowledge and some critical safety violations regarding food handling at home (Unusan 2007; Jevšnik et al. 2008a, d; Redmond and Griffith 2009; Sanlier 2009; Byrd-Bredbenner et al. 2013). Private households/domestic kitchens are responsible for 38.5 % of all verified outbreaks in the European Union and are presenting the main setting of the verified outbreak occurrence (EFSA 2015). However, outbreaks of foodborne illness occurring in private homes are less likely to be reported than those in commercial and public premises and it is believed that infections attributed to the private home are three times more frequent than those attributed to the canteens (Borneff 1998; Scott 2003). Gustafson et al. (2014) established that proper sanitation and disinfection education and appropriate supervision, along with the continued investigation of SFP outbreaks, remain major tools for prevention. They also emphasised that consumers must be informed, and follow the basic instructions regarding storage temperature, cooking, and measures designed to prevent food contamination.

An increasingly important role for food control systems is the delivery information, education, or advice to actors across the farm to table continuum. Insufficient product information can lead to products being mishandled at later stages in the food chain, which can result in foodborne illness and that is why the protection from insufficient product information as one of the strengths is needed. In these days, we are facing on one side with insufficient knowledge and awareness of food safety issues among food handlers and on the other side we have insufficient informed consumers about food safety principles at home (Jevšnik et al. 2008b; Sanlier 2009; Raspor et al. 2013; Schmeiser 2014).

6 Environmental Impact

Upgrading and updating technology and agricultural practices are fundamental human activities for ages and most of all have been important to suppress hunger in the world. With elimination of hunger, consumers are becoming increasingly demanding about the quality of the food they purchase, increasing the market demands for good quality products. Increasing food demand and technological and economic changes have led to an intensification of agriculture and farming, but in these days the global agri-food system is confronting environmental (e.g. use of agrochemicals like pesticides and fertilisers; veterinary medicinal residues, impacts of climate change), social (e.g. local versus global food supply, fair trade, cultural certificates like halal and kosher, organic versus intensive production), and economic (e.g. reduce costs and the purchase prices, standard certification) challenges, which can represent an important threat to human health and at the same time defy effective food safety.

Soil and water pollution and food safety are the most important interlinked issues nowadays. Pollution and food contamination related to the use of production technologies, processes, and also consumption have significant environmental consequences. Driven by public pressure, pollution regulations, and growing environmental friendliness, efforts to reduce the impacts of industry and agriculture are on the rise, because modern food production and consumption are one of the largest contributors to environmental degradation. Management practices including environmental issues are extending the range of business responsibilities. Environmental points of views with the aim to ensure sustainable food supply are increasingly important aspects also in good practices. This is largely due to the food industry, which is challenged with competitive and global markets in which process efficiency, product and process quality, and consumers' trust, elimination of hazards, tracing and tracking of food products within food supply chain, animal welfare, and environmental protection have become critical elements. That is the reason to cope with both enhancing the beneficial and reducing the harmful environmental effects. Agriculture carries a high responsibility for the management of water, land, energy, and waste resources.

Food production and consumption behaviour have major negative impacts on human health and on the sustainability of the environment like greenhouse gas emissions, waste, water use, and land degradation. Many food consumers are more and more concerned about negative impacts of the food system and demand environmentally friendly food products. Climate change is a global concern with consequences like global warming, unusual regional weather patterns, more frequent droughts, changes in nutrient loads, changes in contaminants' transport, etc. The impact of climate change (Miraglia et al. 2009; Tirado et al. 2010; Food Ethics Council 2015) on various aspects of human and animal health and welfare is a globally debated topic. Climate change has an impact not only on food production and food security but also on food safety, incidence, and prevalence of foodborne diseases. The information is mainly focused on the consequence of climate change on food security defined by WHO as access to sufficient, safe, and nutritious food (FAO 1996). Local climate conditions influence local vegetation and consequently also on livestock systems, which impacts on the stability and security of the local food supply. This could lead to changes in plant and animal epidemiology and transformations in entire ecosystems (Lin et al. 2009; Lennon 2015).That is why identifying and understanding the potential influences of the climate variables on microorganisms that cause foodborne diseases and their impact on these local industries are essential (Stewart and Elliott 2015). When we take into account the production, packaging, transport, retail, and preparation of our food, its contribution to climate change is even greater. Mitigating agriculture's contribution to climate change means embracing sustainable farming practices, relying on fewer chemical inputs, and producing less energy and resource-intensive foods. Climate change has also socio-economic effects related to food systems such as agriculture, animal production, global trade, demographics, and human behaviour, all of which influence food safety.

Growing demand with changes in lifestyle and health consciousness encourage the use of ready to use and convenience foods. Roughly one-third of the edible parts of food produced for human consumption gets lost or wasted globally, which is about 1.3 billion ton per year (FAO 2015). Nearly 100 million tonnes of food are wasted annually in the EU (estimation for 2012). If nothing is done, food waste could rise to over 120 million tonnes by 2020 (EC 2015c). Wasting food is not only an ethical and economic issue but also depletes the environment of limited natural resources. The needs of environmental protection from generated waste are overlooked and in some cases also ignored. Food production and waste generation directly affect resources and consumption and often contaminate the environment. This consequently also means that huge amounts of the resources used in food production are used in vain and that the greenhouse gas emissions caused by production of food that gets lost or wasted are also emissions in vain (FAO 2011; Eriksson et al. 2015). In Europe and North America, per capita food loss is 280–300 kg/year. In sub-Saharan Africa and South/Southeast Asia, it is 120–170 kg/year. The total per capita production of edible parts of food for human consumption is, in Europe and North America, about 900 kg/year and in sub-Saharan Africa and South/Southeast Asia, 460 kg/year (FAO 2011). Food losses in industrialised countries are as high as in developing countries, but in developing countries more than 40 % of the food losses occur at post-harvest and processing levels, while in industrialised countries more than 40 % of the food losses occur at retail and consumer levels. Food waste at consumer level in industrialised countries is almost as high as the total net food production in sub-Saharan Africa (FAO 2011). Across the food-abundant nations of Europe, a large portion of waste is thrown out by households (37 million tonnes) (EC 2010).

The central goal of EU food safety policy is to protect both human and animal health and welfare. Food law is aimed at ensuring a high level of protection of human life and health, protection of consumer interests, and their rights of being informed on food they consume. In this respect, it is evolving and adapting to time and needs. In cooperation with Member States and stakeholders, there is a need to prevent food waste and strengthen sustainability of the food system. Currently, legislation on the provision of food information to consumers (EC 2011) reserves the "use by" date for highly perishable foods, which are from a microbiological point of view an immediate danger to human health. After this date, they are deemed unsafe. The "best before" date refers to minimum durability; beyond this date it is unlikely to cause any harm but a warning from the manufacturer that the sensory qualities may not be as good as intended, but the product would remain safe to eat, provided that storage instructions have been respected and the packaging is not damaged (EC 2011). Products usually remain edible beyond this date, but are nonetheless thrown away. Some countries are working to raise awareness and to encourage more cooperation along the food chain to prevent and reduce food losses and waste. The EU is considering exempting more foods with a long shelf life from the requirement to provide a "best before" date on the label in a bid to cut down on food waste.

By FAO (2013) reports, the carbon footprint of food produced and not eaten is estimated to be 3.3 Gtonnes of CO_2 equivalent. Globally, the blue water footprint (i.e. the consumption of surface and groundwater resources) of food wastage is about 250 km^3, which is equivalent to three times the volume of Lake Geneva. Finally, produced but uneaten food vainly occupies almost 1.4 billion hectares of land; this represents close to 30 % of the world's agricultural land area. While it is difficult to estimate impacts on biodiversity at a global level, food wastage unduly compounds the negative externalities that monocropping and agriculture expansion into wild areas create on biodiversity loss, including mammals, birds, fish, and amphibians.

Emissions of greenhouse gases (GHG) arise mainly from the combustion of fossil fuels in the energy and transport sectors. However, the food sector has been identified as one of major contributor to anthropogenic climate change. The production of food causes greenhouse gases (GHG) at all stages along the food supply chain. Agriculture was estimated to be the cause for around 10–15 % global greenhouse gas (GHG) emissions (Muller et al. 2011; Eurostat 2015).

Transport is highly related to almost all human activities. Today's food system is built upon food miles connected to refrigeration, where necessary. However, local food consumption is increasing. In addition to this food transport refrigeration is a critical link in the food chain, but not only in terms of maintaining the temperature integrity, but also its impact on energy consumption and CO_2 emissions (Tassou et al. 2009; Wu et al. 2013). Refrigerated storage is one of the most widely practiced methods of preserving and maintaining the safety and quality of many perishable foods. The data suggest that currently the cold chain accounts for approximately 1–2 % of CO_2 production in the world (Watkiss et al. 2005; James and James 2010). The cold chain is vital part of modern global trade as it impacts on all food commodities.

7 Ethics in a Food Safety Field

Nowadays we live in a consumer society in which people are having a wide range of choices in a growing area of consumer goods and services. That is why most of the power is concentrated in the hands of big retailers and companies, who are aware of their power and are subconsciously dictating what we need and should have. Modern consumers are no longer involved in food production and have less and less knowledge and consequently trust in production processes but at the same time have concerns about certain ethically questionable issues in the food supply chain. Recent food emergencies throughout the world have raised some serious ethical and legal concerns. The most common consumer concerns on ethical issues include the safety of food (e.g. the use of hormones and antibiotics in animal feed, use of chemical pesticides and fertilisers, (un)intentional microbial contaminations), technological advancement (e.g. GM crops, nanotechnologies, irradiation), the quality of the food, the healthiness of the food (e.g. labelling, chemical preservatives, adverse health effects), issues relating to animal welfare (e.g. transport of animals and slaughtering, import/export of animals and animal products, local versus global production), the impact of food production on the quality of the landscape (e.g. contamination of groundwater), the environmental effects of food production (e.g. erosion), the fair trade, and fair treatment of farmers (Coff et al. 2008; Omer et al. 2010).

Food industry daily faces dilemmas about where their products and ingredients come from, their quality and ethical issues, and who are their consumers and where they come from. Advertisements, headlines, newspaper articles, and criticisms, whether over food poisoning or contamination scares or new technologies like GM crops, cloning, irradiation, and nanotechnologies, create confusions and raise ethical concerns from the consumer's point of view. However, rapid development of agriculture and food (bio) technology have generated gap between corporate ethics and social responsibility within the agriculture and food technology process. Thompson and Noll (2014) described that as agricultural sciences, farming methods, and various other activities surrounding food are all human practices, they can all be subjugated to ethical evaluation and critique. The consequences of this gap are chronic health risks, farming crises, food safety concerns, and the overuse of resources including land and water. Consumers are expressing their concerns and expectations about the ethical behaviour of companies by means of ethical buying and consumer behaviour.

For a long time, the ethics of food was only concerned with food security (Coff et al. 2008) and consequently with distribution of food within developed and developing countries. Technological advances and organisational changes affecting food systems in recent years have been radical and rapid and have created many ethical dilemmas and social responsibility gaps. Food safety and its regulation are becoming a major international concern from the ethical point of view (FAO 2002). Ethics of food safety is a dynamic area that continues challenging our precipitation of food consumption, health risks, and public responsibility for foodborne illness. Ethics refers to the values, principles, and codes by which people live (Food Ethics Council 2015). The word "ethics" is derived from the Greek word "ethos" meaning conduct, customs, or character and can be described as the application of morals to human activity (Manning et al. 2006). The issue of food safety and foodborne risk is gaining widespread public attention. For building and maintaining the confidence in food safety systems, there is a need to define the role of ethics in food safety policy development, because in these days ethical and moral values are often neglected and intentionally forgotten. Highly publicised food safety problems have given rise to general state of distrust among consumers, the food industry, and the institutions established to safeguard the food supply (FAO 2002). Managing food safety hazards and risks is a top priority for any who is involved at any step in food supply chain including consumers.

Olsen and Bánáti (2014) stressed that food production is more complex than ever and several ethical issues are raised in relation to agricultural practices and the food supply chain. Making good ethical decisions requires a trained sensitivity to ethical issues and a practised method for exploring the ethical aspects of a decision. The more novel and difficult the ethical choice we face, the more we need to rely on discussion and dialogue with others about the dilemma. A dialogue about the ethical implications of food production, processing, policy, supply, and consumption may help involved partners in making better decisions.

8 New Food Safety Paradigm

Interdisciplinary in nature, the history of food is a subject well suited to research. It is a large space of inspiration for culture, technology, and nutrition and human well-being. As the topic of food history is so wide reaching, it is hard to pinpoint areas of interest. Rather than being comprehensive, it is better to see this field as spring of ideas for further and future research and innovations based on available traditional and somewhat less traditional sources. Less than 10,000 years ago, humans developed agriculture, which has continually improved and altered the way in which food is obtained. This led to a variety of important historical consequences such as increased population, the development of cities, and the wider spread of infectious diseases. Understanding food history gives us possibility to direct old experiences and knowledge to new realms of applications. The types of food consumed, and the way in which they are prepared, vary widely by time, location, and culture. This is the “fil rouge” of humans and their difference from the rest of nature. Humans invent new sources of food, new compositions, new technologies, and new preparations for satisfying their basic need for energy as well as their pleasure (Raspor 2006; Raspor et al. 2013).

By analysing the novelty and the sources of novelty in food area, it can be found out that we can expect novelties along three main streams and in their combinations as shown in Fig. 1.

Although it is known that regulatory agencies are trying to coin systems which would clarify confusions in this area (Kwak and Jukes 2001), there are still many open questions coined by interaction among all three streams enabling innovations in food area and along the food supply chain.

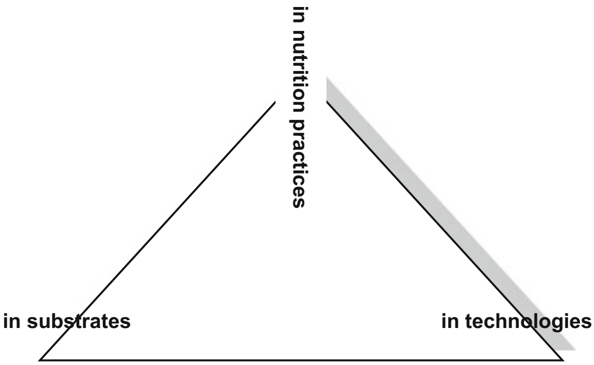

Fig. 1 Innovation filed in food production and nutrition

Table 1 Research and development constraints

Aspects	Constrains	Action
Culture	Religion constrains	Prohibitions
Nutrition	Dietary constrains	Beneficial effects
Environment	Technology constrains	Uncertainty of cost benefits
Health	Nutrigenomic constrains	Undefined

The distinction between substrate development and its application for technology or nutrition sometimes becomes blurred, as the functions are incorporated in the same foodstuff from various points of view. Linking food and natural ingredients to health impacts is not novel, but they are novel approaches how to deal in nutritional practices. Since the beginning of cultural life of humans, experiential knowledge distilled and passed on from one generation to the next has pointed to positive experiences. Scientific discoveries significantly improve traditional experiential knowledge development. Structured scientific methods increase the rate of new knowledge accumulation and improve its accuracy. Furthermore, scientific discoveries focused on the bioactive molecular components of food rather than on whole foods. Technology and processing can influence content of important "vitalins" (Burn and Kishore 2000), and they consequently may be increased, decreased, or stabilised for improved function as shown in Fig. 1.

Radical technical innovation must be followed by institutional innovation to minimise risks and protect consumers. Consequently, we are facing research and developmental constraints from different aspects as shown in Table 1.

Over the last years, there have been both successes and failures in market introductions of novelties in food area around the globe. This is the most probable to continue since consumers, producers, and regulators have to face novelties in practice and have to learn mostly from mistakes. In this transitional period, institutional and market innovation is expected to be as important as technical innovation itself. For that reason, it is important that in food supply chain we build as much as possible expertise for understanding foods from various aspects as is treated with different professions. Raspor (2006) emphasised that The Consumers Future Food reveals that there is a revolution going on from stable to table, from farm to fork, from spring to drink. On the dinner tables of tomorrow, consumers may expect a new food icon, the result of an evolution that is transforming the very nature of the food we eat, to create a new breed of future for healthy and controlled nutrition.

9 Conclusion

It is obvious that each practice deliberately built its own spectrum of independency profession and competence. What is good for food quality and economy is not always sufficient for safety standards. Quality management systems reached high level in recent years and offered a great impact on food systems. Food technology as a profession is responsible for the technical aspects of development of food products, food processes, and distribution of these products through entire food chain to consumers. When we want to satisfy all consumers' needs and producers' requests we strike against conflict of interests. Consumers want a large variety of safe food choices, while producers want safe product to sell, but also less regulation (Olsen and Bánáti 2014). This is in the area of consumer needs and wants that we encounter some of the most difficult problems in fostering rational development of food technology and nutrition is facing in last years. Particularly important are outbreaks of food pathogens and exaggerated concerns about GMOs (Ammon 2005; Kubota et al. 2005; Raspor et al. 2011; Pellegrini 2013).

Kuiper and Davies (2010) pointed out social values which may lead to conflicting beliefs of consumers in the acceptance of new technologies as for instance became evident from the debate concerning the introduction of genetically modified foods and feed. Currently relatively little attention is paid during the risk analysis process to evaluate issues such as different perceptions of risks among the general public, usefulness of the new technology, social and economic consequences, freedom of choice of products, etc. Moreover considerations regarding the impact of new agricultural production methods on animal welfare, quality of life, socio-economic consequences, and sustainability become more relevant. The European Commission has therefore recommended to broaden the risk analysis paradigm and to include socio-economic aspects (EC 2003).

It looks obvious that we have to start to link more profoundly hard and soft sciences and transfer mutual finding, experiences, and skills towards consumer but engaging all elements of food supply chain. Olsen and Bánáti (2014) warning that it is not always straightforward to say what is right and what is wrong when it comes to the production of food. Many ethical questions can be raised regarding the food supply chain, including agricultural production.

We should have in mind that safe food is the aim of all; therefore, every misleading act and information (intentional or unintentional) that could happen in food supply chain in the end affect consumers. More effective system of primary education and lifelong learning of food related topics are needed. To achieve total quality and safe life, a multidisciplinary and an innovative approach, which would be capable of quick and effective responding in the food supply chain, is needed. This would involve and stress out the importance of subjective comprehension of health and safety concept, which is constituent part of well-being.

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Regulations for Food Toxins

Muhammad Alim, Shahzad Zafar Iqbal, Jinap Selamat, and Agustin Ariño

Abstract To ensure food safety, food regulations are important and integral part and steps should be taken to ensure stricter food regulations for these toxins. These toxins, if present in levels greater than permissible limits, are toxic, carcinogenic, and mutagenic for humans as well as for animals. Several countries have established permissible limits for these food toxins. It is reported that around two million deaths including of children are associated with the use of unsafe food. The current chapter deals with the importance, regulations for different food toxins, and future challenges for food safety issues.

1 Introduction

Food regulations and safety measures are important part of food safety and steps should be taken to make them stricter, considering increased globalization and high demand of food supply. Annually, around two million deaths including of children

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are associated with the use of unsafe food. It is estimated that food contaminated with harmful pathogens, microbes, or chemical substances leads to more than 200 diseases. Food safety is susceptible to new challenges such as changes in procedures for production and distribution, changed food habits, emerging pathogens, and increased contamination due to rise in travel and trade, among others. The World Health Organization (WHO) has decided to include food safety as their agenda on the World Health Day, 7 April 2015. They have decided that food safety measures require implementation of necessary actions in all stages of food production, i.e., from harvest, transport, processing, and storage to preparation (World Health Organization 2015). It is quite difficult task for regulatory bodies and the scientific community to ensure food safety. Currently, the inadequacy of conventional methods demands for novel and reliable techniques to enable convenient, high-speed, and sensitive analysis of food contaminants.

In the current scenario, food safety draws substantial attention of the world owing to rapidly changing food recipes and food habits. Foodborne illnesses linked with pathogens, toxins, and other contaminants create serious threat to human as well as animal's health. Food industry faces significant loss due to the expenditure of budget on analyses and control measures. Nowadays assurance of food safety moves more and more from finished product testing to proactive food safety management. The control activities are aiming at prevention/reduction of a food safety hazard and are typically related to product and process controls (Luning et al. 2008) while preventive measures include cleaning and sanitation, temperature control of the production environment, and hygiene of the workers. Assurance activities have the main objective to provide evidence that products and processes are within set specifications like sampling, validation, verification, and documentation (Luning et al. 2009).

2 Regulation About Mycotoxins/Aflatoxins in Foodstuff

Food that we eat is not absolutely free from natural contamination. However, it is also not feasible to test every single item for every possible contaminant, toxin, adulterant, or foodborne pathogen. Food having reasonably no harm to human or animals is known as safe food. Worldwide, every country has an agency or organization that oversees food safety and regulates the type and concentration of additives in food. In the USA, Food and Drug Agency (USFDA, Table 1) is responsible for the safety of all foods except meat, poultry, and egg products, which are harmonized by the Food Safety Inspection Service (FSIS) of the US Department of Agriculture (USDA). These agencies conduct monitoring on a regular basis in order to implement permissible levels of contaminants and toxins. If they found any contaminant or scientific discoveries pointed out a new hazard at high level, then they carry out risk assessments. Risk assessment is a combination of hazard identification and characterization, exposure assessments, and subsequent risk characterization.

Table 1 USDA tolerance levels for total aflatoxins

Commodity	Level (in ng/g)
All commodities	20
Milk (finished)	0.5
Corn meal for dairy cattle	20
Corn meal for breeding cattles	100
Cottonseed meal used as a feed ingredient	300

Internationally, regulatory agencies take a chemical-by-chemical approach for risk assessment. However, we are exposed to hundreds of chemicals on a regular basis and that many of these chemicals may share a common mode of action and affect same target organ(s) or tissue(s). Implementation or setting regulatory standards is very difficult not because of potential health benefits but also taking consideration of political and economic issues. During the implementation of regulations on mycotoxins in food and products, several scientific and socioeconomic factors have also been considered (Egmond and Jonger 2004) like

- Availability and accessibility of toxicological data
- Availability of data on incidence in different food commodities
- Knowledge on the distribution of mycotoxins within a lot
- Availability of analytical methods
- National permissible limits
- Need for sufficient food supply

The enforcement of regulations has required the availability of reliable and sophisticated analytical methods. It would be wastage of resources if the tolerance levels do not have reasonable expectation and thus will reject those products which are perfectly fit for consumption. The European Standardization Committee and AOAC International have a number of standardized methods for mycotoxins that are validated in formal inter-laboratory method validation studies (Egmond and Jonger 2004).

The Joint FAO/WHO Food Standards Program and the Codex Alimentarius Commission (CAC) implemented the food standards and codes of practice related to food as shown in Table 2. The CAC meeting alternates between the FAO headquarters in Rome and the WHO in Geneva regularly after 2 years. The CAC has more than 165 Nations Members, and in 1956, FAO/WHO Joint Expert Committee on Food Additives (JECFA) was established as the scientific advisory body which collaborates with FAO, WHO, and Codex Alimentarius. JECFA organized meetings regularly after each year or twice every year and deals with the assessment of food additives, contaminants, toxins, and residues of veterinary drugs in food and feed. It is the responsibility of JECFA to provide risk assessment advice to Codex Committees.

The economic costs and damages occurring due to mycotoxins are almost impossible to be determined accurately; however, the US Food and Drug Administration (FDA) provided estimations based on a computer model. In the USA

Table 2 Aflatoxins tolerable limits set by the Joint FAO/WHO Expert Committee

Aflatoxins	Tolerance level (μg/kg)	Food/feed
AFB_1	5	Feed for dairy cattle
AFM_1	0.05	Milk
$AFB_1 + AFG_1 + AFB_2 + AFG_2$	15	Raw peanut and spices for human consumption
$AFB_1 + AFG_1 + AFB_2 + AFG_2$	10	Spices

alone, the mean economic annual costs of crop losses from mycotoxins, especially aflatoxins, fumonisins, and deoxynivalenol, were estimated to be US$932 million (Cast Report 2003).

3 Regulations on Mycotoxins

Mycotoxins regulations have been documented and adopted in about 100 countries, out of which 15 belongs to African countries, in order to protect the consumer from the harmful effects of these toxins (Van Egmond 2002; Barug et al. 2003; Fellinger 2006). In food used for human consumption the permissible limits range between 4 and 30 ppb for aflatoxins and mainly depend on the limits implemented by law enforcing agencies of that country (FDA 2004). In the USA, 20 μg/kg is the maximum total AFs residue limit in food for human consumption, except for milk (Wu 2006), while 4 μg/kg total AFs in food for human consumption is the maximum acceptable limit in the European Union (EU), the most strictest worldwide (EC 2006; Wu 2006). The toxicity of various mycotoxins is presented in Fig. 1.

The EU has recently issued a proposal to lower maximum tolerated limits for several other mycotoxins in food and feed which became effective from 1st October 2010 (European Commission 2010).

4 Regulations on Ochratoxin A

Ochratoxin A, which is produced by *Aspergillus ochraceus*, *Aspergillus carbonarius*, and *Penicillium verrucosum*, is one of the important mycotoxins. It is also a frequent contaminant of water-damaged houses and of heating ducts. Human exposure can occur through consumption of contaminated food products, like contaminated grain and pork products, as well as coffee, wine grapes, and dried grapes. Legal limits for ochratoxin A in different food products set by the European Commission (No.123/2005 of 26 January 2005) are presented in Table 3.

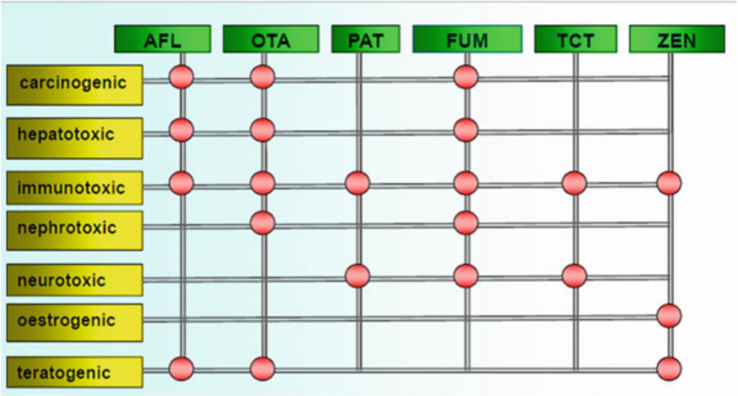

Fig. 1 The toxicity of mycotoxins according to International Agency for Research on Cancer

Table 3 Ochratoxin A regulations in different foodstuff

	Products	Maximum levels (µg/kg)
1	All products derived from cereals (including processed cereal products and cereal grains intended for direct human consumption)	3.0
2	Raw cereal grains (including raw rice and buckwheat)	5.0
3	Dried vine fruits (currants, raisins, and sultanas)	10
4	Roasted coffee beans and ground roasted coffee with the exception of soluble coffee	5
5	Soluble coffee (instant coffee)	10
6	Wine (red, white, and rose) and other wine and/or grape must based drinks	2
7	Grape juice, grape juice ingredients in other beverages, including grape nectar and concentrated grape juice as reconstituted	2
8	Grape must and concentrated grape must as reconstituted, intended for direct human consumption	2
9	Baby foods and processed cereal-based foods for infants and young children	0.50
10	Dietary foods for special medical purposes intended specifically for infants	0.50

5 Heavy Metal Regulations in Food and Food Products

There are almost 35 metals that concern us because of occupational or residential exposure and 23 of these are termed as heavy elements like antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc. Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood

Table 4 Heavy metal regulation in different food and food products

Metal	Food stuff	Maximum limits (mg/l)
Antimony (Sb)	Natural mineral water	0.005
	All other liquid food stuff	0.15
Arsenic (As)	Chocolate	0.5
	Composite, filled, and unsweetened chocolate	1.0
	Fruit juices and nectars	0.2
	Edible fat and oils	0.1
	Natural mineral water	0.01
	Fish and processed fish	3.0
	Meat and processed meat	1.0
Cadmium (Cd)	Cereals, pulses, and legumes	1.0
	Fruit and other vegetables	0.5
	Shellfish and shellfish products	3.0
	Fish and processed fish	1.0
	Meat and processed meat	0.05
	Natural mineral water	0.003
Copper (Cu)	Chocolate	15
	Composite, filled, and unsweetened chocolate	20
	Unsweetened chocolate	30
	Fruit juices, vegetables juices, and nectars	5.0
	Natural mineral water	1.0
	Mayonnaise	2.0
	Margarine	0.1
Lead (Pb)	Cereals, pulses, and legumes	0.2
	Fruit and other vegetables	0.1
	Milk and milk products	0.02
	Meat and processed meat	0.1
	Fish and processed fish	0.5

EU maximum limits for heavy metals (1994)

composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease. EU regulations on heavy metals are presented in Table 4.

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Part II
Chemical Food Contaminants

Safe Food Production with Minimum and Judicious Use of Pesticides

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Abstract In agricultural ecosystems, pests, plant pathogens and weeds pose a major challenge to crop productivity and global food security. Without crop protection measures, the crop damage inflicted would be more severe by almost 30 % than that is at present. Pesticides have proved to be an efficient and reliable way of minimizing pest pressure in most cases. Nowadays, however, the excessive and uncontrolled use of pesticides is called into question, with the increasing knowledge of negative impacts and the demonstration of undesirable effects on ecosystems, on non-target species and on human health. Overreliance on pesticides is also counterproductive to the sustainability of pest control, especially with respect to the increasing problem of pest resistance. Concerns about the sustainability of agricultural ecosystems lead to the need of developing technologies and practices that do not adversely influence environmental goods and services, are readily accessible, easy to implement and effective for farmers and improve crop productivity. Because pesticides will likely remain a tool for modern agriculture, it is important to design strategies that will reduce the impact of pesticides. The use of advanced ecological knowledge at high levels of the hierarchy of the agro-ecosystem, which means utilization of comprehensive information on the life cycles of pests, maximization of the use of natural processes in the cropping system, rational decision-making for pest control taking into account the severity of the infestation and introduction of the damage threshold concept, is gaining popularity. With respect to pest control, regardless of the method selected, it should be implemented with precision and with as few chemicals as possible. Integrated Pest Management (IPM) is seen as a way to achieve sustainable agricultural production with less damage to the environment. IPM provides a toolbox of complementary solutions for pest control by using complementary technologies. It relies on minimum use of pesticides that target specific pests, can be applied at low rates and are less toxic to beneficial organisms. IPM projects have been able to deliver substantial reductions in the use of pesticides coupled with increased yields. From their side, agrochemical companies try to expand their product portfolio by investing in the research of new chemical compounds with innovative modes of

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action, aiming at environmentally friendly and sustainable crop protection products that are effective with smaller amounts of active ingredients. Adaptive pest control based on IPM with rational use of pesticides and only as a last resort seems to be the most viable way forward for safe food production.

1 Introduction

Finding a way to feed an estimated 9.3 billion people expected to populate planet Earth by the year 2050 is considered a major challenge in terms of agricultural pest management (Godfray et al. 2010). On the other hand, crop productivity is at constant risk due to the continuous incidence of common pests, especially weeds, pathogens and arthropod pests (Oerke 2006). From the beginning of agriculture, pests have been a major problem for crop production and continue today. Despite substantial increase in pesticide use since the 1960s, global crop losses to pests have remained unsustainably high or even increasing in some cases (Oerke 2006). It is estimated that pests, i.e. insects, plant pathogens and weeds, destroy about 40 % of all major crops every year (Pimentel 2005). Among crops, the total global potential loss due to pests varied from about 50 % in wheat to more than 80 % in cotton (Oerke 2006). Absolute crop losses and loss rates vary largely among crops due to differences in their reaction to the competition of weeds and to the attack of other pest groups (Oerke 2006). The overall loss potential is especially high in crops grown under high productivity conditions as well as in the tropics and subtropics, where climatic conditions favour the damaging function of pests.

Obviously, agriculture will always have to cope with crop losses caused by biotic stresses. During the last 50 years, these stresses were controlled mainly by pesticides. Ecosystem management for pest reduction is not a recent cultural attribute, given that some form of pesticide use was recorded since the ancient times (Fishel 2013). Nowadays, in the context of modern agriculture, the objectives of pesticide use are to increase production efficiency and yields, to reduce production costs and, especially, to increase the availability of commodities, improve food quality and minimize losses during transport and storage, improve soil conservation and ensure a stable and predictable food supply. Indeed, pesticides have played a key role in providing reliable supplies of agricultural produce at prices affordable to consumers, improving the quality of produce and ensuring high profits to farmers. Thus, they are now considered a major component of modern farming, playing an important role in maintaining high agricultural productivity (Cooper and Dobson 2007; Damalas 2009). Additionally, pesticides allowed the maintenance of crop yields and thus contributed to economic viability. Easy to apply and rather inexpensive, chemical control products have proved to be efficient and reliable in a large number of cases, on large surface areas. However, concerns about potential human health and environmental effects of pesticides have increased over the past several years (Van der Werf 1996; Pimentel 2005; Damalas and Eleftherohorinos 2011).

Today, the systematic use of pesticides is called into question, with the increasing awareness of their negative impacts and the demonstration of undesirable adverse effects on ecosystems, on non-target species and on human health. Concerns about sustainability of agricultural ecosystems centre on the need to develop technologies and practices that do not have adverse effects on environmental goods and services, are accessible and effective for farmers and lead to improvements in food productivity. Pesticide residues, the pesticides that may remain on or in food after application to food crops, are also of great concern for public health (Jackson 2009; Kantiani et al. 2010). Consumers do not want pesticide residues in their food because they can potentially pose a risk to health. On the other hand, pesticides are required to ensure that a consistent supply of economical and high-quality food is available. In this sense, sometimes residues will remain in the food supply. As a compromise, consumers require that the amounts of these residues in their food and drinking water will not be harmful to their health and should be no more than the regulation limits. In the last three decades, pesticides have been increasingly recognized for their adverse effects on the environment and human health. Pretty et al. (2001) calculated the annual external costs of pesticide applications in the UK, Germany and the USA, reporting a total cost in the USA at about $35 billion. Pimentel (2005) estimated the external cost of pesticide applications at the recommended dose rates to equal approximately $10 billion each year, mainly comprising $1.1 billion by human health impacts, $1.5 billion by resistance in pests, $1.4 billion by crop losses caused by pesticides, $2.2 billion by bird losses due to pesticides and $2.0 billion by groundwater contamination. In a similar study, Tegtmeier and Duffy (2004) calculated the external cost in the US agricultural sector between $5.7 and $16.9 billion. While most existing studies investigated the current external cost of pesticides, Koleva and Schneider (2009) estimated relationships between pesticide applications, weather and climate to compute the impacts of climate change on the external cost of pesticides. They calculated the current average external cost of pesticide use in US agriculture at $42 per hectare, and under projected climate change, this value increased up to $72 per hectare by 2100 (Koleva and Schneider 2009). However, this estimation approach neglected possible agricultural adaptations regarding crop and management choice.

Evidently, there is a need for new crop management systems better adapted to pest control constraints. However, the selection of such systems that are expected to reduce pesticide costs, maintain yields and ensure high profitability of production remains always a great challenge. The objective of this chapter is to summarize basic concepts of the constraints of pesticides in modern agriculture and of how these constraints can be minimized or eliminated through improved pest control that is based on ecological principles.

2 Crop Losses to Pests

In agricultural ecosystems, herbivorous insects and microbial pathogens can have major impacts on plant productivity. Pests can reduce crop productivity in various ways and can be classified by their impact into several categories, such as stand reducers (e.g. damping-off fungi), photosynthetic rate reducers (e.g. fungi, bacteria and viruses), leaf senescence accelerators (e.g. pathogens), light stealers (e.g. weeds and some pathogens), assimilate sappers (e.g. nematodes, pathogens, sucking arthropods), tissue consumers (e.g. chewing animals, necrotrophic pathogens) and turgor reducers (e.g. root feeders) (Boote et al. 1983). Weeds typically affect crop productivity due to competition for inorganic nutrients. Crop losses occur because the physiology of the growing crop is negatively affected by pests in a dynamic way over time as the crop grows (i.e. it increases in biomass) and develops (i.e. it passes through the different stages of its physiological development). Crop losses may be divided into quantitative and qualitative. Quantitative losses result from reduced crop productivity, leading to smaller yields per unit area, whereas qualitative losses may result from reduced content of valuable ingredients or market quality, e.g. due to aesthetic features, due to reduced storage characteristics, or due to contamination of the harvested product with pests or toxic products of the pests (e.g. mycotoxins).

Worldwide an estimated 70,000 different pest species damage agricultural crops. Of these, approximately 9,000 species are insects and mites, 50,000 species are plant pathogens and also 8,000 species are weeds. In general, less than 10 % of these organisms are considered major pests. Despite the yearly investment of about $40 billion for the application of three million metric tons of pesticides worldwide, in addition to the use of various biological and other non-chemical controls, between 35 and 42 % of the potential crop production is destroyed by pests (Pimentel 1997). Worldwide, insect pests cause an estimated 14 % loss, plant pathogens cause 13 % loss and weeds 13 % loss. The value of this crop loss is estimated to be $2,000 billion per year, yet there is still about a $4 return per dollar invested in pesticide control. Among crops, the total global potential loss due to pests varied from about 50 % in wheat to more than 80 % in cotton (Oerke 2006). The responses are estimated as losses of 26–29 % for soybean, wheat and cotton and 31, 37 and 40 % for maize, rice and potatoes, respectively. In total, weeds produced the highest potential loss (34 %), with animal pests and pathogens being less important (losses of 18 and 16 %, respectively). The steady rise in the number of species is predicted to continue under many future global biodiversity scenarios (Sala et al. 2000), and also environmental change could cause non-alien species to become invasive. Environmental change (e.g. rising atmospheric CO_2, increased deposition of nitrogen, fragmentation of habitats and climate change) could promote further invasions (Malcolm et al. 2002; Le Maitre et al. 2004; Song et al. 2008). As invasive or alien species comprise over 70 % of all weeds in agriculture (estimated in the USA) (Pimentel et al. 2005), increases in invasive species can be a major threat to food production (Mack et al. 2000; Pimentel et al. 2005; Van Wilgen et al. 2007). In addition, climate extremes may promote the spread of invasive species, plant diseases and pest outbreaks (Alig and Butler 2004; Anderson et al. 2004; Gan 2004).

Crop losses due to harmful organisms can be reduced largely by various crop protection measures. Without pesticides and non-chemical controls, the damage inflicted by pests would be more severe by almost 30 % than that is at present. Such an increase would cause a significant economic loss with negative impacts on world food supply. Over the last years, farmers have changed the way they produce food to meet the expectations of consumers, governments and more recently, food processors and retailers. In doing so, they made many changes to the way they farm, including the extensive use of pesticides. Although pesticide use has increased over the past decades, crop losses have not shown a concurrent decline, mainly because various changes have occurred in the agricultural practices that encouraged pest outbreaks. The increased use of pesticides since 1960 obviously has not resulted in a significant decrease of crop losses; however, in many regions they have enabled farmers to increase crop productivity considerably without losing an economically non-acceptable proportion of the crop to pests. Obviously, to maximize the benefits of pesticide use at minimum human and environmental cost, pesticides must be regulated strictly and used judiciously by properly trained and appropriately equipped personnel, ideally in tight integration with other complementary technologies.

3 Major Drawbacks of Chemical Pest Control

The use of chemicals in modern agriculture has significantly increased crop productivity, but chemical control rapidly revealed its limitations. Pesticides are not a homogeneous group of chemicals. There are numerous different chemicals with different characteristics, potential health hazards and potential environmental effects. Due to the nature of synthetic pesticides, their use involves danger to humans, animals and the environment. As a result, continuous use of pesticides produces significant negative externalities that have been broadly outlined in the scientific literature (Tegtmeier and Duffy 2004; Pimentel 2005; Pretty and Waibel 2005). In general, externalities of pesticides can be distinguished into two categories: health and environmental externalities. These substances can be dangerous for human health when the degree of exposure exceeds the safety levels. This exposure can be direct, such as the exposure of farm workers applying pesticides to various crops and indirect by consumers consuming agricultural products containing chemical traces or even bystanders from near application areas. Health costs to non-farming members of the community can be labelled external, as well as costs that are covered by the communal health centres, and a case can be made for health costs to farmers' children. Exposure to pesticides is responsible for various short- and long-run ailments and even deaths (Wilson and Tisdell 2001). Numerous cases of pesticide poisonings occur worldwide each year (Richter 2002). The largest number of poisonings and deaths is recorded in developing countries as most of the times the farmers do not use the appropriate protective equipment. In the developed world, farmers use pesticides from a closed environment, such as tractors and aircrafts, while in developing countries, many of the farmers are mainly small-scale operators who do not use protective equipment during pesticide handling and come in direct contact with pesticides as they use hand sprayers. Moreover, it is now better understood that pesticides can have significant chronic health effects. These health effects may differ depending on the degree and the type of exposure to pesticides. Normally, the effects are different for farmers who are directly exposed to pesticides than non-farming members of the community who are less directly exposed. There are also effects on consumers through pesticide residues in food.

Additionally, the excessive and uncontrolled use of pesticides can pose significant and irreversible environmental risks and costs. Fauna and flora have been adversely affected, while the decline of the number of beneficial pest predators has led to the proliferation of different pests and diseases (Pimentel and Greiner 1997). Certain pesticides applied to crops eventually end up in ground and surface water. In surface water, like streams and lakes, pesticides can contribute to fishery losses in several ways (Pimentel et al. 1992). High chemical concentrations can kill aquatic organisms directly or indirectly by affecting the availability of food. Moreover, the extensive use of pesticides has often resulted in the development of pesticide-resistant weeds and pests. This can trigger an increased pesticide application in an effort to reduce the respective damage that results in high economic costs that the respective farmers must shoulder. Pimentel et al. (1992) reported several adverse consequences of the overuse of pesticides, such as animal poisoning, contaminated products, destruction of beneficial natural predators and parasites, outbreaks of formerly suppressed pests, bee poisoning and reduced pollination and crop and biodiversity losses.

Lack of knowledge coupled with the usual misperception of pesticides as an exceptionally dangerous class of chemicals provides fertile ground for intense debate among groups with conflicting opinions on the benefits and risks of pesticide use (Damalas 2009). The effort to develop conclusive evidence of safety is ongoing, but absolute safety cannot be guaranteed. Great controversy exists surrounding the identification of many chronic effects of pesticide exposure, due to inconsistencies in research, contradictions among existing studies and data gaps. Therefore, it is difficult to demonstrate a link between pesticides and certain illnesses. Despite the confounding factors in these studies, it is clear now that the potential for serious impact on human health is of great concern. While the evidence may be limited, the hypotheses developed by the scientific community are of sufficient concern that they warrant further investigation.

4 Pathways of Pesticide Exposure

In general, exposure to pesticides depends on the duration, intensity and frequency of the contact between a pesticide and the body's portals of entry (i.e. mouth, nose or skin surface). The routes of exposure include ingestion, inhalation or dermal absorption (Fig. 1). The extent to which such contact is important depends on the relative concentration of the contaminant in the environmental media, the availability and the rate of contact with these media. It will also depend on the characteristics of the individual who is exposed. Thus, the level of exposure to a given pesticide varies widely among farmers, depending on a number of conditions, such as the method and rate of application, the available spraying equipment, the type of pesticide formulation, the environmental conditions (i.e. prevailing wind, temperature and humidity), the physical posture and individual constraints caused by variables such as height of crop, duration of work and the use of personal protective devices (gloves, face masks or other protective clothing). Social and cultural factors also influence decisions for using pesticides and the quantity to be used. For example, the 'absolutely clean crop' attitude and the 'quick kill' belief have resulted in many farmers using higher concentrations of pesticides than recommended. Access to technology may also affect exposure to pesticides. The technology available to small farmers for pesticide application has been often inappropriate; this often results in faulty sprayers, lack of protective equipment and absence of first-aid provisions (Forget 1991).

Farmers are directly exposed to pesticides when cultivating and harvesting crops in the fields, orchards and greenhouses, as well as when handling and transporting agricultural products in packing houses and storage facilities (Damalas and Eleftherohorinos 2011). Pesticide exposure mainly occurs during loading and spraying pesticides, disposal of used containers, care of pesticide sprayers and also by re-entering sprayed fields shortly after application. Re-entering sprayed fields shortly after application is of great importance because farmers may have substantial physical contact with plant parts that may contain pesticide residues. This is a common problem for farmers working in greenhouses, where re-entry may a pose a health hazard, especially after application of high rates of highly toxic pesticides that can easily penetrate the skin (Brouwer et al. 1992). Because many farmers work on several different crops, they are exposed to different types of pesticides throughout a given growing season. In some cases, exposure can occur from accidental pesticide spills or leakages from faulty sprayers. Exposure can also occur from misuse of personal protective equipment and appropriate clothing;

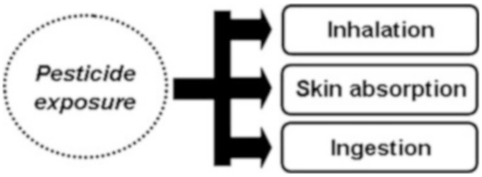

Fig. 1 Common pathways of pesticide exposure

unsafe working habits, such as drinking, eating and smoking while applying pesticides; and lack of common personal hygiene practices. Major exposures to pesticides are also faced by pest control operators, exterminators and workers applying pesticides to turf, lawns, roadways, railways and other applications (Damalas and Eleftherohorinos 2011).

5 Alternative Cropping Systems Less Dependent on Pesticides

To achieve the desirable goal of minimum use of pesticides, it is essential to shift towards alternative cropping systems that are less dependent on pesticides. This can be realized by focusing more on ecological approaches of crop protection based on available ecological knowledge. The use of advanced ecological knowledge by agronomists is fairly recent, especially at higher levels of the hierarchy of the agroecosystem. The purpose of this approach is to increase the strengths of natural systems to reinforce the natural processes of pest regulation and improve agricultural production. Ecologically sustainable systems of management of pests, diseases and weeds should include three elements: prevention, decision-making and control (Struik and Kropff 2003). Prevention can be optimized by maximizing the use of natural processes in the cropping system, suppressing the harmful organisms by promoting the development of antagonists, optimizing the diversity of the system and stimulating the recycling of internal resources (Ratnadass et al. 2012). Instruments and tools to achieve that may include (1) farm hygiene with an important element: the use of clean seed or planting material and maintaining temporal and spatial separation between crops of the same species (control of volunteers), (2) synergistic and antagonistic effects that occur in a cropping system, e.g. the suppression of diseases and pests by a designed system of non-chemical preventive methods, including the cultivation of catch crops and the use of soil amendments to enhance populations of antagonists, (3) cultural practices that support ecological processes, such as delayed planting to reduce weed growth or even prevent seed set, removal of crop residues or plant debris, management of soil organic matter and soil tillage strategies, (4) optimization of other inputs so that a crop can grow in a healthy condition that will assist it in withstanding attacks of pathogens or that will increase the damage threshold and (5) breeding for tolerance, e.g. by selecting for specific plant types that are more competitive against weeds or resistant to diseases, e.g. against blights.

If pest problems still do occur, it is crucial to make a wise decision on crop protection. Operational decision-making for pest control changed with the introduction of the damage threshold concept (Pedigo et al. 1986). Only in cases when the damage reaches or is expected to reach a certain economic limit, the application of a pesticide is advisable. Operational decisions, however, should include not only the immediate effects on the current crop, but also the mid-term and long-term effects. This is the case, for example, in weed control, where not only must the immediate competition between crop and weed plant be shifted in favour of the growth of the crop plant, but also the production of survival structures such as seeds, spores, tubers and so on must be taken into account, since they form a threat to future crops. Decision-making in weed control is in fact long-term population management. Therefore, the threshold concept does not hold for weed management and should be restricted to pests and diseases, which have to colonize the agro-ecosystem in every crop cycle. To allow rational decision-making, the severity of the infestation and its effects must be known quantitatively, e.g. on the basis of a decision support system. For soil-borne diseases, this quantitative information must be available before the growing season, for seed-borne pathogens at planting or sowing and for air-borne or water-borne pathogens early during the growing season. Knowledge of the severity of the infestation can help to predict crop yield losses (both in terms of quantity and quality), but also the multiplication potential of the harmful organisms (weed seed, nematodes, etc.). Criteria must be defined, based on objectives, planning and risk attitude of the farmer, to allow economic decisions to be made. At the same time, costs of control can be assessed quantitatively and the long-term damage of taking no control measures can be estimated. Efficacy of control methods in relation to the technology and the timing can also be determined, as well as the possible side effects of the application.

Control of pests, diseases or weeds may occur through different methods: mechanical, chemical, biological (through a one-to-one relation between pathogen and antagonist), ecological (involving a much wider range of harmful and beneficial organisms) or integrated (using different methods simultaneously). Whatever method is selected, control should take place with precision, high efficacy and preferably with as few chemicals as possible. Control techniques are rapidly developing; precision management is not far away. Optical techniques for weed control and control of pests and diseases that cause clearly visible above-ground plant symptoms may be available in the near future. Many pathogens cause discrete foci of disease within crops due to uneven survival or arrival of propagules or vectors or the patchy distribution of favourable microclimates within the field (West et al. 2003). Since diseases in fields are frequently patchy, sprays may be applied unnecessarily to disease-free areas. Disease control could be more efficient if disease patches within fields could be identified and spray applied only to the infected areas. Changing agronomic practices by enhancing the use of green manure crops, repellent crops, lure crops, trap crops and killing crops with a beneficial effect on soil life, use of mulches, development and use of techniques to enhance possible decline effects in crop rotations, rethinking the possibilities of re-introducing intercropping and enhancing use of proper crop management to reduce disease spread and increase tolerance, resistance, or recovery of a crop could be beneficial. Additionally, changing attitudes to pesticide use by stimulating mechanical control measures, developing and using warning systems, developing, maintaining and using decision support systems and improving existing systems of threshold levels of diseases could assist in reduction of pesticide use.

6 Rational Pesticide Use as Part of an IPM Regime

Pesticides will remain a tool for modern agriculture, and therefore, it is important to design strategies that will reduce pesticide impact (Ekström and Ekbom 2011). Rational pesticide use, considered as a 'subset' of Integrated Pest Management (IPM), is a pest control strategy that aims at maximum efficacy with minimum health and environmental impact as well as with minimum residues on food. IPM promotes the careful use of pesticides based on an informed decision-making process. This can be achieved by a minimum use of pesticides using accurate diagnosis of pest problems, optimized timing of interventions for maximum long-term efficiency and minimum pesticide use, selection of a pesticide with minimum impact on non-target organisms and the operator, improved application of the selected pesticide for maximum dose transfer to the biological target, reduced pesticide costs, minimum contamination of the environment and the operator and minimum residues on food crops (Dent 2005). IPM offers a toolbox of complementary crop protection solutions to address rising pressures by the uncontrolled use of pesticides (Birch et al. 2011). IPM aims for more sustainable solutions by using complementary technologies, with an effort to reduce selection pressure on single solution strategies, by creating synergistic interactions between IPM components. This system is compatible with organic and conventional cropping systems and is flexible, allowing regional adjustment. It reduces pests below economic thresholds utilizing key 'ecological services'. IPM can reduce pesticide use and increase yields of most of the major crops studied (Pretty and Bharucha 2015). A multisectoral approach was suggested to resolve pesticide-related problems, involving the government and the society and of course the pesticide industry, based on hazard reduction principles (Murray and Taylor 2001). These principles focus on (1) elimination of the most toxic products of pesticides, (2) introduction of safer crop protection products or alternative technologies of crop protection, (3) implementation of administrative controls, including training and education and (4) introduction of personal protective equipment (Sherwood et al. 2005).

Regarding the elimination of the most toxic products of pesticides, governments and the pesticide industry together need to begin by banning the most problematic products currently in use. Obviously, when the elimination of these pesticides is pursued, the immediate concern is for what will replace them. The pesticide industry and governments will need to take more aggressive steps to promote alternative products and practices to support the elimination of the most problematic pesticides. In the agricultural sector in the developing world, turnover among farm workers is high and increases pesticide hazards because training and skill development are undermined. Thus, alternative organizational changes, such as relying on a trained core of pesticide applicators and also providing appropriate exposure monitoring and control measures for pesticide users, are required. It is readily apparent in the developing world that personal protective equipment is neither effective nor appropriate in many settings. It is too expensive for many pesticide users and is completely unrealistic for hot tropical climates. The efforts of the industry to promote the use of locally developed PPE, such as adapting plastic bags as protective clothing, may further compound the problem. Research has demonstrated that PPE may give a false sense of protection under certain conditions, when in fact exposure to pesticides can be quite high even when PPE is used.

Companies try to expand their product portfolio by investing in the research of new chemical compounds with innovative modes of action. In response to increasing levels of regulation, the agrochemical industry aims at the development of environmentally friendly and sustainable plant protection products that are more targeted, less toxic, less harmful to beneficial organisms and effective while using smaller amounts of active ingredients. Product development also focuses on preventing any undesirable side effects of existing chemicals. For example, specialized application devices can reduce the amount of pesticides used as well as the risks for human health and the environment. In developing countries, appropriate package sizes are introduced for small-scale farmers. The industry tries to find threshold levels for optimal product use and the best practice in combining and handling agrochemicals.

7 Conclusions

The use of pesticides affects agricultural sustainability through several externalities. While usually beneficial, pesticides are risky by nature and misuse occurs regularly. Even when used correctly, some pesticides can harm the environment and non-target species. Thus, concerns about the sustainability of agricultural ecosystems lead to the need of developing technologies and practices that do not adversely impact environmental goods and services, are readily accessible, easy to implement and effective for farmers and improve food productivity. Because pesticides will likely remain a tool for modern agriculture, it is important to design strategies that will reduce the impact of pesticides. The use of advanced ecological knowledge at higher levels of the hierarchy of the agro-ecosystem, which means utilization of comprehensive information on the life cycles of pests and their interaction with the environment, maximization of the use of natural processes in the cropping system, rational decision-making, taking into account the severity of the infestation and introduction of the damage threshold concept, is gaining popularity. With respect to pest control, regardless of the method selected, it should be implemented with precision and preferably with as few chemicals as possible. To this end, Integrated Pest Management (IPM) is seen now as a way to achieve sustainable agricultural production with less damage to the environment. Agrochemical companies continue to expand their product portfolio by investing in the research of new chemical compounds with innovative modes of action, aiming at environmentally friendly and sustainable crop protection products that are effective with smaller amounts of active ingredients. Adaptive pest control based on IPM with rational use of pesticides and only as a last resort seems to be the most viable way forward for safe food production.

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Toxic Elements

Parvaneh Hajeb, Shahram Shakibazadeh, and Jens J. Sloth

Abstract Food is considered the main source of toxic element (arsenic, cadmium, lead, and mercury) exposure to humans, and they can cause major public health effects. In this chapter, we discuss the most important sources for toxic element in food and the foodstuffs which are significant contributors to human exposure. The occurrence of each element in food classes from different regions is presented. Some of the current toxicological risk assessments on toxic elements, the human health effect of each toxic element, and their contents in the food legislations are presented. An overview of analytical techniques and challenges for determination of toxic elements in food is also given.

1 Introduction

Trace elements are natural components of the Earth's crust, which are not degraded with time. Their amount in food depends on the natural content and on the condition under which the food is produced and processed. Some trace elements have nutritional functions to life (e.g., selenium, iodine, and zinc) and are essential to humans and animals to maintain a good health. Other trace elements, e.g., mercury (Hg), cadmium (Cd), and lead (Pb), have no nutritional properties and exposure to these elements can lead to severe adverse health effects. In 2010, the World Health Organization (WHO) listed the four elements (Hg, As, Cd, Pb) on their prioritized list of the top ten chemicals of major public health concern (WHO 2010). These elements and other elements with toxic properties are often named "heavy metals" and this term is well perceived in the general population although due to contradictory definitions in the literature and lack of coherent scientific basis, it is in general not an accepted term in the scientific community (Duffus 2002). An

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alternative term is "toxic elements" for which no general scientific consensus or exact definition exists either, but it seems to have a more general broad acceptance. Hence, in this chapter the term "toxic elements" will be used throughout and comprise the elements which exert toxicological adverse effects at a certain (acute or chronic) exposure level.

Humans are exposed to toxic elements via their diet. Hg, Cd, and Pb are usually the toxic elements, which have drawn most attention, with regard to dietary exposure, and emphasis in this chapter will be on these three "classical" toxic elements. However, also other toxic elements with relevance to food will be discussed, including arsenic (As). The most important sources for toxic elements in food will be discussed as well as the food classes, which are significant contributors to exposure. An overview of analytical methods and challenges for determination of toxic elements in food will be given. Furthermore, some of the current toxicological risk assessments on toxic elements, the human health effect of each toxic elements, and their contents in the food legislations are presented.

2 Sources of Toxic Elements in Food

Almost all elements present in the environment have been biogeochemically cycled since the formation of the Earth, and human activities have increased the rate of redistribution of metals between different environmental compartments, especially since the industrial revolution started (Garrett 2000). Hence, many different sources of both natural and anthropogenic character are responsible for the presence of toxic elements in the surrounding environment. Once released to the environment, the toxic elements are introduced via various routes into the food chain. Table 1 provides a list of toxic elements and their routes of exposure to selected foodstuffs.

Table 1 Examples on sources of toxic elements and the routes to food contamination

Toxic element	Sources (selected examples)
Mercury	• Natural sources (e.g., water surfaces, forest fires, volcanic activity) • Anthropogenic sources (e.g., agriculture, incineration, fossil fuels) • Bioacummulation in the aquatic environment (seafood)
Arsenic	• Weathering of minerals → groundwater → rice • Bioacummulation in the aquatic environment → marine food • Additive to animal feed, veterinary medicine → animals, manures → meat, crops • Pesticides, insecticides, herbicides, fungicides, rodenticides, algicides → soil → crops
Cadmium	• Atmospheric precipitation → soil → crops • Use of phosphate fertilizers → soil → crops • Contaminated feed → animals → meat
Lead	• Atmospheric precipitation of Pb containing dust from industrial processes → vegetables (especially with large surface area) • Use of Pb containing ammunition → animals → meat

2.1 Natural Sources

The natural sources include weathering of minerals, by which the elements are released to the surrounding environment and introduced into the natural food chains. The pH of the contact fluids and the environmental redox state are key factors influencing the weathering products. An example is the release of As from As-containing minerals, of which more than 200 exist (Mandal and Suzuki 2002). In As-rich areas throughout the world, high As concentrations (>50 μg/L) can be found in the groundwater. An area of great concern is the Ganges delta in Bangladesh where more than 100 million people are exposed to potentially lethal concentrations of As from the drinking water and from food prepared with As-contaminated water (Smith et al. 2000; Chowdhury et al. 1999). Furthermore, the similarity of ionic radius and electronegativity of the elements may provide an explanation for geochemical associations between elements; e.g., Cd has a similar electronegativity to zinc (Zn) and is often found to be associated with Zn in sulfide minerals. Volcanic activity, through eruption, gaseous fumaroles, and hot-spring activity, is another important natural source of toxic elements to the environment, which can provide significant sources of elements especially to the locals but also to a certain degree to the global environment. As a result, large variations in the Earth's surface geochemical composition can be found. Mount Pinatubo in the Philippines erupted in June 1991 and released 3–5 km^3 of rock containing approximately 100,000 tons of Pb, 1000 tons of Cd and 800 tons of Hg. Most of the material fell within 100 km of the volcano, but a significant amount reached the stratosphere and circles the globe with several weeks (Garrett 2000).

2.2 Anthropogenic Sources

Various human activities are responsible for the release of toxic elements to the environment. Release may occur from the start of the production procedure from mining of mineral ores or during production and use of the metal containing products as well as at the end of the chain when the products are disposed as waste. The main anthropogenic sources of toxic elements are agricultural activities including fertilizers, animal manures, and pesticides containing toxic elements. Other sources include metallurgical activities (e.g., mining, smelting, metal finishing), energy production and transportation, microelectronic products, and waste disposal (Bradl 2005). For instance, naturally occurring Cd levels are very low; i.e., Cd concentrations in non-contaminated soil range from 0.01 to 5 μg/g of soil (Kabata-Pendias 2001). The main source of Cd pollution is fertilizers produced from phosphate ores and inappropriate disposal of Cd containing wastes which both contributes to the Cd emission to the environment (Chen et al. 2007; Järup 2003).

2.2.1 Agricultural Activities

Soil amendments produced from sewage sludge, animal manure, and dredged sediments from harbors and rivers are also sources of toxic elements to the environment (Darby et al. 1986). Since soil, surface, and groundwaters are closely interconnected systems, metals introduced into soils can also affect aquifers or surface waters by infiltration. Furthermore, irrigation may also trigger release of toxic elements, exemplified by the release of toxic elements from aquifer water used for irrigation reported in West Bengal, India, and East Bangladesh. Due to the reduced water level, strata containing pyrite (FeS_2) were exposed to oxidation and As substitutes in part for Fe. Subsequently, As was released into the aquifer by oxidation and decomposition. In the aquifer, the toxic arsenite complex was formed, which heavily affects the local population (Bradl 2005; Nickson et al. 2000). Cd has a similar ionic radius to calcium and can consequently be found in calcium phosphates, which are used as fertilizers in agriculture. Phosphatic fertilizers also contain various amounts of Zn and other toxic elements (Adriano 2001). Hence, fertilizers may be an undesired route of toxic element release to agricultural soils and further to crops. Although metal-based pesticides are not used frequently anymore, their earlier application leads to increased accumulation of toxic elements, especially Hg, As, and Pb into soils and groundwater (Bradl 2005).

Land application of waste water in industrialized countries has led to toxic element (e.g., Cd, Zn, Cu, Ni, Pb) contamination in soils (McGrath et al. 1994). The application of municipal sewage sludge to agricultural soils as a fertilizer can be a significant source of Cd pollution in areas where it is used (Stacey et al. 2001). Biosolids are sewage sludge, animal wastes, municipal solid waste, and some industrial wastes such as paper pulp sludge. They are used for soil enhancement due to their increased content in nutrients and organic matter. However, biosolids may contain not only nutritional elements but also toxic elements. The main toxic elements of concern in sewage sludge are As, Cd, Pb, and Hg (Adriano 2001). Animal wastes and manure can also potentially contaminate surface water and groundwater. Toxic element concentration in animal wastes depends on age and class of animal (cattle, swine, poultry, etc.), type of ration, housing type, and waste management practice (Adriano 2001).

2.2.2 Industrial Activities

Mining, coal combustion, effluent streams, and waste disposal are the most important industrial activities, which introduce toxic elements into the environment. However, nowadays contamination of ecosystems with toxic elements has been reduced considerably in many countries due to enhanced legislation concerning capture and handling of pollutants. The concentration of most metals occurring in mining ore deposits is usually low. Higher amounts of toxic elements are found in waste rocks, which usually are disposed to mine tailings or rock spoils (Bradl 2005).

Minerals usually weather in the tailing due to oxidizing conditions and produce acid mine drainage which mobilizes toxic elements such as Cd, As, Hg, and Pb from the waste rock. This mobilization can increase the exposure and lead to health problems through drinking and cooking with contaminated water and eating foodstuffs grown on soils influenced by irrigation with contaminated water. Gold mining is an example where Hg is released into the river water and the atmosphere resulting in severe bioaccumulation in the food web (Palapa and Maramis 2015; Hu et al. 2014).

The combustion of fossil fuels is another important source, which releases high amounts of toxic elements into the atmosphere (Miller and Srivastava 2000). Fly ash and flue gas desulfurization residues amount to more than 106 million tons in the USA yearly (Adriano 2001). The type and amount of toxic elements in coal residues depends on composition of the parent coal, conditions during combustion, efficiency of emission control devices, storage and handling of the by-products, and climate (Obernberger and Biedermannm 1998). For example, high combustion temperature and a reducing atmosphere enhance the volatilization of Zn, Pb, and Cd. The toxic elements of highest concern in coal residues are As and Cd, particularly compared to their mobilization due to natural weathering (Bullock and Gregory 1991). Due to the growing human population and the increased demands for energy, release of toxic elements from these activities can be expected to increase in the future. Urban waste generation is another source of toxic elements. For instance, a main input of Cd and Pb comes from house dust and potable water (Zheng et al. 2013; Hogervorst et al. 2007). The pollution with toxic elements from automobile exhausts is a serious worldwide environmental issue. Automobile exhausts contaminate soils and plants with Pb, Zn, Cd, Cu, and Ni (Aslam et al. 2013). The use of waste incinerators for the thermal treatment of solid waste is considered the main source of atmospheric Pb and Hg in many cities (Chillrud et al. 1999). Solid wastes from industrial activities such as energy generation and municipal solid waste (e.g., batteries, tires, appliances, junked automobiles) are also important sources of toxic elements. Such wastes are usually deposited at sites where it potentially may come in contact with groundwater or can be released to the environment after being burned in open fires.

3 Occurrence of Toxic Elements in Food and Dietary Exposure

The concentration of the toxic elements in food varies widely depending on element–foodstuffs combination. In general, the levels typically range from the low ppb (μg/kg) to ppm (mg/kg) range. Figure 1 shows some examples of food items, where elevated contents of toxic elements typically have been reported. The reason for the elevated levels may be due to natural/biological causes, i.e., the particular food item has a capability of accumulating the element or contamination by a man-made source, i.e., use of cadmium-contaminated fertilizers. The examples will be discussed further in the text later. There have been several publications

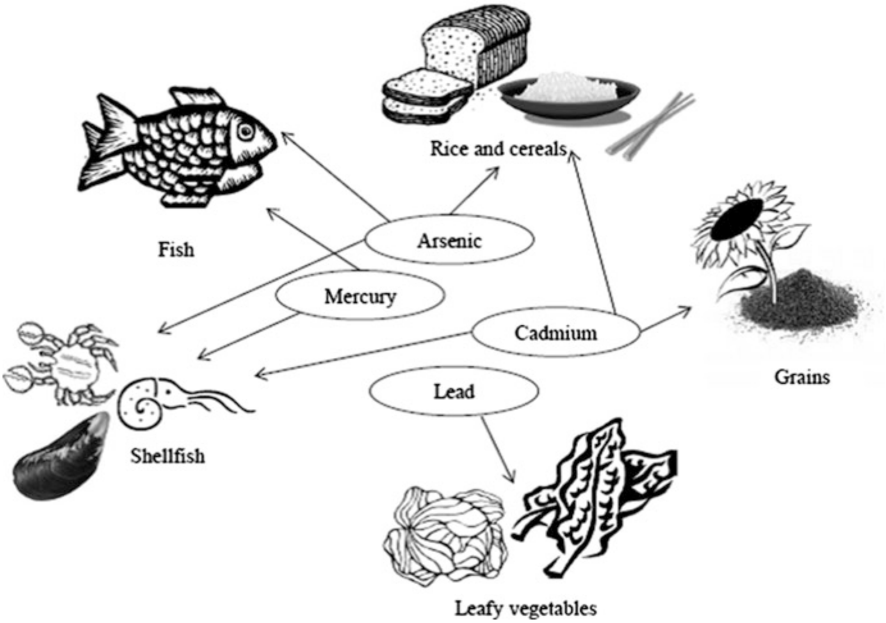

Fig. 1 Selected examples of foodstuff with links to toxic elements which have been reported at significant levels in them

including reviews and reports about occurrence and dietary exposure of toxic elements in foods. In this chapter, the focus will be on foodstuffs which are the main contributors for the dietary exposure to toxic elements.

In several regions around the world, farms and cropland are irrigated with wastewater. Among crops, rice has been of special concern due to its capacity to absorb Cd and As. Many studies (Zavala and Duxbury 2008; Chaney et al. 2004) have reported the ability of rice to accumulate soil Cd and As in grains and exclude Fe, Zn, and Ca. Rice is mainly produced in Asia; China, India, Indonesia, and Bangladesh account for almost 70 % of the global rice production (Statista 2013). Rice is consumed as a staple food in many regions of world; therefore, it contributes a main part to the total daily food intake. In some places, rice contains As levels of tenfold higher than other cereal crops (Zavala and Duxbury 2008). The situation is worse when rice is cooked with water containing elevated levels of As and Cd (Roychowdhury 2008; Ackerman et al. 2005; Laparra et al. 2005; Bae et al. 2002). The study by Torres-Escribano et al. (2008) showed that after cooking, rice retained between 45 and 107 % of the As added to the cooking water. Studies also showed that unpolished and brown rice types always contained higher amounts of Cd and As compared to white rice types (Peralta-Videa et al. 2009). Both inorganic and organic As compounds [monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA)] have been detected in samples of rice (Williams et al. 2005; Heitkemper et al. 2001), where the inorganic form is usually the predominant form (Azizur and

Hiroshi 2011; Meharg et al. 2009; Signes et al. 2008). However, it also depends on several factors such as the As concentration in soils, irrigation water, As bioavailability, rice cultivars, and country of origin, among others (Torres-Escribano et al. 2008; Meharg and Rahman 2003; Abedin et al. 2002). For instance, US-produced rice contains a larger percentage of DMA than rice from Bangladesh (Smith et al. 2006; Williams et al. 2005; Heitkemper et al. 2001).

Table 2 showing the levels of Cd and As in rice from different regions provides an overview on the concentration ranges of Cd and As in rice worldwide. Rice crops irrigated with untreated mining wastewater in China contained 0.24 μg/g Cd, illustrating the ability of rice to accumulate Cd. The dietary uptake of Cd was calculated to be 2.2 and 1.5 μg/kg bodyweight per day for a 60-kg adult and 40-kg child, respectively (Yang et al. 2006). Meharg et al. (2008) reported higher amounts of total As found in brown rice from Bangladesh paddy fields as compared to rice from USA and China. High levels of As have also been detected in rice sold in Taiwan (Williams et al. 2005), Vietnam, and Australia (Phuong et al. 1999). Rice from Spain contained on average 0.188 μg/g total As and the As intake of the

Table 2 Toxic element concentrations (μg/g) in rice from different regions

Arsenic	Cadmium	Region	Reference
0.03	–	Australia	Williams et al. (2006)
0.776	–	”	Phuong et al. (1999)
0.61	–	Bangladesh	Meharg et al. (2008)
1.83	–	”	Meharg and Rahman (2003)
0.11	–	Canada	Heitkemper et al. (2001)
0.36	–	China	Meharg et al. (2008)
–	0.24	”	Yang et al. (2006)
–	2.40	”	Jin et al. (2002)
0.82	–	”	Sun et al. (2008)
0.04	–	Egypt	Meharg et al. (2009)
0.28	–	France	”
0.07	–	India	”
0.15	–	Italy	”
0.19	–	Japan	”
–	0.77	Korea	Jung and Thornton (1997)
0.07	–	Philippines	Williams et al. (2006)
0.188	–	Spain	Torres-Escribano et al. (2008)
0.20	0.024	Sweden	Jorhem et al. (2008)
0.76	–	Taiwan	Williams et al. (2005)
0.14	–	Thailand	Meharg et al. (2009)
0.44	–	USA	Meharg et al. (2008)
0.25	–	”	”
0.697	–	Vietnam	Phuong et al. (1999)
0.21	–	”	”
0.33	–	West Bengal (India)	Roychowdhury et al. (2002)

Spanish population from rice consumption was estimated at 1.23 μg/kg body weight/day (Torres-Escribano et al. 2008). A survey on As, Cd, and Pb in different types of rice in the Swedish market (in 2001–2003) found elevated levels of As (0.2 μg/g), Cd (0.024 μg/g), and Pb (0.004 μg/g) (Jorhem et al. 2008). Meharg et al. (2009) provided an extensive data set of total As in rice samples from ten countries. Samples from Egypt (0.04 μg/g) and India (0.07 μg/g) had the lowest As levels, while the rice from the USA (0.25 μg/g) and France (0.28 μg/g) had the highest levels. Daily intake of total As was estimated at 38.6, 59.2, and 280 μg/kg BW for American males, Canadian males, and Japanese females, respectively (Roychowdhury et al. 2002). Total diet studies showed the variability of As intake in different countries. In some countries such as Czech Republic, the USA, and Canada, it was as low as 20, 38.6, and 9.2 μg/day and as high as 245 and 345 μg/day for Spanish and Japanese population. In most of countries, the highest contribution to the intake of As is from rice and seafood products (Roychowdhury et al. 2002; Devesa et al. 2001; Herce-Pagliai et al. 1999; NIPH 1998). In other terrestrial organisms, except for rice, As content does generally not vary too much and in most cases does not exceed 0.02 μg/g (Heitkemper et al. 2009; Jorhem et al. 2008; Goessler and Kuehnelt 2003).

Plants are the main dietary source of Cd; more than 70 % of the human Cd uptake comes from vegetables (Chen et al. 2012; Jorhem et al. 2008; Lin et al. 2004; Gorbunov et al. 2003; Shimbo et al. 2001; Jung and Thornton 1997). A considerable amount of Cd (0.9–2.5 μg/g) has been detected in mushrooms from the eastern Black Sea (Tuzen et al. 2007). In contrast, fish and seafood usually only contain trace levels of Cd (Castro-González and Méndez-Armenta 2008). Cd content of rice grains was found 2.40 μg/g in China (Jin et al. 2002) and 0.77 μg/g in Korea (Jung and Thornton 1997). In plants, Hg and Pb are kept in roots, which reduce their bioaccumulation risk in humans (Chary et al. 2008).

Lead enters the human diet through various ways of food production, food processing, food transport and marketing, and food handling post-market. Generally, rootstalk vegetables (radish, carrot, and potato) tend to absorb higher levels of Pb from soil to edible parts than leafy vegetables (Luo et al. 2011; Gaw et al. 2008; Alexander et al. 2006). However, in regions with elevated atmospheric Pb pollution, leafy vegetables and plant produces are also main sources of Pb in food (De Temmerman et al. 2012; Li et al. 2012; Luo et al. 2009; Kabata-Pendias 2001). According to Ding et al. (2013), Pb concentration in edible parts of plants is significantly affected by plant genotype, soil type, and the interaction between these two factors. The variation of Pb concentration in different cultivars is governed by Pb absorption and the transfer of Pb from aerial to edible part. Consumption of lead-laced and canned beverages is also the major source of Pb to human. A study on Pb level in beverages from Nigeria reported Pb levels at 2.0–7.3 and 1.0–92.0 μg/L in canned and non-canned beverages, respectively, and the Pb level in 100 % of the canned beverages and 79.3 % of the non-canned beverages exceeded the maximum contaminant level (MCL) of 5 μg/L set by US EPA. The estimated intake of lead in three beverages was 34.29 μg/day

(Maduabuchi et al. 2006). Danish food monitoring program 2004–2011 also showed that the highest intake of Pb was from beverages (approximately 47 % of total Pb exposure). The estimated total lead exposure to Danish population (aged 4–75) was reported 15 μg/day (0.25 μg/kg bw/day) (DTU Food 2013).

Trace element uptake in fish occurs through food ingestion and water via the gills. Toxic elements are nonbiodegradable and they bio-concentrate in the fish tissue via metabolic and biosorption processes (Wicklund-Glynn 1991). Studies proved that fish has the tendency to bioaccumulate toxic elements especially in polluted environments (Kwok et al. 2014; Souza et al. 2013; Kaoud and El-Dahshan 2010). Metals are transported in fish body through blood and they are brought into contact with different organs and consequently accumulated in organs and tissues of the fish (Kalay and Canli 2000). Accumulation sites of each toxic element in fish vary with route of uptake (i.e., food or water) and also with the intensity and duration of exposure (Reinfelder et al. 1998). Water chemistry, the ability of the organisms to depurate the metals, and the route of metals intake were identified as the main bioaccumulation factors (Ciardullo et al. 2008). While Hg and As are relatively well absorbed from food and retained in fish body, foodborne Cd and Pb are poorly absorbed and accumulated in fish (Ciardullo et al. 2008; Alves and Wood 2006; Amlund et al. 2006; Sloth et al. 2005; Soeroes et al. 2005; Amlund and Berntssen 2004). According to previous studies, MeHg concentrations in fish increase with trophic level and almost all the Hg is in the form of MeHg in predatory fishes (Ciardullo et al. 2008; Amlund et al. 2007). MeHg is usually distributed evenly throughout the fish organs, whereas Hg, As, and Cd are higher in detoxifying organs (Ciardullo et al. 2008; Chowdhury et al. 2005; Baatrup and Danscher 1987). Fish is exposed to As almost exclusively through their diet. Arsenobetaine (AB) is the major water-soluble and nontoxic arsenical in fish feed products and it represented the predominant As species identified in fish muscles (Ciardullo et al. 2008; Amlund et al. 2006; Sloth et al. 2005; Soeroes et al. 2005; Shiomi et al. 1995).

A large number of studies have been carried out on toxic elements in fish and seafood in different countries. Table 3 shows selected examples of As, Cd, Pb, and Hg in fish and seafood products from different regions. Fish and seafood are considered as the major source of Hg exposure for humans. Hg contamination in fish and seafood is mainly in the form of organic Hg, especially methylmercury (MeHg) which forms more than 70 % of total Hg in predatory fish (Krystek and Ritsema 2004; Jures and Blanus 2003; Clarkson 1994). Carnivorous fishes such as tuna, swordfish, sharks, whales, and dolphins are reported to contain up to 6 μg/g of Hg (Pethybridge et al. 2010; Endo et al. 2008; Hueter et al. 1995). Seafood besides rice are also the main source of total As; however, the content of inorganic As in fish and seafood is generally low (<0.1 μg/g) (Julshamn et al. 2012; Muñoz et al. 2000). As content significantly varies for different marine organisms and species, it has been reported between 0.3 and 110 μg/g for different fish and seafood (Julshamn et al. 2012). Marine oils extracted from livers and other organs of fish and invertebrates have been stated to be “rich in As: from 3 to 46 μg/g oil

Table 3 Toxic element concentrations (μg/g) in fish and seafood from different regions

Fish/seafood	Arsenic	Cadmium	Lead	Mercury	Region	Reference
Marine fishes	–		–	0.01–0.49	Malaysia	Hajeb et al. (2009)
”	–	0.19–20.20	0.04–0.78	0.10–2.4	”	Agusa et al. (2007)
”	–	0.17–13.20	0.07–0.69	0.05–1.80	Cambodia	”
”	–	0.11–12.40	0.02–1.53	0.07–1.40	Indonesia	”
”	–	0.01–8.26	ND–1.92	0.05–0.44	Thailand	”
Freshwater fish	0.16	–	–	–	USA	Cragin et al. (1999)
Marine fish	2.36	–	–	–	”	”
Benthic fish	–	4.81	–	–	Tunisia	Barhoumi et al. (2009)
Fish	–	0.01–0.05	ND–1.18	0.07–1.56	Italy	Storelli (2008)
Crustaceans	–	0.02–0.04	ND–0.03	0.27–0.33	”	”
Cephalopod mollusks	–	0.18–0.59	ND–0.17	0.10–0.55	”	”
”	–	0.08–12.44	–	–	Atlantic Ocean	Bustamante et al. (1998)
Seafood	1.00–17.80	0.01–0.24	0.02–0.23	0.01–2.30	Spain	Martí-Cid et al. (2007)
Oyster	–	1.17–3.57	–	–	Canada	Lekhi et al. (2008)
”	–	0.5–3.18	–	–	”	Bendell and Feng (2009)
”	–	0.9–4.9	–	–	”	Kruzynski et al. (2002)
”	–	0.44–2.5	–	–	USA	USDA (2008)
”	–	1.64–2.49	–	–	Alaska	”

(Sele et al. 2012; Måge et al. 2005, 2006, 2007, 2008; Schmeisser 2005; Julshamn et al. 2004; Foran et al. 2003; Kołakowska et al. 2002; Lunde 1968). Studies also showed that oil from invertebrates and fatty fish, e.g., herring, mackerel, and capelin, contains higher levels of As compared to oil from leaner fish, such as plaice. Samples of Oysters collected from different parts of the USA and Canada during different years contained elevated levels of Cd (0.44–3.18 μg/g) (Bendell and Feng 2009; Lekhi et al. 2008; USDA 2008; Kruzynski et al. 2002). Barhoumi et al. (2009) reported levels of 4.81 μg Cd/g of benthic fish from Tunisia. Agusa et al. (2007) surveyed toxic elements in marine fishes from Southeast Asia countries including Cambodia, Indonesia, Malaysia, and Thailand.

Fish, crustaceans, and cephalopod mollusks from the Adriatic Sea were tested for content in toxic elements. Highest levels of Hg were detected in fish followed by cephalopods and crustaceans. Cd levels were the highest in cephalopods, followed by fish, and crustaceans. Pb was generally low in all the samples (Storelli 2008). Cephalopod mollusks are well known to concentrate high levels of Cd (Storelli 2008; Bustamante et al. 1998; Miramand and Bentley 1992; Miramand and Guary 1980). Martí-Cid et al. (2007) reported the highest levels of As in red mullet, Cd in clam mussel, Hg in swordfish, and Pb in salmon from Spain market (Table 3). Ikeda et al. (2000) investigated urban population exposure to Pb and Cd in east and southeast Asia. They surveyed two cities in Japan (Tokyo and Kyoto), two cities in Korea (Seoul and Pusan), four cities in China (Beijing, Jinan, Nanning, Xian, and Shanghai), Bangkok in Thailand, Kuala Lumpur in Malaysia, Manila in the Philippines, and Tainan in Taiwan. The mean Dietary intake of Pb was 7.0, 9.3, 11.3, 15.1, 19.5, 21.5, and 24.6 μg/day in Malaysia, Japan, the Philippines, Thailand, Taiwan, Korea, and China, respectively. The mean Dietary intake of Cd was 7.0, 8.7, 8.7, 9.7, 14.1, 20.9, and 32.0 μg/day in Thailand, Malaysia, China, Taiwan, the Philippines, Korea, and Japan, respectively.

4 Health Effects and International Risk Assessments of Toxic Elements

Food is an important pathway for toxic elements, especially in populations consuming contaminated foods. Excessive intake of some contaminants may occur in people who have especially high intakes of certain foods. Populations who limit their diet to locally grown products are especially at risk from environmental contamination, since toxic elements in their diet are not diluted by foodstuffs from other non-contaminated regions (Chary et al. 2008). It is well known that excessive intake of toxic elements can cause detrimental health effects.

The impact of toxic elements on human health greatly depends on the form of elements ingested. Elemental Hg (Hg^0) causes a broad series of deleterious symptoms when acutely or chronically ingested. Oxidation of lipophilic Hg^0 results in its accumulation in the brain and liver. However, food is the major source of organic Hg. The main toxic effects of MeHg are on the central nervous system (Guzzi and La Porta 2008). MeHg poisoning was first recognized in Minamata, Japan, around 1960s. Hundreds of fishermen and their families were severely poisoned by MeHg that bioaccumulated in fish as a result of release of Hg to the local environment from a local chemical plant (Futatsuka et al. 2000). Another well-known example of Hg poisoning was from the consumption of grain treated with organomercurial fungicides in Iraq in 1971 (Amin-Zaki et al. 1974). In both recorded cases of Hg poisoning in Japan and Iraq, there were many resulting deaths and the surviving population and their offspring displayed several symptoms of mercury intoxication, including mental retardation, cerebral palsy, muteness, and blindness. This was particularly observed in children exposed while in the fetal stage (Guzzi and La Porta 2008; Kondo 2000). The toxicity of Hg is explained by the strong attraction between Hg and sulfur. MeHg enters the tissue through changes to sulfur adducts (Horvat 2005). Hg–cysteines complexes can enter the endothelial cells of the blood–brain barrier. MeHg crosses the placental barrier and levels in fetal brains are 5–7 times higher than in maternal blood (Guzzi and La Porta 2008). Inorganic Hg induces fatigue, insomnia, weight loss, hyper salivation, renal dysfunction, and neurological disorders (Rooney 2014; Guzzi and La Porta 2008).

More than 100 different naturally occurring compounds of As have been identified and categorized into water-soluble and lipid-soluble arsenicals and organic and inorganic compounds (Petursdottir 2014; Francesconi 2010; Foster et al. 2005; Goessler and Kuehnelt 2003). The As compounds have varying toxic properties of the As compounds are very varying. While inorganic As is regarded as highly toxic, the simple methylated As compounds are considered as compounds of intermediate toxicity, and some organic compounds such as arsenobetaine are considered nontoxic (Sele et al. 2012; Donohue and Abernaty 1994; Shiomi 1994). Inorganic As species, As(III) and As(V), are also classified as carcinogens for humans (IARC 2012). They has been found to cause lungs, urinary, bladder, and skin cancers after long-term exposure at low doses, particularly in populations of areas with contaminated drinking water (Straif et al. 2009; EPA 2005). Epidemiological studies revealed that biomethylation of inorganic As contributes to inorganic As-induced carcinogenicity (Lindberg et al. 2008; Ahsan et al. 2007; McCarty et al. 2007). In contrast to the several studies on inorganic As, the human toxicology of most of the organoarsenic compounds is still unknown, mainly due to difficulties associated with isolation and analysis of these compounds (Schmeisser 2005). Upon ingestion of inorganic As, arsenate can be reduced to arsenite, which can then be further transformed through a series of reductive methylation and conjugation reactions, some of which involve reoxidation of trivalent to pentavalent As in the liver (Thomas 2007). Studies showed that some of the inorganic As metabolites, including the trivalent mono- and dimethylated arsenicals, exert higher cytotoxicity and genotoxicity than arsenite (Bartel et al. 2011; Ebert et al. 2011; Naranmandura et al. 2007; Schwerdtle et al. 2003; Mass et al. 2001; Petrick et al. 2000; Styblo et al. 2000). Although arsenobetaine is bioavailable to humans, it is not metabolized and is rapidly excreted unchanged in urine (Brown et al. 1990). Therefore, arsenobetaine is generally assumed to be not toxicological (Francesconi 2010; Ma and Le 1998). In contrast, arsenosugars are metabolized by humans to a multitude of arsenicmetabolites, which are subsequently excreted in the urine (Raml et al. 2009; Raml et al. 2005; Francesconi et al. 2002).

Epidemiologic studies have linked low-level Cd exposure with some adverse effects to almost every organ and tissue where Cd accumulates, including kidney, bone, and eye tissues (Satarug et al. 2010). Kidney damage has been identified as the major problem for patients chronically exposed to Cd (Barbier et al. 2005). Numerous studies have revealed adverse kidney effects at urinary Cd levels of less than 0.5 μg/g creatinine (Satarug and Moore 2004). Cd reaches the kidney in the form of Cd-metallothionein (Cd-MT). Cd-MT is filtrated in the glomerulus and subsequently reabsorbed in the proximal tubulus. It then remains in the tubulus cells and makes up for the major part of the Cd body burden (Svartengren et al. 1986). Long-term exposure to high-dose Cd causes Itai-itai disease, which is characterized by severely impaired tubular and glomerular function and generalized osteomalacia and osteoporosis that result in multiple bone fractures (Inaba et al. 2005; Kobayashi et al. 2002, 2006). Long-term exposure to low-dose Cd has been linked to tubular impairment with a loss of re-absorptive capacity for nutrients, vitamins, and minerals. These losses include zinc and copper bound to the metal binding protein metallothionein (MT), glucose, amino acids, phosphate, calcium, β2-MG, and retinol-binding protein (RBP) (IPCS 1992). The abnormal urinary excretion of low-molecular-weight proteins, calcium, amino acid, phosphate, and glucose observed in Cd-exposed individuals share some similarities with Fanconi's syndrome, a genetic disorder of renal tubular transport (Teeyakasem et al. 2007). Generally, the urinary Cd level reflects the body burden over long-term exposure before the development of kidney damage, and blood Cd is considered an indicator of recent exposure (IPCS 1992). Studies also revealed a dose response between urinary Cd level and an increased risk of prediabetes, diabetes and hypertension, peripheral artery disease (PAD), myocardial infarction, diminished lung function, periodontal disease, and age-related macular degeneration (AMD) (Arora et al. 2009; Wills et al. 2009; Eum et al. 2008; Lampe et al. 2008; Schutte et al. 2008; Navas-Acien et al. 2005; Schwartz et al. 2003). Studies also link Cd exposure to increased cancer incidence and IARC (International Agency for Research on Cancer) classified Cd as a human carcinogen group I (Godt et al. 2006). Epidemiological studies proved Cd to be a cause of prostate and renal cancer in humans (Il'yasova 2005; Sahmoun et al. 2005). For instance, in prospective studies in Japan and the USA, excess cancer mortality was found to be associated with exposure to Cd (Menke et al. 2009; Arisawa et al. 2007; Nishijo et al. 2006). Increased endometrial cancer risk was observed in a Swedish cohort among participants who consumed more than 15 μg/day of Cd, mainly from cereals and vegetables (Åkesson et al. 2008). These findings suggest a very large health burden associated with exposure to Cd at levels experienced by many populations worldwide.

Pb causes a range of adverse health effects in humans, beginning with very subtle effects in asymptomatic children, which include decreases in IQ and academic achievement and increases in a range of neurobehavioral problems such as attention and performance deficits, neuroelectrophysiological and social behavioral indices, immunotoxicity, cardiotoxicity, nephrotoxicity, and alterations in hematological indices. Higher levels of exposure produce additional signs and symptoms of Pb poisoning in both adults and children, such as anemia, chronic and acute Pb encephalopathy, and in certain cases added adverse effects on the kidney, cardiovascular effects, and continued, more severe neurotoxicity and immunotoxicity

(Mushak 2011). After Pb enters human body, it transfers in different pathways depending on its bioavailability and source. The body absorption of Pb mainly depends on the physical and chemical form, particle size, and the solubility of the specific compound. Age, sex, nutritional status, and genetic background are also important factors for Pb absorption to human body (ATSDR 1999; NRC 1993). Once Pb absorbed into the blood system, it has a mean biological half-life of about 10–12 days. The half-life is longer in children and in pregnant women because of bone remodeling (Brito et al. 2005; Manton et al. 2000). Pb from blood is incorporated into calcified tissues (e.g., bone and teeth), and it can remain for 10–30 years (O'Flaherty 1995; Rabinowitz 1991). Pb is slowly released from calcified tissue stores, depending on bone turnover rates, which are a function of the type of bone, whether compact (slow turnover) or trabecular (rapid turnover) (O'Flaherty 1995). Physiologic differences between children and adults are the main reason for the increased susceptibility of small children to the deleterious effects of Pb. In children, 70 % of Pb body burden is stored in bones and teeth, while this proportion is 94 % in adults (Barry 1981). Furthermore, the growth of children implies constant bone remodeling for skeletal development (O'Flaherty 1995). Therefore, Pb stored in bone is continually released back into the blood compartment. This process is called "endogenous contamination" (Gulson et al. 1996). It is especially significant for pregnant women due to increased bone remodeling during pregnancy (Rust et al. 1999). Pb is known to compete with calcium in the body, thereby affecting neurotransmitter release and heme synthesis (Papanikolaou et al. 2005). Organ systems affected by Pb include the nervous, hematological, and reproductive systems as well as the kidneys (Bellinger 2004; Needleman 2004). While adults absorb approximately 10–15 % of ingested Pb, infants and young children may absorb up to 50 % of the ingested quantity of Pb depending on nutritional status (Markowitz 2000; Philip and Gerson 1994).

5 Legislation on Toxic Elements in Food

Food safety is main concern worldwide. Toxic elements are among the major contaminants of foodstuffs. The fact that toxic elements are natural elements of foods provides a considerable dilemma for health authorities. On the one hand, they wish to protect human health from food containing too much toxic elements, while on the other hand, they may not wish to ban a food just because it naturally contains elevated metal concentrations. The outcome is usually a compromise in which naturally occurring metals appear to be treated moderately (Francesconi 2007). As a protection for human health, guidelines and regulations specifying maximum limits (MLs) of toxic elements in foods and tolerance intake levels have been set by several national and international authorities to limit dietary exposure to toxic elements. These regulations have been updated over many years based on new findings in toxicology and health effects of toxic elements. The major food safety authorities are Codex, European Commission (EC), Food and Agriculture Organization (FAO), World Health Organization (WHO), US Food and Drug Administration (FDA), Great Britain (GB), Food Standards Australia New Zealand (FSANZ), and other mainland food safety authorities. Each of these authorities has set different standards for the main four toxic elements (As, Cd, Pb, Hg) in foodstuffs. The leading international authorities are JECFA and EFSA. JECFA (The Joint FAO/WHO Codex Alimentarius Commission) is one of the main international authorities established to detail international food legislation and propose MLs for toxic elements in various food categories. JECFA serves as an independent scientific committee which performs risk assessments and provides advice to FAO, WHO, and the member countries of both organizations. The requests for scientific advice are for the main part channeled through the Codex Alimentarius Commission (CAC) in their work to develop international food standards and guidelines under the Joint FAO/WHO Food Standards Programme. The European Food Safety Authority (EFSA) is the agency of the European Union (EU) that provides independent scientific advice to member national authorities on existing and emerging risks in food safety and communicates on existing and emerging risks associated with the food chain. Table 4 provides an overview of the latest BMDLs (Benchmark dose lower confidence limit) and health-based guidance values [provisional tolerable monthly intake (PTMI), provisional tolerable weekly intake (PTWI), and tolerable weekly intake (TWI)] for the toxicological tolerable exposure established by JECFA and EFSA. These guidelines are amended based on the latest epidemiological assessments.

Table 4 Health-based guideline value for tolerance exposure established by JECFA and EFSA for toxic elements

Element	Body	Year	Type	Value
Inorganic arsenic	JECFA	2011a	$BMDL_{0.5}$	3 μg/kg bw/day
	EFSA	2009a	$BMDL_{01}$	0.3–8 μg/kg bw/day (lifetime risk)
Total cadmium	JECFA	2011b	PTMI	25 μg/kg bw/month
	EFSA	2009b	TWI	2.5 μg/kg bw/week
Total lead	JECFA	2011b	PTWI	Withdrawn, no no-effect level identified
	EFSA	2010	PTWI	Withdrawn, no no-effect level identified
			$BMDL_{01}$	0.50 μg/kg bw/day (developmental neurotoxicity)
			$BMDL_{01}$	1.50 μg/kg bw/day (effects on systolic blood pressure)
			$BMDL_{10}$	0.63 μg/kg bw/day (chronic kidney disease)
Inorganic mercury	JECFA	2011a	PTWI	4 μg/kg bw/week
	EFSA	2012	TWI	4 μg/kg bw/week
Methylmercury	JECFA	2004	PTWI	1.6 μg/kg bw/week
	EFSA	2012	TWI	1.3 μg/kg bw/week

Reproduced from DTU Food (2013)

6 Analytical Challenges for Determination of Toxic Elements in Foodstuffs

Figure 2 gives an overview of the various main steps in the analytical procedure for determination of toxic elements in foodstuffs. It is important that all steps in the procedure are controlled to ascertain a reliable result for the sample in question. It is of course highly important to avoid contamination of the sample in all the steps of the analytical procedure as well as during storage.

6.1 Sampling

Sampling is often an overlooked step in the analytical procedure, which has not been paid so much attention. It is important that the collected samples are representative of the parent original population. All procedures used for acquisition, reduction, and preservation of the sample may affect the reliability of the analytical result. It is also important to avoid contamination and analyte loss during handling and transport to the laboratory. Furthermore, a proper labeling of samples with all the needed information (e.g., sample type, sampling place, date, amount, etc.) is required to keep track on the sample throughout the whole procedure.

6.2 Sample Preparation

The basic requirement in the sample preparation step is to ensure a sufficient homogenization and representative subsample for further analysis. Usually, the samples are prepared in a usual way in the normal household and only the part intended for eating is subjected to analysis. Parts which are not intended for eating should be discarded from the sample, e.g., outer leaves, shell, skin, and bones. Furthermore, gross surface contamination like soil or rotten parts of plants should be removed. After preparation, the samples should be homogenized, e.g., by grinding or milling. Freeze drying of samples following milling to a fine powder is sometimes used to enable proper homogenization. Frozen food may be

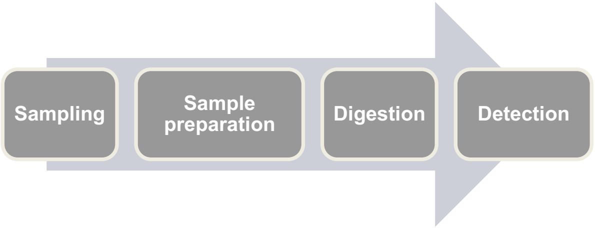

Fig. 2 Overview of the steps in an analytical procedure for toxic element detection

homogenized prior to defrosting and loss of liquid in the defrosting stage should be avoided. For some samples (e.g., dry samples), it may be beneficial to add a known amount of water to aid the homogenization process. Any equipment that comes into direct contact with the sample should be properly cleaned with, e.g., detergent and hot water followed by rinsing with purified water. From the final homogenate, representative subsamples can be taken for further analysis. If storage of the (sub) samples is needed, it must be carried out in such a way that the composition does not change, e.g., by drying, evaporative loss, or spoilage. For most samples, it is advisable to preserve samples under cooled conditions.

6.3 Digestion

Prior to the determination of the elements, the analytes in the sample have to be brought into solution. The composition of foodstuffs may vary greatly with varying proportions of fat, proteins, and carbohydrates as the main components and in addition the foodstuffs contain a varying amount of salt and different other minerals. Due to this large variation, proper precautions should be taken to ensure a complete digestion of the sample digestion prior to analysis. The two most commonly used digestion techniques include dry ashing and wet digestion. In the first method, the samples are dry ashed in crucibles at elevated temperatures (e.g., 450 °C) under a gradual increase in temperature in a furnace oven (usually starting from <100 °C and increasing at 50 °C/h). Usually, 10–20 g of test sample is weighed in and suitable ashing aids (e.g., $Mg(NO_3)_2$ or HNO_3) may be added to speed up the process. It is important to avoid loss of elements by volatilization due to too high temperature or too rapid temperature increase. Cross contamination between samples may happen since open vessels are used, but is usually not considered to be a major problem. Usually, the ashing is complete overnight, but several days may be required for complete ashing. Following ashing, the ash is dissolved in hydrochloric acid and the solution obtained evaporated to dryness. The final residue is redissolved in dilute nitric acid, and the contents of toxic elements can then be determined. Wet digestion using strong acids is another main technique for bringing food samples into solution. The predominant acid used is HNO_3, either alone or in combination with H_2O_2. The digestion may be done in closed vessels made of plastic or glass/quartz contained in steel cylinders and heated under pressure in an autoclave or another heating device. However, the dominating technique nowadays is digestion in closed vessels (e.g., quartz or PTFE) and heating under pressure by means of microwave irradiation. Both volatile and more refractory elements can be analyzed in the digests. The technique provides highly reproducible results; however, only small test portions (typically <0.5 g dry matter) are used, which may result in homogeneity problems for certain food samples. Table 5 presents the advantages and disadvantages of the two commonly used digestion method.

Table 5 Advantages and disadvantages of different digestion methods

	Advantages	Disadvantages
Dry ashing	Large test sample sizes Reduced limits of detection Less problem with inhomogeneity	Contamination problems Long durations (up to several days) Volatilization of analytes
	High sample throughput with little sample manipulation	
Wet digestion	Low risk of contamination Short time required (typically <1 h)	Large dilution factors Higher limit of detection
	Good reproducibility between replicates	Small sample test portions Inhomogeneity problems

Table 6 Features of atomic spectrometry techniques

Technique	Elements	LOD range	Advantages	Disadvantages
ICP-MS	Most elements (both metals and nonmetals)	ppt	Rapid, sensitive, multielement, wide dynamic range, good control of interferences	Limited total dissolved solid tolerance
ICP-OES	Most metals and some nonmetals	mid ppb to mid ppm	Rapid, multielement, high tolerance for total dissolved solids	Complex interferences, relatively poor sensitivity
ET-AAS	Many elements (commonly Pb, Cd, As, Se, Ni, Cu, Co)	ppt	Sensitive, few interferences	Single element technique, limited dynamic range
HG-AAS	Hydride-forming elements (As, Se, Tl, Pb, Bi, Sb, Te)	ppt to ppb	Sensitive, few interferences	Single element technique, slow, complex
CV-AAS	Hg	ppt	Sensitive, simple, few interferences	Single element technique, slow

Reproduced from Agilent (2005)

6.4 Detection

6.4.1 Total Content of Toxic Elements

There are several different detection techniques available for the determination of total content of toxic elements. The most commonly used are techniques based on atomic absorption spectrometry (AAS techniques) or inductively coupled plasma (ICP techniques). Table 6 shows a comparison of different detection techniques for toxic element determination. Information is provided about commonly detected elements, limit of detection (LOD) range, as well as the advantages and disadvantages of the different approaches.

In Atomic Absorption Spectroscopy (AAS), the determination of elements is based on their absorption of light at element-specific wavelengths by free atoms in a gaseous phase. More than 70 different elements can be determined by this technique. The quantification relies on Lambert–Beer law, which describes the relationship between analyte concentration and absorbance. A disadvantage of the AAS technique is the nonlinearity of the calibration curves when absorbance becomes higher than 0.5–1. Several different atomizers exist. The oldest and most simple setup is the flame AAS (F-AAS), where an acetylene-air flame at 2300 °C is used. The liquid sample is aspirated by a nebulizer and the aerosol and sent to the flame via a spray chamber, where the analytes are atomized and ionized. Electrothermal atomizers (ET-AAS) use graphite furnaces, where the sample is placed (typically 10–50 µL or 1 mg), and then subjected to a temperature program. The sensitivity for ET-AAS is typically 2–3 orders of magnitude better than FAAS. For the hydride-forming elements (e.g., As, Se, Sb), the use of hydride-generation AAS (HG-AAS) will enhance the sensitivity by 1–2 orders of magnitude compared to alternative methods. The gaseous hydrides are formed by reaction with sodium borohydride and swept into the atomization chamber by an inert gas. The gaseous analytes are measured by absorption or emission spectrometry. For mercury, the Cold-vapor technique (CV-AAS) may be used for enhanced sensitivity, due to the high vapor pressure of mercury at ambient temperature. In this approach, mercury compounds are converted to Hg^{2+} ions by oxidation followed by a reduction step to Hg^0 with tin(II)chloride.

There are two forms of instrumental techniques based on inductively coupled plasma—namely ICP-OES (coupling to an optical emission spectrometer) and ICP-MS (coupling to a mass spectrometer). In the ICP, argon gas is ionized in an intense electromagnetic field and a stable, high-temperature plasma of about 7000–10,000 K is generated as a result of the inelastic collisions created between the neutral argon atoms and charged particles. In ICP-OES, the argon plasma is used to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element. The intensity of this emission is indicative of the concentration of the element within the sample. As detector in ICP-OES instruments, photomultipliers have been used to measure the light intensity at element-specific wavelengths. In more modern units, an array of semiconductor photodetectors such as charge-coupled devices (CCDs) has been used. In instruments using these detector arrays, the intensities of all wavelengths (within the system's range) can be measured simultaneously, allowing the instrument to analyze for the elements to which the unit is sensitive all at once. Consequently, samples can be analyzed very quickly. In ICP-MS, the argon plasma is used to atomize and ionize the isotopes of the elements, which then can be determined according to their mass in the mass spectrometer. The sample solution is introduced via a peristaltic pump to a nebulizer, which forms an aerosol in the spray chamber. Here the larger droplets are discarded and only the smaller droplets are sent to the ICP via the torch. In the interface region, a rotary pump makes a vacuum and the atomized and ionized elements are drawn through the sample and skimmer cones. In the following section, several lenses are responsible for focusing of the ion beam. The quadrupole acts as a mass filter, which allows only the isotopes with a preselected mass-to-charge ratio (m/z) to reach the detector. The detector is most often an electron multiplier, which means that it can generate a measurable signal

Table 7 Comparison of analytical performance of atomic analysis methods

	FAAS	ETAAS	ICPOES	ICPMS
LOD (ng/g)	10–1000	0.01–1	0.1–10	0.001–0.1
Linear range	10^2	10^2	10^5	10^8
Precision				
– Short term (5–10 min)	0.1–1%	0.5–5%	0.1–2%	0.5–2%
– Long term (hours)	1–10%	1–10%	1–5%	<5%
Interferences				
– Spectral	Very few	Very few	Many	Few
– Chemical	Many	Many	Very few	Some
– Mass	–	–	–	Many
Sample throughput	10–15 s/ element	3–4 min/ element	6–60 elements/ min	All elements/ 2–5 min
Sample volume	Large	Very small	Medium	Medium

pulse from the impact of a single ion. Table 7 shows a comparison of various typical performance characteristics for atomic analysis method as well as indication of sample throughput and sample volume. However, there are large differences between various instrument models and the figures also depend on the application.

6.4.2 Toxic Element Speciation

The toxicity of elements varies a lot depending on their chemical forms, and for food safety evaluations, it is important to be able to analytically distinguish between the different chemical forms. Oxidation state of the elements is one of the reasons for their differential toxicity, for instance, the case of Cr(VI) against Cr(III). Alkylation grade is also an important toxicity issue, for instance, trialkyltins with respect to di- or monoalkyltin, Hg(II), and MeHg (Gómez-Ariza et al. 2004). Speciation analyses include the study of different oxidation states of elements, stable species, or individual organometallic species, and stable or inert compounds (Gómez-Ariza et al. 2001). To determine the different forms of a particular element in a sample, a separation technique has to be coupled to a sensitive element-specific detector. In the standard setup, the AAS or ICP-MS can only determine the total amount of the elements. In order to be able to determine different element-containing compounds (element species), the AAS or ICP-MS can be coupled to various separation techniques. Liquid chromatography (LC), gas chromatography (GC), ion chromatography (IC), and capillary electrophoresis (CE) are the most popular separation techniques that are usually combined with ICP-MS, ICP-AES, AAS, or AES (Zhang and Zhang 2003). Comparison between the commonly used methods for toxic element speciation is shown in Table 8. Among the separation techniques, LC has been one of the most popular techniques for elemental speciation analysis (Rao and Talluri 2007; Cornelis et al. 2003). For hyphenated

Table 8 Comparison of analytical performance of the commonly used techniques for toxic element speciation

Technique	Principle	Type of analysis	Applications
LC	Repartition of the analyte between a stationary and a mobile liquid phase	Simultaneous multielement analysis	LC-ICP-MS LC-ICP-AES LC-AES, LC-AAS
GC	Repartition of the analyte between a stationary and a mobile gas phase	Simultaneous multielement analysis	GC-MS GC-AAS GC-AES
IC	LC technique which uses ion-exchange resins	Simultaneous multielement analysis	IC-ICP-MS IC-ICP-AES IC-AAS
CE	Differential migration of charged analytes along a capillary filled with a suitable conducting electrolyte	Simultaneous multielement analysis	CE-ICP-MS CE-MS

Reproduced from Morais et al. (2012)

techniques, it was required that the sample is pretreated to permit introduction on the instrumentation (Mishra et al. 2005). Such sample pretreatment often involve a number of operative steps, but, on the other hand, it is possible to achieve very high analyte enrichment in the sample through optimization of the treatment procedure. Most of the current methods of Hg, Pb, and As speciation analysis required complete (or partial) extraction of species, with or without previous defatting and cleanup of crude extracts, followed by chromatographic separation and element-selective detection (Karadjova et al. 2007). Application of specific complexing agents and solid-phase extractions has improved the selectivity of methods and lowered its limits of detection (Szyczewski et al. 2009).

7 Future Trends

Due to diverse toxicity of metal species, speciation analysis is required to provide a more reliable assessment of the health risk associated with food consumption, especially foodstaffs with higher toxic element contents. Improved knowledge about chemical structures, levels, bioavailability, and toxicity of the individual metal species is needed for a more comprehensive risk assessment of toxic elements in food. This knowledge will also be of importance for implementation of toxic element regulations of food. Currently, only the total concentration of some toxic elements is regulated and there is no specific legislation on element species. Detailed information about chemical structures is required for further studies of toxic element species in different food products. However, speciation of elements is still an analytical challenge due to unstable species and very low concentrations found in different matrices. Development of robust analytical techniques for the qualification and quantification of different metal species is currently the most basic research need. The effect of food processing and preparation on the stability of metal species has yet to be evaluated. Further studies on the mechanism and kinetics of transformations of toxic element compounds are required for the evaluation of their bioaccessibility, bioavailability, and toxicity in humans. Metals are endocrine disruptors (Rana 2014); studies on the possible additive, synergistic, or antagonistic effects on the endocrine system following exposure to a mixture of metals are lacking.

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Heterocyclic Amines

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Abstract Heterocyclic amines are the potential mutagens and carcinogens that are generally responsible for inducing several types of cancers and DNA damage after accumulation in the body. Formation of these carcinogenic compounds is linked with the meat products that are subjected to higher temperature during processing for longer periods of time. Detection and quantification of these compounds is a big challenge for the scientists. With the advancement in the technology, several reliable and comprehensive techniques have been developed to detect the presence of these mutagens. However, still there is a need to introduce some rapid and more precise techniques that can determine the actual concentrations and types of heterocyclic amines in the food samples. Additionally, more studies should be conducted to evaluate the potential of several antioxidant compounds that can control the quantity of heterocyclic amines without adversely affecting the organoleptic attributes of food products.

1 Introduction

Meat is an essential part of our diet and contains several important nutrients. Cooking of meat at higher temperatures results in the development of several carcinogenic compounds called heterocyclic aromatic amines (HAAs). Cooking of meat for longer duration also produces HAAs (Rahman et al. 2014). White meat

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is more prone to the production of HAAs during cooking as compared to the red meat (Augustsson et al. 1999). Level and quantity of HAAs is influenced by several factors like method of cooking, time of cooking, and cooking intensity. Consumption of HAAs is directly linked with the onset of cancer, but the risk can be reduced by adding different spices, fruit and vegetable extracts, and other antioxidants. Moreover, the formation of these carcinogenic compounds can also be controlled by adopting low-temperature cooking methods or by controlling the time factor. The chances of HAA production can also be minimized by marination before frying and by applying microwave pretreatment.

Professor Sugimura firstly discovered HAAs in 1977 in meat. Later on, 20 types of HAAs were discovered in cooked meat (Sugimura 1997). The concentration and production of HAAs depends on the meat type, temperature of cooking, duration, degree of browning, and method of cooking (Skog et al. 1998). Several studies confirmed that grilled, broiled, fried, roasted, and barbecued meat contains higher concentrations of HAAs (Jagerstad and Skog 2005) as compared to other methods.

Two main classes of HAAs are aminoimidazole-azaarenes (AIAs) and amino-carbolines (Jagerstad et al. 1998). AIAs are produced as a reaction between creatine, creatinine, and hexose during conventional cooking (150–300 °C), while aminocarbolines are formed due to pyrolytic reaction between proteins and amino acids at higher temperatures (Toribio et al. 2002).

HAAs are also classified as follows:

- Five-membered heterocyclic amines
- Six-membered heterocyclic amines

Five-membered heterocyclic amines contain a ring of five atoms. The cyclic structure of these compounds is composed of one nitrogen and four carbon atoms. Nicotine and pyrrole are the examples of such compounds. The structure of six-membered heterocyclic amines is very similar to benzene. The only difference is that nitrogen replaces carbon atom in the ring.

HAAs have a strong association with cancer development and need to be controlled by using various approaches. Level of HAAs can be controlled by evading direct contact of meat surface with flame, by microwave cooking, and by continuous flipping during the cooking process (Knize and Felton 2005). Moreover, different herbs, spices, fruit and vegetable extracts, and several synthetic anticarcinogenic compounds can also be used to reduce the formation of HAAs in meat products (Hala and Heba 2010).

Scientists have also studied the occurrence of HAAs in other foods and concluded that HAAs are not produced in significant quantities in other heat processed foods (Jagerstad and Skog 2005), so it can be stated that the presence of HAAs is limited to cooked meat products. Several studies concluded that HAA consumption leads toward cancer formation in human beings and animals (Sugimura et al. 2004). Cancer of colon, gastrointestinal tract cancer, prostate cancer, lung cancer, breast cancer, and liver cancer are most common types of cancers that develop as a result of meat consumption containing HAAs.

Meat is being extensively consumed in our society which is resulting in increased health risks. Various scientists are working to minimize HAA formation

Table 1 Chemical names, years of discovery, and detected quantities of few HAAs in beef

Chemical name	Abbreviation	Year discovered	Maximum quantity in ground beef (ng/g)
2-Amino-3methylimidazo [4,5-*f*] quinolone	IQ	1980	1.61
2-Amino-3,4-dimethylimidazo [4,5-*f*] quinoline	MeIQ	1980	1.71
2-Amino-3,8-dimethylimidazo [4,5-*f*] quinoxaline	MeIQx	1981	16.41
2-Amino-1-methyl-6-phenylimiazo [4,5-*b*] pyridine	PhIP	1986	68.58

during meat processing. This chapter provides an overview about the chemistry and formation of HAAs in meat. Additionally, health problems related to the consumption of HAAs will also be covered in this chapter including various types of cancers and mutagenic effects. Furthermore, attenuation of HAAs by using different techniques will also be discussed in detail. Table 1 presents the most common types of HAAs that are significant for inducing carcinogenesis after ingestion.

2 Formation of HAAs

Formation of HAAs is strongly related to the cooking temperature. Most commonly used meat processing methods like grilling and pan frying are mainly responsible for the production of these carcinogenic compounds. These compounds are highly stable to the high temperature so considerable amounts of these carcinogens are present in the final product even during the storage period (Skog et al. 1998). Principal types of HAAs like 2-amino-1-methyl-6-phenylimiazo [4,5-*b*] pyridine (PhIPs) are mostly found in the well-done cooked meat products and are strongly linked with the cancer development (Ito et al. 1991). These compounds are also reported in the products prepared at low temperature for a long time period because of the production of a large number of precursors during the processing (Skog et al. 1998). The mechanism involved behind the production of HAAs is that the muscle proteins react with the sugars at higher temperature which results in the development of these carcinogens as a further extension of Millard reaction (Cross and Sinha 2004). Figure 1 represents the basic reaction involved in the formation of PHIP in cooked meat.

3 Factor Effecting Levels of HAAs

Several factors are involved which have a strong relationship with the production level of HAAs in the cooked meat products. Level of HAA formation is linked with all these factors. Reports reveal that 2-amino-3-methylimidazo [4,5-*f*] quinolone

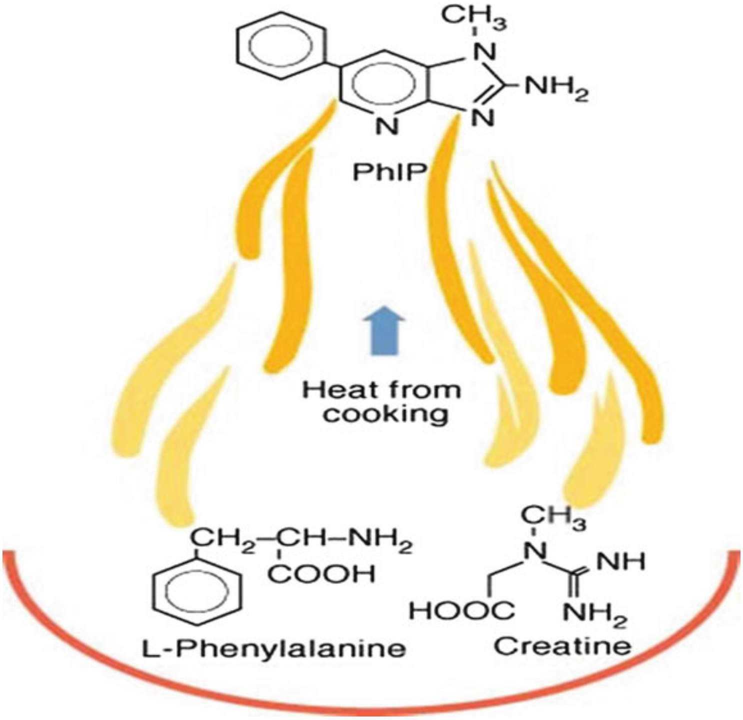

Fig. 1 Formation of HAAs in cooked meat

(IQ) and 2-amino-3,4-dimethylimidazo [4,5-*f*] quinolone (MeIQ) are mostly present in the meat products that are prepared at higher temperatures like roasted and barbecued products. The level of HAA production reaches up to several hundred ppb in fried beef extracts (Skog et al. 1998). The major factors that contribute to HAA production include:

- Water level
- pH range of meat
- Cooking temperature
- Time of heat contact
- Concentration and characteristics of precursors

3.1 Water Level of Meat

Moisture level of product plays an important role in the production of HAAs. Dry meat products like cured and smoked meat and dry sausages contain higher level of HAAs as compared to the products containing higher moisture levels after processing (Augustsson et al. 1999).

3.2 pH

Formation of HAAs is also affected by pH level of the final product. In general, the level of HAAs decreases with increase in pH. In a real sense, HAAs are not sensitive to pH variations, but the precursors of HAAs are significantly affected by changes in pH which ultimately affects the level of HAA formation. Increasing levels of pH modify the pathways of the formation of HAA precursor which leads to the lower production of HAAs (Singer and Reckhow 1999).

3.3 Cooking Temperature

Temperature is the most important factor that affects the production of HAAs. Formation of these carcinogenic compounds is high at higher temperatures as compared to the low-temperature cooking methods (Singer and Reckhow 1999).

3.4 Time

Time is another important factor that contributes to the level of HAA formation. HAAs are quite heat stable and can withstand for longer duration at elevated temperatures. Long provision of heat stabilizes these carcinogens and the concentration is increased (Singer and Reckhow 1999).

3.5 Concentration and Characteristics of Precursors

Level of HAAs also depends on the concentration of precursors. Additionally, characteristics and types of precursors also affect the concentration of precursors (Letterman et al. 1999). Therefore, controlling the level of HAA precursors is very important to effectively reduce the level of HAAs.

4 Current Issues

HAAs are possible carcinogenic compounds. This hypothesis has been confirmed by various studies in the past (Knize et al. 1994). Moreover, sedentary lifestyle has changed the eating habits of people and ready-to-cook, ready-to-eat, and processed foods are usually preferred by people nowadays (Skog et al. 1998). High-temperature cooking and some processing techniques are involved in the preparation of these industrial products that leads toward the production of HAAs in significant amount. It is obvious from the results of various epidemiological studies that the risk of different types of cancers has been enormously increasing by using such types of products, and certain effective control measures are needed to get rid of the potential harmful effects of the processed food (Persson et al. 2003).

According to a survey report of US National Toxicology Program (2011), uptake of HAAs ranges up to 17 ng/kg body weight which is strongly correlated with the consumption of meat products. Continuing Survey of Food Intakes by individuals (CSFII) also claimed that meat products are mainly responsible for the accumulation of HAAs in the body (Keating 2001). Several other studies also found a positive relationship in the consumption of meat and presence of HAAs in human body (Zheng and Lee 2009).

HAAs lead to the development of cancer by causing gene mutation and abnormal growth patterns of cells (Sugimura et al. 2004). These mutagenic compounds have been widely originated by high-temperature cooking methods such as frying, barbecuing, and broiling (Keating et al. 2000). Mostly cancer of colon and rectum is caused by consuming such type of processed meat that contains significant quantities of HAAs (Weisburger 2002). Usually 7–9 % colon cancer cases have been reported due to the intake of red meat containing HAAs.

Studies also confirmed a positive relationship between the meat intake and development of colorectal cancer (Lang et al. 1994). Rohrmann et al. (2009) found that increase in the uptake of HAAs up to 41.4 ng/day enhances the risk of colorectal cancer. Butler et al. (2003) confirmed a positive relation between accumulation of HAAs in the body by meat consumption and progression of colon cancer. Some researchers found out that intake of HAAs results in the development of prostate cancer (John et al. 2011). Sugimura et al. (2004) indicated that colorectal and prostate cancers are associated with the excessive intake of HAAs through diet in rodents and human. HAAs are also responsible for the onset of lung cancer (Lim et al. 2011) and breast cancer development (Nobuyuki et al. 1997). Additionally, studies also claimed that HAAs also develop colorectal adenoma which is a precursor of cancer. Some researchers showed that colon, prostate, and breast cancers have been developed with the chronic intake of HAAs (Archer et al. 2000).

Lagergren et al. (2000) reported that squamous cell carcinoma is associated with the intake of HAAs. Oreglia et al. (2001) observed a strong relation between excessive consumption of red meat and laryngeal cancer. It is estimated that chances of pancreatic cancer are higher in persons who prefer meat consumption over those who prefer fruits and vegetables (Anderson et al. 2002). Studies reveal that consumption of meat increases the risk of various types of cancers up to 50 % (Alaejos et al. 2007). Studies also link some other types of cancers with the consumption of HAAs such as liver and gastrointestinal tract cancer (Sugimura 1986).

HAAs also cause DNA mutation that leads towards the colon, prostate, and breast tumors (Archer et al. 2000). Some studies concluded that there is a positive relationship between HAA accumulation in the body and colon carcinogenesis that ultimately leads towards the development of esophagus adenocarcinomas. Some researchers claim that HAAs are not the only carcinogenic compounds present in the meat, but cooked meat also contains several other biogenic amines such as hydrocarbons, lipid peroxides, N-nitroso compounds, and other pro-oxidants that are also potential mutagens and carcinogens (Sachse et al. 2003).

5 Metabolism of HAAs and Factors Affecting Human HAA Intake

Well-done cooked meat contains a significant amount of HAAs like PhIP and IFP up to the level of 10 ng/g and MeIQx up to 3 ng/g. Moreover, grilled chicken fillets also have a large concentration of PhIP as compared to the homemade chicken products. Studies also conclude that susceptibility to carcinogenic activity of HAAs varies in human beings. A major contributor that affects the metabolism of HAAs is diet. Several studies have been conducted to understand the exact metabolism of HAAs in the human body, which were based on urinary metabolites examination followed by a diet containing well-done cooked meat. HAAs were quantified using solid-phase extraction and LC/MS from urine samples and interaction of food matrix with HAA metabolites as examined. Results concluded that diet pattern have a strong influence on different phases of metabolism in vitro, metabolite excretion rate, and metabolic products of a dietary carcinogen (Knize et al. 2002).

5.1 Dietary Intake and HAAs

Several epidemiological studies have confirmed the vital role of diet intake in the development of human cancer. Diet patterns of human beings and animals are significantly varied among individuals. So, it is of prime importance to study the relationship between dietary intake and chances of human cancer by quantifying the dietary exposures and by identifying the diet practices and habits of individuals that may increase or decrease the risk of cancer development. It is a very complex process and needs ultimate accuracy due to the great diversity of components that is a major critical factor in this regard (Case et al. 1954).

It is apparent from several studies that HAAs are potent carcinogens that are produced in meat products at elevated temperatures and the carcinogenicity of these compounds has also been confirmed through bio-efficacy studies. Furthermore, metabolism of cancer initiation has also been investigated by many researchers. The presence of HAAs has also been reported in meat products, but the onset of cancer varies on the basis of dietary activities of individuals. Concentration of these carcinogenic compounds also varies from nanograms to micrograms depending on cooking habits and dietary patterns (Vineis and Pirastu 1997).

5.2 Relationship of HAAs and Other Aromatic Compounds with Human Cancer

The relationship between HAA intake and cancer development was firstly hypothesized from occupational exposures in the chemical industry. According to a report, about 15 workers due to the exposure of 2-naphthylamine developed bladder cancer (Case et al. 1954). In another study, 27 workers were reported to show the risk of cancer who had been working in a distillation plant of ortho-toluidine and aniline for more than 10 years (Ward et al. 1991). So, risk of bladder cancer is quite high in human beings due to the exposure of HAAs.

However, dose of HAAs was not determined in the abovementioned investigation. Moreover, relationship between occupational exposure and dietary intake of HAAs was also not studied. In the abovementioned investigations, it was revealed that males were more susceptible to development of cancer as compared to the females. Gender differences are just beginning to be investigated in laboratory studies and need further investigation.

Epidemiologists have been investigating the relationship between meat consumption and possible cancer risks. It has also been confirmed that chances of cancer are more in persons who prefer well-done cooked meat as compared to those who consume meat products off and on. A study on the females confirmed the relationship between dose of HAAs and development of cancer. They pointed out that women who were keen to consume hamburgers were more prone to the development of breast cancer as compared to others. Other studies also reported that the risk of colorectal adenomas becomes double with increased well-done meat consumption (Probst-Hensch et al. 1997). Risk of lung cancer is also associated with the consumption of fried meat products containing significant level HAAs. Other studies, however, have shown either equivocal associations with well-done meat and cancers of the prostate gland or negative associations with cancers of the breast, colon, or rectum (Sinha et al. 1999a).

5.3 Prediction of HAAs with Dietary Questionnaires

Precise quantification and detection of dietary intake of HAAs is an essential part of risk assessment. One of the most appropriate methods for accurate quantification and risk determination of HAAs is to establish dietary exposure through questionnaires. This method involves the use of subject recall for the analysis of preparation methods, amount of meat consumed, and meat doneness. Meat doneness is sometimes measured by taking photographs. All these parameters are then compared with the standard databases of HAA content. Although this method is represented as a quite reliable and authentic approach to determine the level and toxicity of HAAs, not a single epidemiological investigation can be claimed as accurate and exact approach for the determination and quantification of these carcinogens because no biomarkers of dose have been used to validate the questionnaires in any of these studies (Sinha et al. 1999b).

5.4 HAA Urinary Metabolites Formation in Human

Activation or metabolism of HAAs in the human body can be determined by using different enzymes. Several enzymes have been discovered in human bodies which have the tendency to study the HAA metabolism and activity in human beings (Calabrese 1996). These enzymes determine the level of toxicity and activation of these carcinogenic compounds by showing variability in their expression, and these variations in the activity of enzymes are due to the variable diets and lifestyle patterns among people of different regions. Chances of activation of these carcinogenic and mutagenic compounds can be reduced by controlling the activity of respective enzymes responsible for bio-activation of HAAs.

One of the most common ways to monitor the metabolic activity, risk of cancer development, and detoxification mechanism of human body against HAAs is to measure the percentage of HAAs excreted through urination. Identification and quantification of metabolites that are produced as a result of recent exposure of meat products containing HAAs through urine examination and monitoring of metabolic activity of enzymes can be studied. First study was conducted by Lynch et al. (1992) to investigate the relationship between dietary intake of HAAs through hamburgers and urinary excretion of the unmetabolized parentage. Several other studies also confirmed the presence of different types of HAAs particularly PhIP in human urine, but the exact mechanism of bio-activation of these carcinogens and their metabolic pathways were not identified properly (Murray et al. 1993; Stillwell et al. 1997; Kidd et al. 1999).

Recently, scientists identified PhIP metabolites in human body and studied the metabolic pathways of these carcinogens in the body by investigating the PhIP metabolism after administrating [^{14}C]-labeled PhIP in the patients undergoing cancer surgery (Garner et al. 1999; Lang et al. 1999; Malfatti et al. 1999). They compared the results with the metabolic pathways of HAAs in rodents and dogs and surprised to see that the results of human studies were quite closer to dogs but not to rodents. Four different types of metabolites, namely, PhIPN2-glucuronide, PhIP-4-sulfate, N2-OH-PhIP-N2-OH-PhIP-N2-glucuronide, and N3-glucuronide, were identified in this study (Malfatti et al. 1999).

5.5 Biomarkers of HAAs: A Need for Accurate Identification

To study the exact and most reliable mechanism about the effect of HAAs exposure on human health, actual exposure of HAAs through diet must be determined. Measuring HAA metabolites by urine analysis is a very effective method to identify the exposure of HAAs to human body, but it only provides information about the percentage of excreted HAAs that had been explored during last 24 h. So, there is need to develop some more accurate methods that can quantify the chronic exposure of HAAs in the human body. The use of biomarkers can be a very helpful approach to study the HAA exposures over a long period of time. Hair has been investigated as a marker of PhIP exposure over the previous 6 months of exposure (Reistad et al. 1999).

Assessment of aflatoxin exposure is quite similar to the assessment of HAA exposures assessment and can be possible through proper information about contamination of food and amount eaten for exact dose determination. Biomarkers are available for the measurement of aflatoxin exposure, but without dietary questionnaire no relationship between blood serum levels of the AFB_1-albumin and dietary exposure would be possible (Turner et al. 1998). Use of biomarkers would only be helpful if dietary questionnaires are useful for the determination of HAA intake. Perhaps what is really needed is data regarding intake 20 years ago for individuals or perhaps the HAA intake during more sensitive adolescent years.

6 Recent Developments

The consumption of meat products having HAAs and other toxic biogenic amines leads toward several health issues, and there is a need to take certain control measures. These carcinogenic compounds cause serious health threats if incorporated in the biological system. To overcome this problem, several studies have been conducted for identification of these carcinogens and to adopt certain measures for the inhibition of threats regarding these compounds. In the light of the current knowledge on HAAs in the context of modern food chain with particular focus on meat products, it is important to look for its mitigation options, monitoring and testing methodologies of HAAs and identification of areas where further research and data collection are needed.

6.1 Analytical Methods for Identification of HAAs

Detection of HAAs is very important to ensure the quality and safety of meat products. Analytical methods for the determination of HAAs are discussed in the following lines.

6.1.1 Extraction Techniques

Extraction is a very important technique which is used before detection and quantification of HAAs. Some analytical methods need extraction process, while others do not require the extraction step for analysis. Extraction is considered as a matrix-dependent process as well as non-matrix dependent (Onal 2007). Extraction is carried out with the help of different acids like trichloroacetic acid, perchloric acid, hydrochloric acid, thiodipropionic acid, and methanesulfonic acid, with different solvents such as petroleum ether, methanol, and chloroform, and by filtration process. The complexity of the product is the major factor that determines the rate of extraction of HAAs.

6.1.2 Biological Methods

Consumers do not like to consume spoiled food intentionally, but it has to be noted that meat products containing HAAs and other carcinogenic compounds seem organoleptically normal even after consumption. Hence, toxic levels of HAAs cannot be detected with biological methods prior to consumption. This observation has been confirmed through several studies that higher concentrations of HAAs and other biogenic amines were acceptable organoleptically (Lopez-Sabater et al. 1996).

The analytical methods for the detection of HAAs in the food depend on detecting in vivo biological activity (AOAC 1995). However, these methods have been replaced by in vitro methods based on different chromatographic, fluorometric, and immunoassay techniques, etc.

6.2 Rapid and Semiquantitative Techniques

6.2.1 Immunoassays

Immunoassays for the detection of HAAs are commercially available. These commercially available assays are predominantly used for marine products, and minimum extraction is required for this technique. These assays also have varying levels of sensitivity with an approximate detection limit of 0.5 mg/kg. These methods are claimed as rapid and used for both qualitative and quantitative analyses. However, no commercial assays are available for the determination of other biogenic amines in foods. Main advantages of Immunoassays are the provision of semiquantitative data and to analyze multiple samples within 20 min to 2 h. This provides a suitable screening method for biogenic amines without additional equipment for quantitative assays.

6.2.2 Flow Injection Analysis

A flow injection analysis (FIA) system coupled with fluorimetric detection for the detection of HAAs has developed to provide rapid results. This method involves microfluidic manipulation of food samples that require a particular reagent for sample injection. After the injection of sample, the mixture is transported to the detector. During this transportation, several biochemical reactions take place that ensure the quantification of the target analyte by detecting and observing the absorbance peaks. Another advantage of this technique is that no pretreatment is required for the sample, but care must be taken to select the proper concentration of reagent and to ensure the desired flow rate of carrier–analyte mixture (Hungerford et al. 1990). In recent times, commercial FIA systems have also been tested for the screening of fishery products and are claimed to have satisfactory performance, with a detection limit from about 0.8 up to 340 mg/kg (Hungerford et al. 2001).

6.2.3 Colorimetric Techniques

Colorimetric techniques have also been developed which are based on the formation of complex between biogenic amines and copper ions. This analysis has a detection limit of 5 mg/kg and quantifies the biogenic amines by taking the absorbance at 496 nm with the help of spectrophotometer. The process also has the advantage that it takes only 45 min in analysis. Moreover, it is also a cost-effective method and does not need specialized laboratory equipment (Patange et al. 2005).

6.3 Quantitative Techniques for HAAs

6.3.1 Fluorometric Methods

Fluorometric assay has widely been used for the determination of HAAs, histamines, and other biogenic compounds in foods. This technique was considered as the most accurate quantitative technique before the development of chromatographic procedures. This method is still being extensively used in the USA, Australia, South Africa, and European countries. Fluorometric methods involve methanol extraction from the meat sample which is further subjected to the organic extraction. The desired compounds are purified by ion exchange and a fluorometric product is formed which is quantified by spectrofluorometer (Taylor et al. 1978). This method is not suitable for most classes of biogenic amines and has a very poor validation of data regarding the food materials other than fish. This procedure has a quantification limit of about 0.5 mg/kg. It also provides a wide range of analysis and has been successfully subjected to the inter-laboratory trails. However, this method requires specialized equipment. Synchronous fluorescence spectroscopy has also been used to quantify the amount of several HAAs in meat samples that were cooked under controlled condition (Sahar et al. 2010).

6.3.2 Chromatographic Techniques

Different chromatographic techniques have shown their potential for determination of HAAs and several other biogenic amines in foods. The most prominent techniques include thin-layer chromatography (TLC), capillary electrophoretic chromatography, gas chromatography (GC), and high-pressure liquid chromatography (HPLC). Among these techniques, HPLC is the most prominently used technique for quantifying HAAs. HPLC has been broadly used in Europe as a reference method for the determination of HAAs in fresh and processed meat products (Duflos et al. 1999). Various reagents used for derivatization include dansyl and dansyl chloride, fluoresceine, 9-fluorenylmethyl chloroformate, benzoly chloride, *o*-phthaladehyde (OPA), *N*-acetylcysteine, 2-mercaptoethanol, and naphthalene-2,3-dicarboxaldehyde. Dansyl chloride is most commonly used for pre-column derivatization, whereas OPA is the best option for post-column derivatization. Different detectors used for the analysis include fluorescence detector, UV detector, and electrochemical detectors. HPLC is very sensitive equipment and has a detection limit of 0.1 mg/kg. The technique also requires skills and specialized equipment. Since HPLC has the potential to identify all biogenic amines, it must be considered as an analytical method for Official Control.

Presently, HPLC is the only method which can detect and quantify the HAAs in cooked meat samples in a quite reliable and accurate way; therefore, it is the most reliable method for food analysis.

7 Inhibition of HAAs

Meat has become an integral part of diet, and consumption of well-done cooked meat products leads toward the exposure of HAAs that are associated with cancer development (Ito et al. 1991). However, concentration of these carcinogens can be controlled in meat products by adding several antioxidant-enriched compounds (Balogh et al. 2000). Carcinogenicity of these compounds can be reduced by adding soy protein concentrates in meat (Wang et al. 1982). Likewise, vitamin E is another antioxidant that plays a significant role to alleviate the production of HAAs in several meat products (Faulkner 1994). Tart cherry extract is also a suitable choice to attenuate the quantity of HAAs (Britt et al. 1998). Use of onion during the cooking of ground beef also reduces the amount of HAAs due to the presence of several antioxidant compounds in the onion (Shon et al. 2004).

Other commonly used meat flavorings like garlic, thyme, ginger, rosemary, black pepper, and red chili also possess antioxidant activity which is quite helpful in minimizing the production of HAAs. Several studies conclude that amount of HAAs can also be significantly controlled by using spices (Puangsombat et al. 2011). Moreover, different pretreatments like marination and microwave application are also good option for the attenuation of HAAs (Taylor et al. 1986; Nerurkar et al. 1999).

7.1 Ingredients Responsible for HAA Inhibition

Several types of natural and synthetic antioxidants are used to inhibit or control the formation of HAAs in the well-done cooked meat products. Additionally, extracts of different spices, fruits, and vegetables also contain a number of antioxidants that have shown the potential to attenuate the level of HAA formation. These ingredients can be incorporated either through feeding or can be mixed during the processing of meat products. A brief discussion of some important ingredients that can be used to prevent HAA formation is presented in the following section.

7.1.1 Antioxidants from Natural Sources

Use of natural antioxidants is quite beneficial to reduce the level of HAAs in meat cooked at high temperature. A number of studies have been conducted to evaluate the antioxidant potential of several natural ingredients that concluded that these natural antioxidants can significantly reduce the level of HAAs in meat products.

7.1.2 Antioxidant Potential of Phytogenic Extracts to Inhibit HAA Formation

Fruit and vegetable extracts contain many phytochemicals that can be used as anticarcinogenic compounds (Wightman 2004). Vitaglione and Fogliano (2004) studied the potential of tomatoes to reduce the formation of HAAs and reported that tomatoes have a variety of compounds that can considerably reduce the formation of HAAs, particularly IQs in beef. They further revealed that tomatoes contain carotenoids that have the potential to attenuate the level of IQ and MeIQx in meat samples up to 36 % and 11 %, respectively, at the rate of 1000 ppm. Moreover, flavonoid compounds, like quercetin, also reduced HAAs up to 67 % when used in the concentration of 10 ppm (Vitaglione and Fogliano 2004). Rauscher et al. (1998) used extracts of apricot, carrots, oranges, tomatoes, peppers, and Brussels sprouts for HAA inhibition and confirmed their antimutagenic potential due to the presence of several bioactive compounds like xanthophylls and carotenoids. Edenharder et al. (1995) also reported that fruit and vegetable extracts are quite helpful in the reduction of HAAs particularly IQ and MeIQ.

Cherry extracts are also claimed to control the production of HAAs in cooked meat samples. The anticancer activity of cherry extract is due to anthocyanin that has great potential to alleviate HAA level by showing its antioxidant activity (Vitaglione and Fogliano 2004). In addition, grapefruit extract suppresses the

PhIP contents in a considerable manner (Monika 2007). Edenharder et al. (2002) found out that blueberries, grapes, watermelon, spinach, blackberries, and parsley reduced the concentrations of HAAs in beef patties. Corn seeds also contain anthocyanin which reduced the mutagenicity caused by PhIP when used at the level of 5 % in rat studies (Nobuyuki et al. 1997). Likewise, cacao contains pro-anthocyanides which inhibit the carcinogenic effects of HAAs.

Vitamin C and α-tocopherol also have a great antioxidant potential and several studies confirmed the use of these natural antioxidants for the reduction of HAAs in meat products. A study conducted by Balogh et al. (2000) reported that the addition of vitamin E (1–10 %) in beef before frying can significantly reduce the level of HAA formation. The reason behind is that tocopherol inhibits the formation of free radicals which are actually among one of the precursors of HAAs. Moreover, Balogh et al. (2000) also applied vitamin E (1 % on the base of fat contents) on the surface of beef patties before frying and found excellent inhibition in HAA formation.

Zheng and Lee (2009) demonstrated that phenolic antioxidants like flavonoids also significantly reduced the formation of HAAs. Edenharder et al. (2002) found similar results when applied flavones on different meat products. Ellagic acid positively reduced the formation of some HAAs, especially MeIQx (Oguri et al. 1998). Weisburger et al. (1994) pointed out that epigallocatechin gallate (EGCG) suppressed the formation of HAAs. Kato et al. (1996) revealed that by using 0.5 % EGCG, HAAs could be reduced up to 35 %. Soy protein concentrates (SPC) contain chlorogenic acid which has the potential to reduce the carcinogenicity of HAAs. Wang et al. (1982) postulated that SPC significantly reduced the amount of HAAs when applied on beef patties during frying.

Tea extracts have polyphenolic compounds that have the capacity to lessen the quantity of HAAs in cooked meat products (Weisburger et al. 1994; Yen and Chen 1995). The mechanisms involved in the antimutagenic activity of tea are inhibition of NADPH cytochrome P450 reductase (Stavric et al. 1996) and electrophile scavenging. Stavric et al. (1996) used extracts of green tea, oolong, chamomile, and orange pekoe for the attenuation of HAAs and showed a significant reduction in meat samples treated with these antioxidants during the processing. Hala (2011) also studied the effect of green tea and olive oil on the production of HAAs and reported that combination of both ingredients showed better results to reduce the level of HAAs in grilled chicken. Furthermore, Monti et al. (2001) also stated the ability of olive oil to eliminate HAAs from the meat products.

7.1.3 Use of Spices and Meat Flavorings for HAAs Inhibition

Spices contain a variety of antioxidant substances that can be potentially used for the attenuation of HAAs in cooked beef (Vitaglione and Fogliano 2004). Balogh et al. (2000) studied the effect of rosemary in ground beef and observed that rosemary has the ability to reduce HAA formation in meat if mixed with ground beef before frying. Moreover, the antioxidant compounds of thyme such as thymol have also shown reduction in the HAA contents, more specifically IQs. Several other researchers have reported that rosemary oleoresin (Oguri et al. 1998), rosemary extracts (Balogh et al. 2000), and red and black pepper (Oz and Kaya 2011; Smith et al. 2008) are helpful in the reduction of HAAs. Puangsombat et al. (2011) found a decrease in HAA contents by using galangal, finger root, turmeric, and coriander seeds from 18.4 to 39.2 %. Onion and garlic showed their potential to control the mutagenic activity of HAAs in fried meat samples (Shin et al. 2002; Shon et al. 2004).

In addition to the abovementioned natural antioxidants, several other natural meat flavorings (clove, bay leaf, cinnamon, galangal, and red prickly ash) were also investigated to evaluate their inhibitory effects on HAA formation. Shun et al. (1996) also pointed out that naturally occurring sulfur-containing compounds present in garlic and onion have had positive influence on the attenuation of HAAs in boiled meat products.

7.1.4 Role of Marinades in HAA Reduction

Mutagenic activity HAAs in well-done cooked meat products can also be controlled by marination. Ahn and Grun (2006) dipped meat cuts in marinades containing different spices before frying and found a significant reduction in the level of HAAs in the samples after frying. Smith et al. (2008) observed similar findings when beef steaks are treated with marinades before grilling. Viegas et al. (2012) studied the influence of beer and wine marinades alone and in combination with meat flavorings like garlic, ginger, thyme, rosemary, and red chili to attenuate HAA formation in pan fried beef. They concluded that these marinades reduced HAA levels by 30–90 % in different combinations. Monika (2007) studied the effect of dipping beef in marinades containing oil and several other meat flavorings like garlic, lemon juice and onion and concluded that the level of HAAs was reduced up to 28.6 %, 14.6 %, and 31.2 %, respectively.

7.2 Inhibition of HAAs by Synthetic Antioxidants

With the concept of ease in the availability of synthetic antioxidants, scientists moved toward synthetic chemicals and investigated their anticarcinogenic activities induced by meat products in several studies. It has been reported through several studies that butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and tert-butylhydroquinone (TBHQ) have a great potential to reduce HAA production. Furthermore, BHA and PG can decrease the severity of IQ and MeIQx in a very effective manner (Kato et al. 1996; Weisburger et al. 1994).

7.3 Microwave Pretreatment

Microwave pretreatment is another effective way to reduce the carcinogenicity of cooked meat. Taylor et al. (1986) first used this treatment before frying the beef samples and postulated that HAA level can be effectively minimized by adopting these kinds of methods that use less time as compared to traditional cooking methods. Felton et al. (2000) also reported 95 % reduction in the concentration of HAAs by pretreating beef samples before final frying.

8 Future Challenges

Various analytical, quantitative, semiquantitative, and biological methods have been introduced to explore the assessment of HAAs and their health impacts, but due to a great diversity in the concentration of HAAs with processing environments, it is quite difficult to acquire an accurate estimation about these HAAs. To overcome this problem, different biomarkers have been investigated. With the help of these biomarkers, metabolism of two most important types of HAAs, namely, 2-amino-1-methyl-6-phenylimidazo [4,5-*b*] pyridine (PhIP) and 2-amino-3,8-dimethylimidazo [4,5-*f*] quinoxaline (MeIQx), is well characterized. Several human studies reveal that the approximate time for the excretion of HAAs is 24–48 h following a meal. A minute fraction of these carcinogens is excreted as parent compounds, whereas the rest of the portion is converted into several metabolites. Excretion of HAAs as parent compounds is referred as recent exposure of HAAs, while the pattern of formation and excretion of metabolites reflects the capacity of HAAs to activate or detoxify. The most suitable marker for N-hydroxylation capacity is glucuronide conjugates of *N*-hydroxy-PhIP and *N*-hydroxy-MeIQx. Recently, work is being done to evaluate the potential of 5-OH-PhIP as a marker for the reactive metabolite of PhIP, since it is responsible for the formation of this compound in addition to PhIP–DNA adducts. Additionally, blood protein adducts have been investigated as biomarkers to reflect the exposure of these carcinogens over some time. Furthermore, PhIP adducts have also been reported as biomarkers in meat-consuming people.

Still no biomarker is developed which can confidently confirm the relationship between dose, exposure time, and onset of disease. Urine analysis in different trials gives information only about the recent exposure of HAAs. However, there is need to determine certain metabolites which makes it possible to obtain evidence regarding the bio-activation and detoxification capacity of different bio-transforming enzymes in order to control the adverse effects of HAAs. These studies could be very helpful for the invention of certain reactive species of metabolites to prevent DNA damage and cancer formation in the target cells. Moreover, a recent idea about the use of different HAA markers is very attractive. These biomarkers still need validation to explore their role in humans and need improvement when it comes to the chemical analytical method.

8.1 Analytical Challenges

The exposure of HAAs up to nano- and microgram ranges to quantify the concentration of analyte at the rate of picogram per gram or per ml in complex biological matrices requires extensive efforts to develop more specific and sophisticated methods to determine the quantity of HAAs. A recent development in this regard is the introduction of multistage solvent and solid-phase extraction techniques for sample preparation (Kulp et al. 2000). Additionally, more specific extraction methods such as immuno-affinity and imprinting columns have also been introduced for the detection and quantification of HAAs (Frandsen et al. 2002). Apart from these sample-extraction and cleaning techniques, several chromatographic and spectrometric techniques (mass spectrometry) are also in the pipeline to investigate their potential for the detection of HAAs. In early studies, use of gas chromatography–mass spectrometry (GC–MS) was very common to quantify the HAAs; however, due to the polar nature of HAAs, there is need to derivatize the exocyclic amino group of HAAs prior to gas chromatography for more accurate results.

9 Conclusion

HAAs are considered as the potent mutagenic compounds that are associated with cooked meat products. Formation of these mutagens depends on several factors including cooking method, time and temperature of cooking, composition of meat, pH value, etc. Detection of HAAs has been carried out recently through several modern and more reliable techniques like HPLC, GC, ELISA, MS, and LC, but still there is need to conduct further research in this domain to evaluate the potential of new rapid and noninvasive techniques for the detection and quantification of HAAs.

Concentration of HAAs can be decreased in the meat products by reducing the time of cooking, modifying cooking temperature, adding different antioxidants of natural as well as synthetic origin, and applying certain pretreatments such as dipping in the marinades and microwave pretreatment. The main hitch with the use of synthetic antioxidants is their residual effects in the cooked meat product that can harm the biological system. Further research is needed to investigate the effect of several other natural antioxidants which have not been tried yet in this regard. Additionally, studies should be conducted to introduce low-temperature processing methods such as boiling, cook-in-bag technology, high-pressure processing, and the use of edible coatings for the attenuation of HAAs in meat and meat products.

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Mycotoxins in Food and Food Products: Current Status

Shahzad Zafar Iqbal, Jinap Selamat, and Agustin Ariño

Abstract Mycotoxins are naturally occurring, toxic secondary metabolites produced by different array of fungi. The name mycotoxin combines the Greek word mykes meaning "fungus" and the Latin word toxicum meaning "poison." The term secondary metabolites are the compounds that are dispensable. Thousands of fungal secondary metabolites have been discovered, but currently 450 classes of mycotoxins are identified and characterized. This chapter deals with important groups of mycotoxins, such as aflatoxins, ochratoxins A, Zearalenone, fumonisins, and patulin, their toxicity, and health hazards on humans.

1 Introduction

Currently, maintaining a safe global food and feed supply is a critical issue facing society. Natural contaminants, such as mycotoxins, pose a challenge since they are present in a wide range of food commodities and significantly differ in chemical structure and symptomatology in humans and animals following their exposure (Kendra and Dyer 2007). It has been reported that many important agricultural products, especially those rich in carbohydrates, are vulnerable to fungal growth (Chelkowski 1998).

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Mycotoxins are characterized as toxic metabolites produced by a diverse group of fungi that contaminate agricultural crops prior to harvest or during storage postharvest, and a wide range of food commodities can be contaminated upon exposure to these harmful substances (Zychowski et al. 2013). Mycotoxins are not only harmful to human and animal health but also responsible for significant economic losses especially in developing countries. These losses are shared by all participants along the chain like production animal/animal producers, grain handlers and distributors, processors of crops, and consumers (Rodrigues et al. 2011). Currently, more than 400 mycotoxins are identified and characterized; however, scientific attention is focused on those classes which are carcinogenic and or toxic (Iqbal et al. 2013). The exposure of mycotoxins in humans may result from consumption of plant-derived foods that are contaminated with toxins or the carryover of mycotoxins and their metabolites in animal products such as meat and eggs (CAST 2003) or direct exposure to air and dust containing toxins (Jarvis 2002). Previous studies have documented that toxigenic molds are known to produce one or more of these toxic secondary metabolites and not all molds are toxigenic and not all secondary metabolites from molds are toxic (Zain 2011). Generally, the potential target for mold growth and mycotoxin formation are the crops that are not stored according to good storage practices. Worldwide the temperate and tropical regions are most vulnerable to fungi or mycotoxins, depending on the species of fungi. Food commodities like cereals, dried fruit, nuts, cocoa, coffee, oil seeds, dried peas, beans, fruit, and spices are affected by mycotoxins. Mycotoxin-contaminated barley, cereals, and grapes used for the production of beer or wine can contaminate these beverages. Meat or animal origin products such as milk, eggs, and cheese as a result of eating contaminated feed also enter the human food chain (Turner et al. 2009). The important classes of mycotoxins of greatest public health and agro-economic significance include aflatoxins (AF), ochratoxins (OTA), zearalenone (ZEN), fumonisins (F), and Patulin (Iqbal et al. 2014b).

2 Toxicity of Mycotoxins

Studies have shown that mycotoxins can contaminate food and animal feed and animals exposed to contaminated feed, could cause acute toxicity as a result of a high-levels or chronic toxicity as a result of low-levels. The side effects on animals which consume feedstuff contaminated with mycotoxins include reduced feed intake, effect production and reproduction system, weight gain, and feed efficacy (Tsiplakou et al. 2014). Furthermore, mycotoxins in feedstuff can cause carcinogenesis, teratogenesis, and immune system suppression as a result of chronic toxicity even at low levels. The issue becomes serious when mycotoxins present in animal's feeds can be transferred to animal products mainly in milk and meat and used for human consumption (Iqbal et al. 2014b). The International Agency for

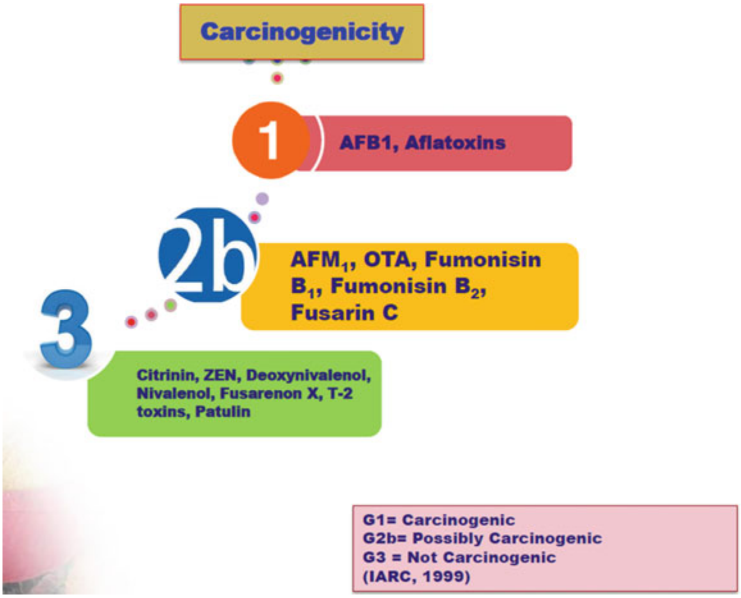

Fig. 1 The classification of mycotoxins on carcinogenicity level

Research on Cancer (IARC) has classified mycotoxins based on carcinogenicity as shown in Fig. 1.

3 Aflatoxins

In 1960, approximately 100,000 domestic turkeys (*Meleagris gallopavo*) and fewer pheasants and ducklings died in England from what was termed as "turkey X disease" (Blount 1961). Eventually, the link between the turkey feed, a Brazilian groundnut (peanut) meal, and turkey X disease was identified, with the causative agent being discovered and 2 years later named "aflatoxin" (Hendrickse 1997). Furthermore, aflatoxins (AFs) were shown to cause liver tumors in rainbow trout (Halver 1965). Since then, extensive research has been focused to determine the effects of aflatoxin on domestic animals, fish, and humans.

AFs are highly toxic, mutagenic, teratogenic, and carcinogenic compounds, produced as secondary metabolites by fungi belonging to several *Aspergillus* species, mainly *A. flavus* and *A. parasiticus* (Iqbal et al. 2014a). The difference between primary and secondary metabolites can be defined as "the chemical components of living organisms that are vital for their normal functioning, while secondary metabolites are the compounds which are dispensable". AFs have a high presence in tropical and subtropical regions where humidity and temperature conditions are optimal for their production. The name AFs has been derived from

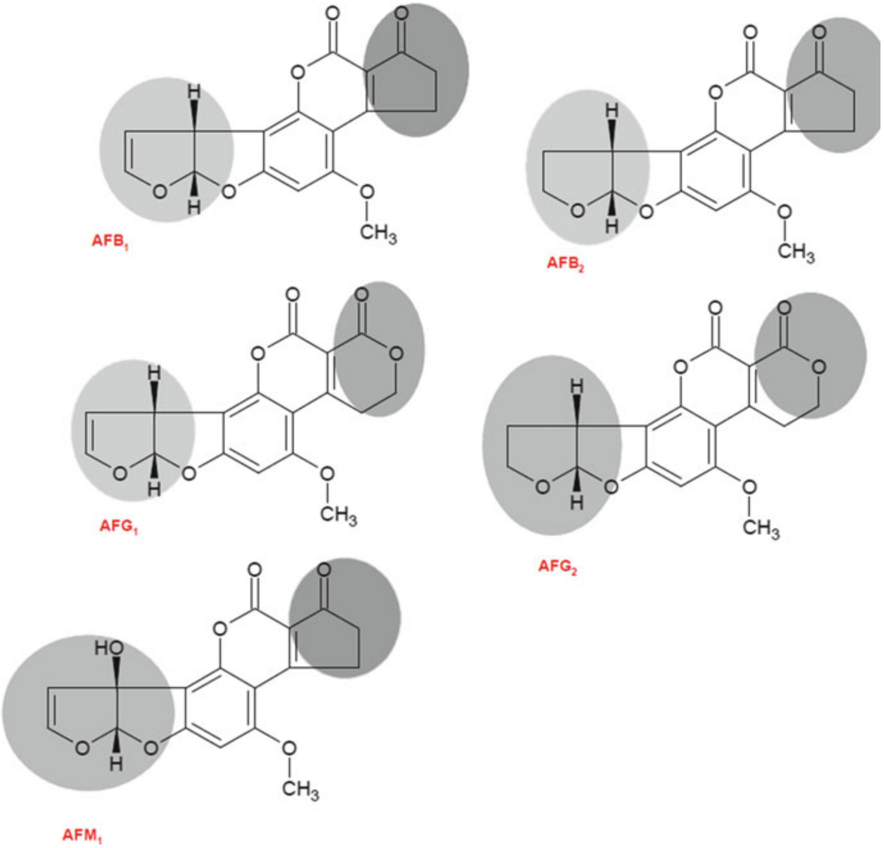

Fig. 2 Structures of some important aflatoxins

the combination of “a” for the *Aspergillus* genus and “fla” for the species *flavus* and toxin meaning poison (Ellis et al. 1991).

AFs are encountered in a wide range of important agricultural commodities, including cereals (maize, sorghum, pearl millet, rice, wheat), spices (chillies, black pepper, coriander, turmeric, ginger), oilseeds (groundnut, soybean, sunflower, cottonseed), tree nuts (almond, pistachio, walnut, coconut), milk (human and animal), and milk products. Currently, 20 different types of AFs have been identified, wherein the major ones include AFB_1, B_2, G_1, G_2, and M_1 as shown in Fig. 2. Fungal species belonging to *A. flavus* typically produce AFB_1 and AFB_2, whereas *A. parasiticus* can produce AFG_1 and AFG_2 as well as AFB_1 and AFB_2. The major AFs (B_1, B_2, G_1, and G_2) are classified based on their fluorescence under blue or green light and their relative mobility during separation by thin-layer chromatography (TLC) (Bennett and Klich 2003).

The AFs are white crystalline solids that are optically active and have a strong absorbance at wavelength of 365 nm with a fluorescence emission of 415–450 nm, depending on the solvent or physical status.

4 Ochratoxin A

Ochratoxin A (OTA) is another important secondary fungal metabolite produced by different array of *Aspergillus* and *Penicillium* species, primarily *Aspergillus ochraceus* and *Penicillium verrucosum*, and can often be found in various food commodities. It is produced by *Penicillium verrucosum* in temperate climates and *Aspergillus ochraceus* and the rare *Aspergillus carbonarius* in warm and tropical countries that can contaminate crops prior to harvest and/or more commonly during storage (EFSA 2006). The scientific data have shown that it possesses carcinogenic, nephrotoxic, teratogenic, and other toxic effects on different organisms (Creppy 1999; Pfohl-Leszkowicz and Manderville 2007). International Agency for Research on Cancer has placed OTA into the 2B Group of possible human carcinogens (IARC 1993), thus representing an issue of concern for human health. The structure is shown in Fig. 3.

It can also cause a fatal human kidney disease referred to as Balkan Endemic Nephropathy and urinary tract cancer. The toxin has also a number of toxic effects on various experimental animals: carcinogenic, teratogenic, immunotoxic, genotoxic, and possibly neurotoxic (JECFA 2001). The studies have revealed that pigs are known to be particularly sensitive to OTA, with their exposure resulting in the accumulation of this toxin in animal tissues and subsequently also in final meat products owing to an indirect transmission from animals fed on contaminated feed.

5 Zearalenone

Zearalenone (ZEA) is a nonsteroidal estrogenic mycotoxin produced by a variety of *Fusarium* fungi in temperate and warm countries. ZEA presents a similar structure to estrogen and therefore competes with 17-estradiol in binding to the estrogen

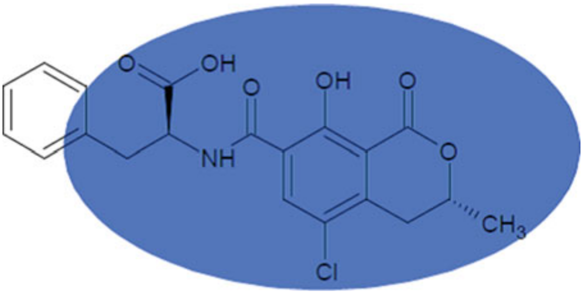

Fig. 3 Structure of ochratoxin A

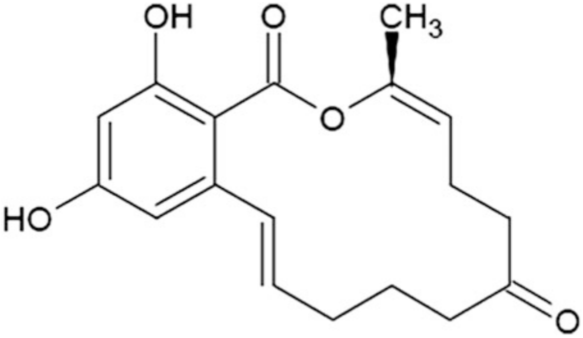

Fig. 4 Molecular structure of zearalenone

receptor as shown in Fig. 4. Therefore, it can cause significant changes in reproductive organs and fertility loss in animals and humans (Zinedine et al. 2007). Furthermore, it also exhibits hepatotoxic, hematotoxic, immunotoxic, and genotoxic properties (Lioi et al. 2004; Berek et al. 2001). Following ingestion, it causes functional and morphological changes in several animal organs.

Moreover, ZEA induces toxic effects, particularly genotoxicity and cytotoxicity, on kidney (Ouanes et al. 2003); nevertheless, data on kidney exposure to ZEA remain limited.

6 Fumonisins

Fumonisins are identified as the secondary metabolites of the *Fusarium* fungi mainly from *Fusarium verticillioides* and *Fusarium proliferatum* and contaminate maize and milled maize fractions and highly processed products. Fumonisins B_1, B_2, and B_3 are the major fumonisins found in food and products, and Fumonisin B_1 (FB_1) is chemically described as a di-ester of propane-1,2,3-tricarboxylic acid (TCA) and 2-amino-12,16-dimethyl-3,5,10,-14,15-pentahydroxyleicosane; the structure of FB_1 and FB_2 is shown in Fig. 5. It has been found that C-14 and C-15 hydroxyl groups are involved in ester formation with the terminal carboxyl group of TCA. Fumonisins B_2 (FB_2) and B_3 (FB_3) are the C-10 and C-5 dehydroxy analogues of FB_1 (Shephard 1998).

Reports have shown that it may adversely influence health in mammals including exhibiting hepatocarcinogenic, hepatotoxic, nephrotoxic, and cytotoxic effects (Bryła et al. 2013a, b; Munkvold and Desjardins 1997). The significant exposition to FB_1 is suspected to increase the risk of esophagus cancer in humans (Pagliuca et al. 2005), while consuming maize-based foods contaminated with fumonisins is associated with neural tube defects (Marasas et al. 2004). The International Agency for Research on Cancer (IARC) characterized FB_1 as a Group 2B carcinogen (possibly carcinogenic to humans) (IARC 2002).

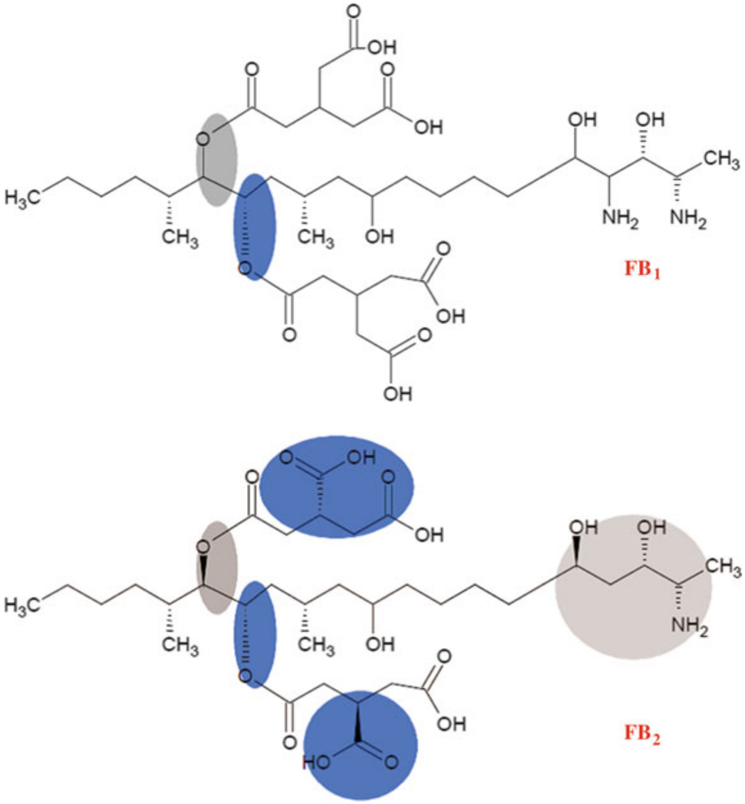

Fig. 5 Structures of FB_1 and FB_2

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) and the Scientific Committee for Food of the European Commission (SCF) established a group tolerable daily intake (TDI) of 2 μg/kg body weight for FB_1, FB_2, and FB_3, alone or in combination (Bolger et al. 2001; SCF 2000). However, European Union has established maximum levels for fumonisins (sum of $FB_1$and FB_2) in maize, and derived products range from 0.2 to 4 mg/kg (European Commission 2006) while US guidelines for total FB_1, FB_2, and FB_3 are 2 or 4 mg/kg in maize products used for human foods and 3 mg/kg for popcorn grain (FAO, Food & Agriculture Organization 2001).

The scientific reports have shown that fumonisins are relatively heat stable and persist through most of the conditions used in food manufacturing industries; however, they may undergo reactions in food systems that alter their toxicity and chemical structure. Therefore, lot of studies have been conducted to investigate the fate of fumonisins during various processing stages and they showed large reductions in contamination levels (Bullerman et al. 2002).

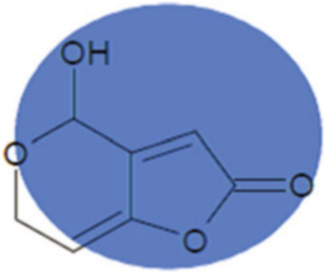

Fig. 6 Chemical structure of patulin

7 Patulin

Patulin (PAT) (4-hydroxy-4H-furo[3,2-c]pyran-2[6H]-one, as shown in Fig. 6) is another class of mycotoxins and is present globally in a wide range of fruit and vegetables. It is produced by fungal species of the genera *Penicillium*, *Aspergillus*, and *Byssochlamys* (Jimenez et al. 1988). The most important PAT producer is *Penicillium* (*p*.) expansum (Firsvad and Thrane 1996).

The studies documented that it has been observed in different types of fruits (apples, pears, peaches, cherries, black currants, oranges, apricots, pineapple, grapes, bananas, strawberries, plums) (Karabulut and Baykal 2002), especially in apples, pears, and peaches and in their processed products like juices and puree (World Health Organization 1996). It is also characterized as the "blue mold rot" found in storage-rotted apples (Bompeis and Cholodowski-Faivre 2000). The studies have shown that *P. expansum* grows often on the surface of healthy fruits (Sydenham et al. 1995), but is normally associated with damaged fruits or fruits already infected by other microorganisms in orchards and postharvest conditions (Buchanan et al. 1974).

Several scientific reports in animals, regarding the effects related to the ingestion of patulin in the long term, have shown genotoxicity (Bürger et al. 1988), immunotoxicity (Paucod et al. 1990), mutagenicity, neurotoxicity (Devaraj et al. 1982), and teratogenicity (Roll et al. 1990). In 1993, it was included in Group 3 by the International Agency for Research on Cancer among those substances "not classifiable as a carcinogen to humans" (IARC 1993). The EC Regulation 1881/2006, which indicates maximum levels for certain contaminants in food, established the maximum recommended concentration of 50 μg/kg of PAT in apple fruit juice and apple juice, 50 μg/kg in spirit drinks, ciders, and other fermented drinks, 25 μg/kg for solid apple products such as apple puree, and 10 μg/kg for solid apple products intended for infants and young children (Commission Regulation No 1881/2006 2006).

8 Critical Review of Recent Analytical Techniques

It has been observed that robust, selective, sensitive, and accurate methods are required for the analysis of mycotoxins because of the low levels at which mycotoxins are usually present in food and food products as well as general restrictive guidelines concerning the maximum acceptable levels (Kralj Cigić and Prosen 2009).

Currently, most analytical methods including TLC, ELISA, HPLC, GC/MS, and LC-MS/MS require some essential steps: (1) sampling, (2) homogenization, (3) sample extraction and clean-up step to avoid or eliminate unwanted matrix components, which may include sample concentration, and (4) the separation and detection steps, usually accomplished either by a chromatographic technique in combination with a variety of detectors or by immunochemical methods. Currently, chromatographic techniques, like liquid chromatography (LC) and gas chromatography (GC) coupled to mass spectrometry (MS) detector, are the most commonly used in quantitative analysis of mycotoxins. However, for a large number of samples initial screening is frequently performed by TLC or immunoassay-based methods like enzyme-linked immunosorbent assay (ELISA), just allowing qualitative or semiquantitative results. The disadvantage of using immunochemical methods is specific quantification, i.e., it is only used for one mycotoxin or a small group of structural related compounds at a time. Currently, chromatographic techniques can separate a great number of analytes, including some with a very different chemical structure. Furthermore, there is a trend developing toward multi-mycotoxin methods for the simultaneous analysis of many mycotoxins belonging to different chemical families, using LC-MS/MS (liquid chromatography with tandem mass spectrometry) technique (Turner et al. 2009).

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Part III
Future Challenges

Food Adulteration and Authenticity

M. Kamruzzaman

Abstract Authenticity and detection of adulteration are the increasing challenges for researchers, consumers, industries, and regulatory agencies. Traditional approaches may not be the most effective option to fight against adulteration. Much effort has been spent in both academia and industry to develop rapid and nondestructive optical techniques for detecting adulteration. Among them, hyperspectral imaging is one of the most promising. Hyperspectral imaging is a rapid, reagentless, nondestructive analytical technique that integrates spectroscopic and imaging techniques into one system to attain both spectral and spatial information simultaneously from an object that cannot be achieved with either digital imaging or conventional spectroscopic techniques. Associated with multivariate analyses, the technique has been successfully implemented for rapid and nondestructive inspection of various food products. In this chapter, latest research outcomes for authenticity and detecting adulteration using hyperspectral imaging will be highlighted and described. Additionally, challenges, opportunities, and future trends of hyperspectral imaging will also be discussed.

1 Introduction

The adulteration of foods is an age-old problem and has a long and inglorious history. It has existed as long as food has been made and sold. History across the globe reminds that our food is under continuous threat from adulteration. Since prehistoric times humans have altered the state of food to extend its longevity or improve its taste. However, the eighteenth and nineteenth centuries saw an explosion of food adulteration when milk, meat, flour, and other foodstuff were often adulterated with inedible and even poisonous/toxic substances, as farmers, suppliers, and grocers all tried to maximize their profits (Filby 1976). Grocers and

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suppliers often watered milk down and then restored its color with chalk, plaster, or white lead. Plaster and chalk were also added to flour, lead to wine and beer, and dust or soot to spices, coffee, and tea. Frederick Accum, a German chemist, was the first to raise the concern about food adulteration. In 1820, he published a book, *A Treatise on Adulteration of Food and Culinary Poisons*, listing foods adulterated and adulterants including the names and addresses of known suppliers of adulterated products in London (Accum 1820). In the "modern" scientific era, this was the first serious attempt to expose both the extent and dangers of food adulteration and received huge public attention.

Now it is a global issue addressed by several researchers, involving economic, quality, safety, ethical, and socioreligious issues (Alamprese et al. 2013). Major food adulteration events appear to regularly occur, for instance, adulteration of spices with Sudan Red dye in 2003, milk powder with melamine in 2008, dioxins in pork in 2008, milk with detergent, fat, and even urea in 2012, and processed beef products with horsemeat in 2013 (Ellis et al. 2012; Kamruzzaman et al. 2015a–c; Zhao et al. 2014). The widely publicized adulteration of milk powder with melamine (also called China's international milk crisis) was one of the largest food safety events in recent years (BBC 2010). This was not an accidental but deliberate adulteration of high technical sophistication. The main intention was to increase profits by watering the milk and then adding melamine to boost apparent protein content of milk (Xin and Stone 2008). Melamine is nitrogen-rich organic base normally used in plastic industry, thus fooling the testing procedures (Xiu and Klein 2010). The melamine scandal has shaken trust in the industry and drew huge media attention to the issue of adulteration, both locally and globally. It was a trigger point that proved adulteration can have global consequences, affecting consumers, companies, industries, and countries (Ellis et al. 2012). This scandal not only has involved economic fraud but is also related to the issue of food safety. It was reported that there were an estimated 300,000 victims affected, including six child fatalities with a further 51,900 people hospitalized due to melamine scandal (Gossner et al. 2009). In some cases, there might be no issue related to safety (i.e., horsemeat scandal); however, such adulteration is always a concern with individuals allergic to particular species, or those with religious taboos or ethical aversions (Zhao et al. 2014). Adulteration varies widely among the thousands of food products, range from tragic, as in the toxic oil syndrome or simply toxic syndrome disaster in Spain in 1981 where thousands were hospitalized and an approximately 600 people died due to rapeseed oil intended for industrial use being sold as olive oil (Terracini 2004), to authentication of the species (Kamruzzaman et al. 2012a; Espiñeira et al. 2010), variety (Manley et al. 2003; Ruoff et al. 2006), purity (Li et al. 2015; Mamani-Linares et al. 2012; Sun et al. 2015), and geographical origin of a product (Kamruzzaman et al. 2014; Longobardi, et al. 2015; Picque et al. 2005; Uríčková, and Sádecká 2015). Although the determination of authenticity and the detection of adulteration have received ample attention, the prevalence of fraud is not easy to assess (Ballin and Lametsch 2008). Basically, detecting adulteration is difficult without resorting to highly sophisticated analytical techniques because the adulterant components are usually very similar to the authentic product (Alamprese et al. 2013). On the other side, fraudsters are always one step ahead of the regulatory agencies and their techniques are increasingly becoming more and more sophisticated with time. Once a specific test has been developed to identify an adulterant, fraudsters can become aware of this and then add or remove that component from the adulterated foodstuff (Ellis et al. 2012). Many methods are available for the detection of qualitative and/or quantitative adulteration in food. Currently, the methods often used for food authentication and detection of fraud include polymerase chain reaction (PCR), chromatography, electrophoretic separation of proteins, immunological procedure and DNA-based techniques, and enzymatic assays (Ballin and Lametsch 2008), all of which are well documented. However, these techniques are invasive, time-consuming, and laborious and demand highly skilled personnel, and thus they are not suitable for online application and routine analysis. In general, methods for these purposes need to be specific, sensitive, rapid, and economic and able to analyze various meat products and to provide quantitative results (Meza-Márquez et al. 2010). Consequently, a cost-effective, efficient, rapid, and reliable method is required. In particular, there is a great interest in developing nondestructive optical technologies that have the capability of monitoring in real-time assessment.

2 Overview of the Chapter

Adulteration of food has always been an international problem and there is a constant requirement for robust analytical methods to be developed in order to detect adulteration in food and food products. During the last two decades, a number of modern techniques have been developed to adulteration and confirm authenticity (Al-Jowder et al. 2002; Morsy and Sun 2013; Peres et al. 2007; Primrose et al 2010; Reid et al. 2006). Among them, fingerprinting techniques have received ample attention. Fingerprinting techniques can be classified into three categories: electrophoresis fingerprinting, chromatographic fingerprinting, and spectral fingerprinting (Zhang et al. 2011). Spectral fingerprinting techniques are economic and facilitate qualitative and quantitative as well as noninvasive and nondestructive analysis. Further advantages include that they are reagent and waste free and require no additional auxiliary chemicals. For all these reasons, spectroscopic techniques are ideally suited for industrial quality control and process monitoring. The application of spectroscopic techniques for adulteration detection in foods is huge, and all of these applications cannot be covered with any depth in a single chapter. In this book chapter, the fundamental theory, instrumental, and application of spectroscopic methods for adulteration detection will not be discussed. These already have been highlighted in several reviews and book (Ashurst and Dennis 1998; Cordella et al. 2002; Ellis et al. 2012; Reid et al. 2006; Sun 2008). Recently, hyperspectral imaging integrates both imaging and spectroscopy in a single system, enabling acquisition of spatial and spectral information simultaneously from an object. As a result, the technology provides extraordinary data, which can be analyzed to detect, identify, and quantify imaged objects in more detail, which otherwise cannot be achieved with spectroscopy alone. As an emerging analytical method, hyperspectral imaging has received ample attention for the assessment of food quality, safety, and authenticity (ElMasry et al. 2007; Feng and Sun 2012; Iqbal et al. 2013; Kamruzzaman et al. 2011, 2012a–c, 2013b; Pu et al. 2014a, b). However, the potential of this technology has not yet been sufficiently exploited for detecting adulteration, but the technique has an enormous potential to fight against adulteration. After presenting some fundamental concept in food adulteration and a brief description of the fundamentals of hyperspectral imaging, this chapter describes the potential of hyperspectral imaging for rapid authentication and detection of adulteration in meat and fish. Additionally, challenges of hyperspectral imaging for real-time application and future trends are also discussed at the end of the chapter. It is hoped that this will encourage the general reader to explore this emerging detection technology in greater depth not only in meat and fish but also in all agro-food products so that the consumer can benefit further from this emerging technology for adulteration detection.

3 Some Fundamental Concepts of Food Adulteration

In recent years, the topic of food adulteration has received a lot of concern in both developed and developing countries. Nowadays, it is widespread all over the world especially in developing countries although the full scale of adulteration is not well known conclusively. This is mainly because most incidents go undetected or unreported since they usually do not result in a food safety risk and consumers often do not notice any quality problem associated with those adulterated food products because the adulterant components are usually very similar to the authentic product (Alamprese et al. 2013). On the side, it is always difficult for ordinary consumer to judge purity and authenticity. The number of documented incidents may be a small fraction of the true number of incidents, but there is no doubt that it is a growing problem worldwide. In today's hypercompetitive marketplace, the food supply chain is now more global and complex than ever and the most food today no longer follows a straight line from producers and distributors to consumers and tracing the source of adulteration, deliberate or accidental, has become more challenging. Around 50 years ago, the average grocery store stocked about 200 food items and most of which were grown, produced, or processed within 100 miles of the store, whereas currently the average supermarket stocks about 39,000 items, which have traveled an average of 1500 miles, making detection harder and adulteration easier (Bail 2014). An example of global supply chain for canned tuna that travels long distance is illustrated in Fig. 1. Therefore, increasingly globalized food supply chains and the economic motivation to provide cheaper food products have contributed to the food adulteration. From the economic point of view, food adulteration alone is believed to cost the world economy around $49

Fig. 1 An example of global supply chain for canned tuna, from harvest in East Asia to finished product in the USA. Source: http://www.ilo.org/public/english/dialouge/sector/techmeet/tmfce07/tmfce-r.pdf

billion annually (Bail 2014), a figure that is expected to rise. Literally, food adulteration can be described as the deliberate contamination of food materials with low-quality, cheap, nonedible, or toxic substances where the substance that degrades or lowers the quality of food is called adulterant. Although the terms food adulteration and food contamination are sometimes synonymously used in the literature, there is a fine line between adulteration and contamination. Food contamination is the presence of a minor or unwanted constituent or impurity while food adulteration indicates the intentional, fraudulent addition of extraneous, improper, or cheaper ingredients to products or the dilution or removal of some valuable ingredient in order to increase profits (Spink and Moyer 2011). Contamination and adulteration differ in that contamination is the unintended presence of harmful substances such as microorganisms, chemicals, or physical objects or when something is added to the food unconsciously or intentionally, while adulteration is when something is intentionally added to or removed from the food. Therefore, adulteration in food is done definitely for financial gain; that is why, adulteration is often called economically motivated adulteration or EMA; however, food contamination could happen due to careless or lack in proper hygiene condition of processing, handling, storing, transportation, and marketing.

Food safety, food fraud, and food defense incidents can create adulteration of food with public health threats. Food fraud is an intentional act for economic gain, whereas a food safety incident is an unintentional act with unintentional harm, and a food defense incident is an intentional act with intentional harm (Busta and

Table 1 Food protection risk: examples, cause, and effects (Spink and Moyer 2011)

Risk type	Example	Cause and motivation	Effect	Public health risk type	Secondary effect
Food quality	Accidental bruising of fruit	Mishandling	Unsalable product or possible addition contamination	None or possible food safety	Reduced product/brand equity or food safety incident
Food fraud	Intentional adulteration of milk with melamine	Increasing profit margins	Toxic poisons	Food safety	Public fear and possible lower price industry wide
Food safety	Unintentional contamination of raw vegetables with *E. coli*	Limited field protection and control during harvesting and processing	Illness and/or death	Food safety	Damaged industry, recall expense, and public fear
Food defense	Intentional contamination of ground beef with nicotine	Revenge against the store/manager through injury to consumers	Nonlethal poisonings	Food defense	Adulterated product, damaged industry, recall expense, public fear

Kennedy 2011). Different types of food related risks, causes, motivation, and effects are summarized with examples in Table 1. Spink and Moyer (2011) identified seven types of food fraud, namely, adulteration, counterfeit product, diversion of products outside of intended markets, overrun, simulation, tampering, and theft (Table 2). There is no statutory definition of economically motivated adulteration (EMA) or more specifically food fraud. According to FDA, EMA is defined as the fraudulent, intentional substitution or addition of a substance in a product for the purpose of increasing the apparent value of the product or reducing the cost of its production. EMA also includes dilution of products with increased quantities of an already present substance to the extent that such dilution poses a known or possible health risk to consumers, as well as the addition or substitution of substances in order to mask dilution (FDA 2009). EMA can be classified into six categories as shown in Table 3. There is no doubt that the motivation for food fraud/adulteration is economic or financial, but the impact is the public heath vulnerability. In some cases, food adulteration is considered more dangerous than traditional food safety threats as the potential adulterants could be unconventional (e.g., addition of melamine in infant formula), and impact is huge as shown in Fig. 2 for melamine adulteration. Almost all the food and food products being sold in the market are prone to adulteration, but high-commercial value products such as coffee, fruit juices, honey, milk, minced meat, sea fish, olive oil, and saffron are the most likely foods to be targeted for intentional or economically motivated adulteration. Table 4 shows some common foodstuff and their adulterants (Johnson 2014).

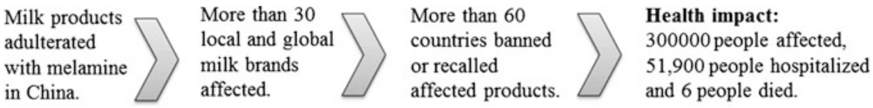
Table 2 Types of food fraud (Spink and Moyer 2011)

Types	Definition	Example
Adulteration	A component of the finished product is fraudulent	Melamine added to milk
Counterfeit	All aspects of the fraudulent product and packaging are fully replicated	Copies of popular foods not produced with same food safety assurances
Diversion	The sale or distribution of legitimate products outside of intended markets	Relief food redirected to markets where aid is not required
Over-run	Legitimate product is made in excess of production agreements	Underreporting of production
Simulation	Illegitimate product is designed to look like but does not exactly copy the legitimate product	"Knockoffs" of popular foods not produced with same food safety assurances
Tampering	Legitimate product and packaging are used in a fraudulent way	Changed expiry information, product up-labeling, so on
Theft	Legitimate product is stolen and passed off as legitimately procured	Stolen products are co-mingled with legitimate products

Table 3 Classification of EMA

Types	Definition	Example
Dilution	Reduce the amount of valuable component	Water used to dilute milk
Substitution	Replace with something less valuable	Use beer sugar instead of honey
Unapproved boosts	Increase the apparent value, quality, or strength of a product	Melamine added to milk to enhance the protein value
Concealment	Conceal known damage or contamination	Salmonella contagion in peanuts
Non-disclosure	Intentional GMP violations	Sulfites in food to hide deterioration
Mislabeling	Reclassification of one product as another	Sunflower oil sold as olive oil

GMP good manufacturing practices



Milk products adulterated with melamine in China.

More than 30 local and global milk brands affected.

More than 60 countries banned or recalled affected products.

Health impact: 300000 people affected, 51,900 people hospitalized and 6 people died.

Fig. 2 Impact of melamine adulteration

4 Fundamental of Hyperspectral Imaging

The theory and application of hyperspectral imaging is based on the interaction between the electromagnetic radiation and the material of interest. All materials reflect, scatter, absorb, and/or emit electromagnetic energy in different proportions

Table 4 List of common food products and their main adulterants

Types of food	Main adulterants
Coffee	Ground coffee mixed with roasted corn, roasted barley, roasted ground parchment, leaves, or twigs. Instant coffee mixed with chicory, cereals, caramel, more parchment, starch, and malt
Honey	Replaced with sugar syrup, corn syrup, fructose, glucose, high-fructose corn syrup, and beet sugar
Milk	Diluted with water or tainted with detergent, caustic soda, sugar, urea, rennet, melamine, skim milk powder, or another animal's milk
Minced meat	Substitute with lower grade meats from the same or different species, mechanically recovered meat, offal, blood, water, eggs, gluten, or proteins from several origins
Sea fish	Mislabeled or masquerading as a more expensive variety
Olive oil	Diluted or entirely substitute with cheaper oil such as hazelnut, soybean, corn, peanut, sunflower, safflower, walnut, vegetable, canola, or palm oil, or a less expensive variety. False declaration of geographic, species, botanical, or varietal origin
Fruit juice	Replaced expensive juice with cheaper juice
Saffron	Added glycerin, sandalwood dust, tartrazine (a yellow dye), barium sulfate, and borax

at specific wavelengths. These differences are characterized by a spectrum that can be considered as the material's spectral signature or spectral fingerprint. In theory, spectral signature can be used for identification, detection, classification, and mapping purposes of the examined products. The fundamentals of hyperspectral imaging technology include hardware to acquire the images and software to process the images so that useful information from the spectral images can be extracted to detect or quantify target attributes. A typical hyperspectral imaging system consists of a light source that illuminates the material of interest, a lens to ensure adequate focus and delineate the field of view, a spectrograph (wavelength dispersion unit) to split the light into various spectral bands, a camera (detector) to capture the resultant spatial–spectral images, and a computer supported with software to control the image acquisition process (Fig. 3a).

The output of the hyperspectral imaging system is the three-dimensional (3D) hypercube (x, y, λ), the 3D data cube, where the three dimensions include two spatial dimensions (x, y) and one spectral dimension (λ). The hypercube $I(x, y, \lambda)$ can be viewed either as a gray level image $I(x, y)$ at each individual wavelength λ or as a spectrum I (λ) at each individual pixel (x, y) as shown in Fig. 3b.

Spectral data obtained from hypercube are multivariate in nature due to a large number of data points, one at each wavelength, for each sample. Therefore, multivariate data analysis technique or chemometrics is required to extract meaningful information from the spectra to correlate with the target attributes to determine and visualize the distribution within the sample. The spectral data can be analyzed directly or following pretreatments, which include baseline corrections, Savitzky–Golay filter for finding derivatives, normalization, and scaling (Cen and

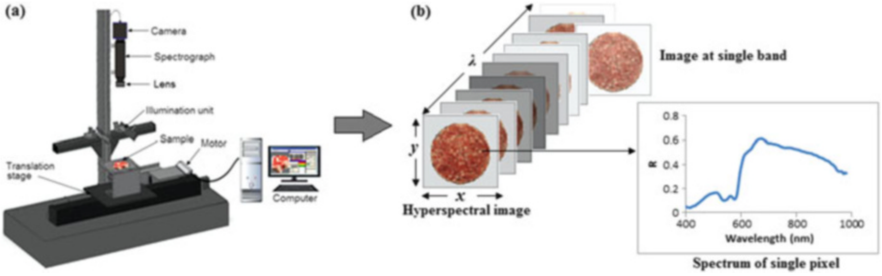


Fig. 3 (**a**) Components of a typical hyperspectral imaging system, (**b**) the conceptual view of a hypercube comprising spatial (*x* and *y*) and spectral (*λ*) and dimensions

He 2007). The data can then be used to develop the multivariate model by employing the appropriate chemometric algorithms such as principal component analysis (PCA), linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), partial least square-discriminant analysis (PLS-DA), artificial neural network (ANN), support vector machine (SVM), multiple linear regression (MLR), and partial least square regression (PLSR) with adequate statistical validation (ElMasry et al. 2012; Kamruzzaman et al. 2015a). A mandatory check is required to validate the integrity and applicability of the developed calibration model in predicting unknown samples to ensure that the model will work in the future for new and similar data. When the developed model is optimized and/or simplified by selecting several important wavelengths/variables, the spectra can be applied in a pixel by pixel manner to obtain the distribution map where the components of the samples are clearly visualized and easily interpretable. A flowchart that explains the complete analysis of the hyperspectral data starting from image acquisition to multivariate modeling and ending with the prediction map is shown in Fig. 4. Details about hyperspectral imaging can be found elsewhere (ElMasry et al. 2012). In the following sections, the application of hyperspectral imaging for detecting adulteration and authenticity will be discussed.

5 Authentication of Species

Authentication of food products is of primary importance for both consumers and industries, at all levels of the production process, from raw materials to finished products. Authentication is also important for the industry for accurate labeling to help consumers to select appropriate types of food products and for traceability as there are consumers who do not accept specific food items in their diet for religious or ethical reasons (Rohman et al. 2011). A hyperspectral imaging system in the spectral range of 900–1700 nm was tested for authentication of different red meat species (Kamruzzaman et al. 2012a). In order to reduce the high dimensionality of the extracted spectral data and to make the models more robust, six (957, 1071,

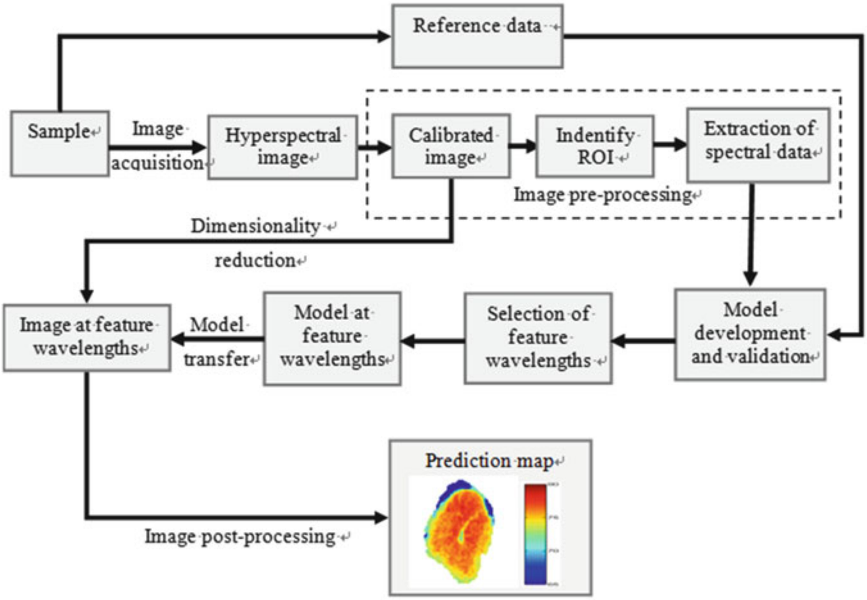


Fig. 4 Flowchart of a full algorithm for hyperspectral image analysis starting from image acquisition to multivariate modeling and ending with the prediction map

1121, 1144, 1368, and 1394 nm) important wavelengths that give the highest discrimination among tested meat categories were first selected using second derivative. Spectral data at six dominant wavelengths were then analyzed by PCA and PLS-DA for recognition and authentication of the tested meat. PCA is a very effective way of identifying patterns in data and expressing the data in such a way as to highlight their properties, groupings, similarities, and differences (Lucio-Gutiérrez et al. 2011). As illustrated in Fig. 5, the score plot of PC1 and PC2 indicated that the tested meat classes had different spectral patterns and can be easily distinguished into three separate classes. PLS-DA model was then developed using these six wavelengths and achieved overall accuracy of 97.33 and 98.67 % in the calibration and validation sets, respectively. Using PLS-DA model, 146 samples were identified correctly out of 150 samples in the training sets and almost all samples (74 out of 75) were correctly classified in the validation sets.

Basically, educated/trained staff can easily differentiate between pork, beef, and lamb muscles simply by visual inspection. On the contrary, minced meats are extremely difficult to visually authenticate as mincing removes the morphological structures of muscles. Therefore, the developed classification algorithms were then applied to both intact and minced meat in the independent testing set. Classification maps of the independent testing set and their corresponding false color images are shown in Fig. 6. False color images of the respective samples are shown for comparison and accentuate the difficulty to identify one type of minced meat

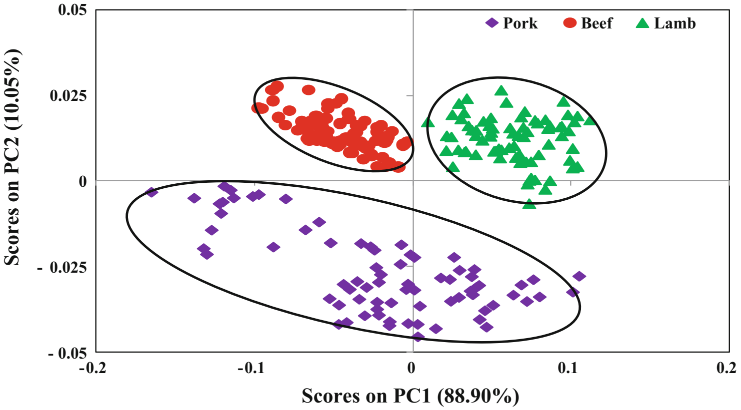


Fig. 5 PCA score plot of spectral data in the spectral range of 910–1700 nm for red meat samples (Kamruzzaman et al. 2012a)

from another by simple imaging method or via visual inspection. Overall, the algorithm performed satisfactorily to distinguish the three meat classes studied. Out of 70 samples, 65 samples were correctly identified in case of intact muscles and almost all samples (69 out of 70) were correctly identified when those samples are minced. These results clearly indicate good recognition capability of the constructed model in identifying new samples. A major result of the study is that the visualization model developed with intact samples can be applied successfully to detect and quantify pork, beef, and lamb when meat is minced. This result is very optimistic to indicate the potential of hyperspectral imaging system for the authentication of different red meat species without referring to any sophisticated techniques.

6 Authentication of Geographical Origin

Authentication of geographical origin is important for regulatory agencies, food processors, retailers, and consumers because expensive ingredients have the potential for adulteration and fraudulent or accidental mislabeling. The reliability and applicability of hyperspectral imaging technique (400–1000 nm) was also investigated for the identification and authentication of geographical origin of beef and pork (Kamruzzaman et al. 2014). Frozen meat samples originated from *Longissimus dorsi* (LD) muscles of pork and beef were used for the investigation. Beef samples were originated from Australia, Japan, New Zealand, and the USA, whereas pork samples were originated from Canada, Japan, and Mexico. Ten samples from each origin were collected for both beef and pork. Therefore, a total of 70 samples were investigated including beef (40) and pork (30).

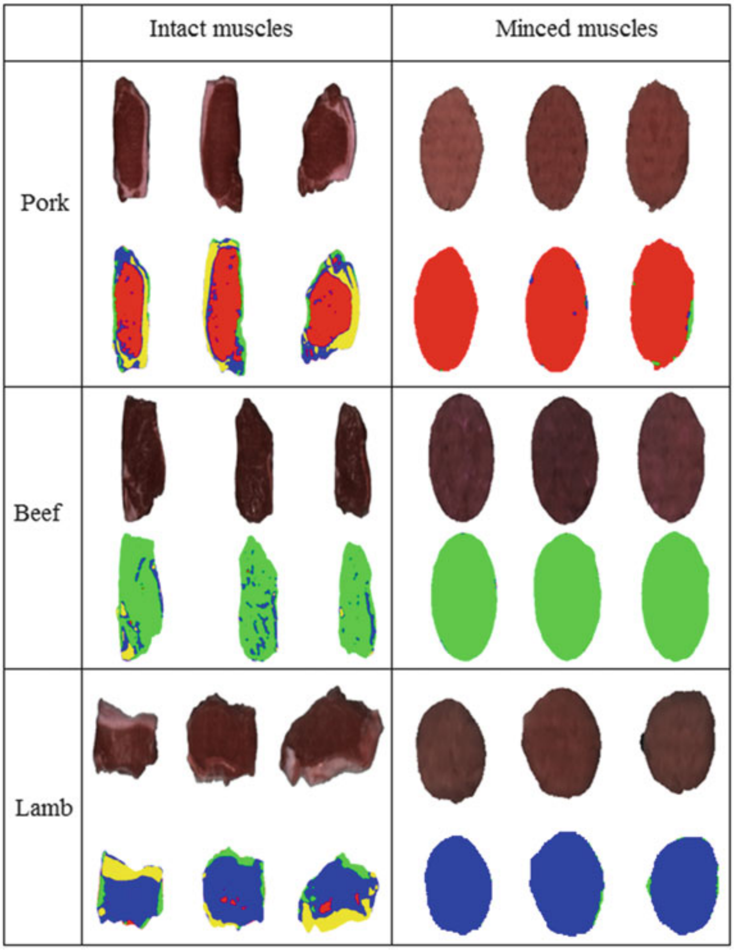


Fig. 6 RGB images and corresponding classification maps of independent testing set containing both intact and minced meat samples (Kamruzzaman et al. 2012a)

Hyperspectral images of samples were acquired using a Vis/NIR hyperspectral imaging and analyzed spectral data by PCA and PLS-DA for correct authentication.

PCA was applied to spectral data to check qualitative authentication in the spectra among the tested samples. The first two PCs explained 99.0 % of the variation among beef samples (PC1—96.0 % and PC2—3.0 %). Figure 7 shows the scores plot of PC1 vs. PC2, which reveals the feasibility of discrimination between the tested muscles. Four different clusters are obviously observed without overlap among them. Similarly, the score plot of the first two PCs (explained 99.0 % variation) shown in Fig. 8 revealed three clear clusters between the tested pork muscles. These plots revealed that tested samples had reasonable variation in their spectral patterns, allowing for the discrimination among them and providing useful

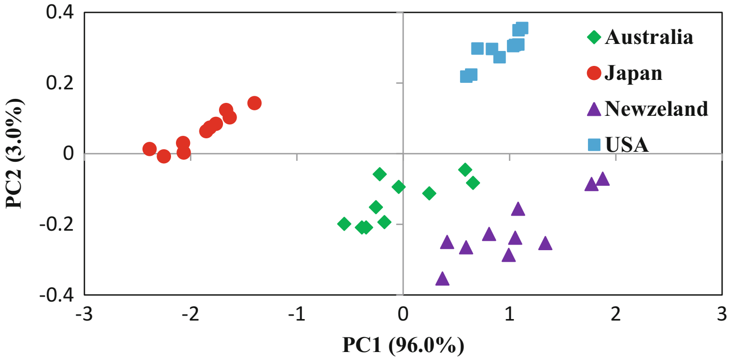


Fig. 7 PCA score plot of beef muscles in the spectral range of 400–1000 nm

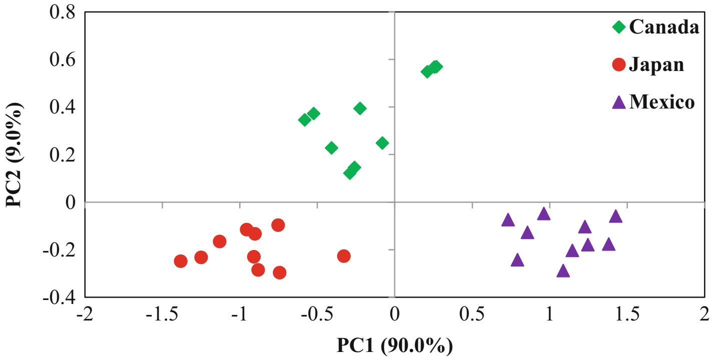


Fig. 8 PCA score plot of pork muscles in the spectral range of 400–1000 nm

information for authentication purposes. PLS-DA model was developed for quantitative authentication of the samples based on geographical origin. Out of 40 beef samples, 38 samples were identified correctly with overall accuracy of 95.0 % for authentication. On the other side, all pork samples were correctly classified, i.e., an overall correct classification of 100.0 %. The results of this study suggested that hyperspectral imaging together with chemometrics has a great potential to be a nondestructive tool for authentication of geographical origin of beef and pork muscles without the aid of physicochemical background information.

7 Adulteration Detection in Minced Lamb

Meat and meat products are the most commonly consumed high value food items throughout the world. Because of its high value, there is always an opportunity for fraudulent replacement of premium quality material with lower grade meats (Al-Jowder et al. 2002; Morsy and Sun 2013; Zhao et al. 2014). The possibility

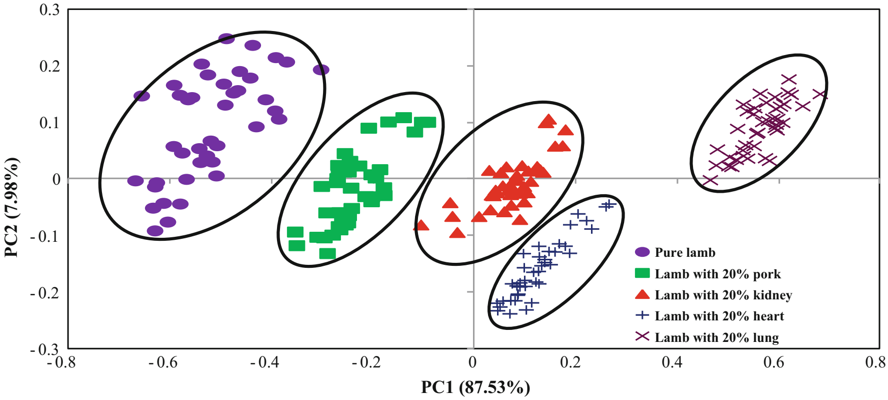


Fig. 9 PCA score plot for pure lamb and lamb mixed with 20 % of different adulterates in the spectral range of 910–1700 nm (Kamruzzaman et al. 2013a)

of developing a rapid analytical technique based on NIR hyperspectral imaging was tested to detect the level of adulteration in minced lamb meat (Kamruzzaman et al. 2013a). The study consisted of two parts: the first concerns the identification of the most potential adulterate, while the second concerns the detection of adulteration level. The first study was conducted using pure minced lamb meat and lamb meat mixed with a range of potential adulterants including pork, heart, kidney, and lung in 20 % w/w proportions. A total of 200 samples (5 classes × 40 samples from each class) were prepared, each of 32 g, for the investigation. The second study was to detect the level of adulteration in minced lamb meat. The lamb samples (~28 % fat) were adulterated by mixing pork (~15 % fat) in the range of 2–40 % at approximately 2 % increments according to weight. The minced lamb and pork were individually weighed and thoroughly mixed and homogenized to obtain a total sample weight of 32 g. In total, 40 samples (two samples per adulterate level) were prepared for the study. For both investigations, the minced meat was put in a circular metal can and imaged using the hyperspectral system.

PCA was used to identify the most potential adulterate among pork, kidney, heart, and lung in minced lamb. The score plot of the first two PCs (explained 95.7 % variation) shown in Fig. 9 revealed the clear clustering between pure minced lamb and adulterated minced lamb, where five different clusters were clearly observed without overlap among them. These results imply the possibility of developing analytical method based on hyperspectral imaging for the authentication of minced lamb meat from lamb mixed with potential adulterates. The samples belonging to pure lamb and lamb mixed with 20 % pork were clustered much closer to each other followed by lamb mixed with different selected offals. Clearly, Fig. 9 suggested that the most potential adulterate was pork among others since lamb and lamb mixed with pork clustered very closely. In reality, if the mixture of lamb and pork are predictable using this technique, then the mixture of lamb and offal would be predicted easily.

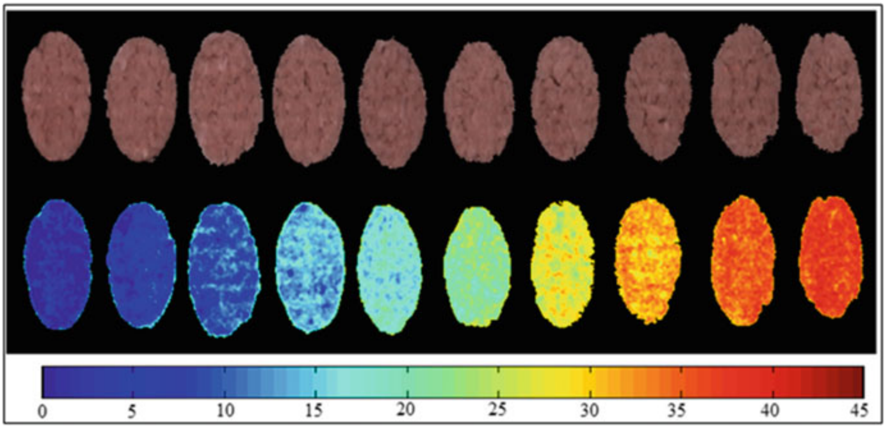


Fig. 10 RGB images (*top*) and corresponding prediction maps (*bottom*) of adulteration at different levels from 4 to 40 % (*left* to *right*) with 4 % increments. RGB images were synthesized by combining calibrated hyperspectral images at the wavelengths of 950, 1250, and 1300 nm (Kamruzzaman et al. 2013a)

Multivariate calibration model then was developed using partial least squares regression (PLSR) to predict the level of pork adulteration in minced lamb. Good prediction model was obtained using the whole spectral range (910–1700 nm) with a coefficient of determination (R^2_{cv}) of 0.99 and root-mean-square errors estimated by cross validation (RMSECV) of 1.37 %. Four important wavelengths (940, 1067, 1144, and 1217 nm) were selected using weighted regression coefficients (Bw), and a multiple linear regression (MLR) model was then established using these important wavelengths to predict adulteration. The MLR model resulted in a coefficient of determination (R^2_{cv}) of 0.98 and RMSECV of 1.45 %. The developed MLR model was then applied to each pixel in the image to obtain prediction maps to visualize the distribution of adulteration of the tested samples. The generated prediction map clearly revealed the change in adulteration from sample to sample and even from spot to spot within the same sample (Fig. 10). However, it was difficult to identify the difference in the adulteration level with the naked eye, as shown with the RGB images in Fig. 10. Thus, these results show that hyperspectral imaging technology is a very effective and promising technique that can detect adulteration in minced meat. It is clear that hyperspectral imaging could be useful to confirm meat authenticity and detection of meat adulteration.

8 Adulteration Detection in Minced Beef

The producer and the consumers consider minced beef as one of the most popular and versatile meat products. Minced meats are the major ingredients in various high-volume meat products such as hamburgers, patties, meatballs, sausages, and salami. In 2013, the horsemeat scandal in the UK and Ireland drew huge attention to the issue of meat adulteration, both locally and globally. The shocking issue involved meat labeled as beef was found to contain undeclared horsemeat as well as meat from pork. This led to the recall of more than ten million beef burgers and other beef products from supermarkets throughout the UK and Ireland (Boyaci et al. 2014). Thus, a hyperspectral imaging system was used in the spectral range of 400–1000 nm with 5 nm intervals to detect the level of horsemeat adulteration in minced beef (Kamruzzaman et al. 2015c). The 400–1000 nm range is industrially advantageous because of the wide availability and low cost of charge-coupled device (CCD) sensors compared to the region between 900 and 1700 nm (Taghizadeh et al. 2009). The minced beef samples were adulterated by mixing horsemeat in the range of 2–50 % (w/w) at approximately 2 % increments. A total of 25 samples (one sample from each adulteration level) were prepared as a calibration set. Similarly, another 25 samples were prepared in a different batch as a testing dataset. However, 13 samples were randomly selected from the testing dataset to be used exclusively to validate the performance of calibration model. As a result, a total of 38 samples consisting of 25 calibration samples and 13 validation samples were investigated for the study.

PLSR models were developed with raw and pretreated spectra. Table 5 shows the main statistical parameters of PLSR models developed using raw spectra and with various pretreatment procedures (MSC, SNV, first derivative, and second derivative) for predicting adulteration in minced beef. The results revealed that none of the spectral pretreatment protocols offered an improvement in the model performance, and some of them even had deteriorative effect compared to the model developed with raw spectra. PLSR models developed using the raw spectra were very accurate with R^2_c of 0.99, SEC of 1.14 %, R^2_{cv} of 0.99, and SECV of 1.56 %. The cross-validation results were highly similar to that obtained for the calibration results. The similarity in model performance implied that the models were not over-fit, and the majority of the variance presented in the measured values was reproduced in the prediction model. When the developed PLSR model was applied to an independent validation set, the level of adulteration in minced beef was predicted with an R^2_p of 0.98 and SEP of 2.23 %. These results suggest that the PLSR calibration model optimized with full cross-validation is representative, and the model can work precisely in the samples that were not used for the development

Table 5 PLSR models with raw and pretreated spectral data using 117 variables (Kamruzzaman et al. 2015c)

		Calibration		Cross-validation		Prediction	
Pre-processing	LVs	R^2_c	SEC (%)	R^2_{cv}	SECV (%)	R^2_p	SEP (%)
None	4	0.99	1.14	0.99	1.56	0.98	2.23
MSC	4	0.99	1.18	0.98	2.06	0.98	2.26
SNV	4	0.99	1.17	0.98	2.04	0.98	2.26
1st derivative	5	0.99	1.18	0.98	1.97	0.97	2.35
2nd derivative	6	0.99	1.38	0.97	2.66	0.96	2.63

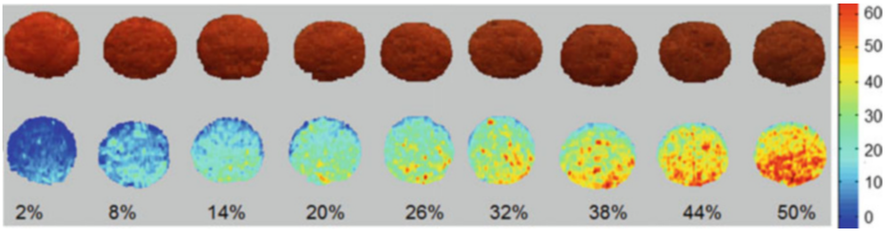


Fig. 11 RGB images (*top*) and prediction maps (*bottom*) of adulteration at different levels. The *number* below each prediction map is the percentage of horsemeat in minced beef. RGB images were formed by combining three different images at 660, 580, and 455 nm (Kamruzzaman et al. 2015c)

of the calibration model. In the spectral analysis, 2 × SEP was regarded as a 95 % confidence interval (Kelly et al. 2004). Therefore, PLSR model with full spectra is capable of predicting adulteration within 4.46 % in the future unseen samples. More specifically, this model cannot accurately estimate samples below 4.46 % adulteration.

To develop optimized PLSR model, four important wavelengths at 515, 595, 650, and 880 nm were selected corresponding to the highest absolute values of BW. By using only these particular wavelengths, new PLSR models were created. The predictability of these models was similar to the PLSR models established based on full spectral range. The new PLSR model had a good performance in predicting adulteration with R^2_c of 0.99, SEC of 1.21 %, R^2_{cv} of 0.99, and SECV of 1.60 %. This PLSR model, when applied to an independent validation set, was capable of predicting the level of adulteration with R^2_p of 0.98 and SEP of 2.20 %. The SEP associated with this model imply that the model will work to predict the true adulteration level within 4.40 % (2 × SEP) in the future for new, similar samples.

The optimized model was transferred in each pixel of the image to create prediction maps or distribution maps. Figure 11 shows the prediction maps of some samples with their corresponding RGB images. In the prediction map, different colors in the prediction map mean different levels of adulteration in the image in proportion to the spectral differences of the corresponding pixels. It was quite clear to aptly figure out how the levels of adulteration vary from sample to sample and even within the same sample. Therefore, the results suggest that hyperspectral imaging could become a good way for rapid and nondestructive prediction of adulteration in minced meat not only in spectral domain but also in the spatial domain. However, it is very important to obtain robust and precise calibration model for such prediction maps. Without a good calibration model, misleading prediction maps might be obtained.

9 Adulteration Detection in Fish

In addition to detection of adulteration in minced meat, hyperspectral imaging was used to detect adulteration in fish. In particular, prawns and shrimp are more susceptible to adulteration. In China, many incidents of a 20–30 % increase in the weight of prawns and shrimp have been reported after the injection of gelatin, which is derived from animal skin and bones, into the head and belly. At present, the gelatin injected into prawns and shrimp is usually identified by the naked eye; however, in most cases, the gelatin is transparent and humans cannot observe it. Thus, Wu et al. (2013) recently investigated hyperspectral imaging to detect gelatin adulteration in prawns. LS-SVM was used to calibrate the gelatin concentrations of prawns with their corresponding spectral data. A combination of uninformative variable elimination and successive projection algorithm (UVE-SPA) was used to select the optimum wavelengths. The simplified model was based on optimum wavelengths that had $R^2{}_\mathrm{p}$ of 0.97. The model was then applied to every pixel in the images that predicted the distribution map of the gelatin concentrations, which showed the magnitude of concentrations that varied from sample to sample or from position to position within the same sample.

10 Challenges of Hyperspectral Imaging and Future Trends

The nondestructive, reagent-less, and multivariate characteristics of hyperspectral imaging techniques provide an interesting platform for adulteration detection and authentication. The main advantage of a hyperspectral imaging system is its ability to incorporate both spectroscopic and imaging techniques to directly assess different components simultaneously and to locate the spatial distribution of such components in the tested products (ElMasry et al. 2012). Despite the aforementioned advantages, hyperspectral imaging has several constraints that limit its widespread applications. A major disadvantage of hyperspectral technology is the speed required for its use in the industry. Rapid acquisition and processing of hyperspectral image data is a necessity; however, it takes a relatively long time to handle, display, visualize, and process the data in a real-time mode (Burger and Gowen 2011). Thus, the speed of the hyperspectral imaging system needs to be improved to augment the rapid acquisition and analysis of hyperspectral data. Future developments in system components coupled with rapid growth in computing power as well as more robust and efficient algorithms will reduce the acquisition and processing time to satisfy real-time requirements. Another obstacle that prevents the widespread use of hyperspectral imaging is the cost. The costs of hyperspectral imaging systems are significantly higher than those of multispectral systems. Thus, a multispectral imaging system with selected wavelengths is an alternative and promising approach for real-time applications.

Moreover, hyperspectral imaging has multicollinearity among its contiguous variables. Therefore, it is essential to extract uncorrelated components and select important spectral bands/wavelengths for overcoming this problem of multicollinearity. Many researchers only analyze spectral data that use the full spectrum without considering wavelength selection. However, some researchers have investigated hyperspectral imaging to select effective wavelengths for building online multispectral imaging instruments. Because hyperspectral imaging is utilized as a precursor for designing dedicated multispectral vision systems, optimal wavelength selection should be considered in all hyperspectral imaging applications. It enables the use of a single simple sensor instead of hundreds of variables with more complex and slower sensors. As a result, both accuracy and speed can be assured that is important for real-time implementation. However, one of the main disadvantages of the hyperspectral imaging technique is that it is an indirect method that requires standardized calibration and model transfer procedures. Thus, transferring these lab-based offline applications to an online industrial setting requires more time and effort. It is hoped that new hardware concepts will continuously emerge to develop improved and novel hyperspectral imaging components for building high-performance systems. Commercial hyperspectral imaging systems have now started appearing in the market. The commercialization of hyperspectral imaging systems will boost the scope of applications not only in meat but also in other agro-food processing industries.

11 Conclusions

History across the globe teaches us that different types of adulteration will happen again but not in quite the same way. Therefore, the challenge is to develop a cost-effective and efficient analytical method to adulteration and confirm authenticity. The various applications delineated in this chapter confirm that hyperspectral imaging techniques provide an attractive solution for detecting adulteration with minimal sample preparation and ease of operation. Therefore, the laborious and time-consuming conventional analytical techniques could be replaced by spectral data to provide a rapid and nondestructive testing technique. Although hyperspectral imaging technology is currently suffering from some drawbacks, the future development of hyperspectral imaging instruments such as lower purchase costs and improved processing speed along with progress in data analysis techniques will lead this technology to have more substantial and widespread applications in the future.

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Climate Change and Food Safety

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Abstract Worldwide, climate change is already affecting the biology and ecology of some organisms because of changing patterns in crop production and livestock intensification, as well as altering the transport pathways of chemical contaminants. Consequently, climate change is expected to aggravate feed and food safety problems during all phases of food production and supply. Temperature increases and changes in rainfall patterns will have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites, fungi, and harmful algae and the patterns of their corresponding foodborne diseases and the risk of toxic contamination. Chemical residues of pesticides and veterinary medicines in plant and animal products will be affected by changes in pest pressure. The food risks of heavy metals and persistent organic pollutants (i.e., dioxins, polychlorinated biphenyls) could rise following changes in soils and long-range atmospheric transport, though quantitative estimates are scarce. This chapter summarizes data on the effect of climate change on biological and chemical food safety hazards, as well as it discusses the need for scientific research and development of improved tools, techniques, and practices to adapt the current risk management systems.

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1 Introduction

There is widespread agreement that greenhouse gas emissions, among other driving forces, are leading to climate change, and this will have a number of impacts, which will include changes in food security and food safety (Lake et al. 2012). Anthropogenic activities have increased concentrations of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons in the atmosphere, resulting in environmental warming. For instance, current atmospheric carbon dioxide concentrations over 400 parts per million (ppm) have increased by more than 40 % from preindustrial times (280 ppm), and they are expected to reach 550 ppm by the end of 2050 (Challinor et al. 2014). Projections for Europe suggest that climate change will result in warming of 2.1–4.4 °C by 2080, with Northern and Eastern Europe expected to become wetter, while the Mediterranean supposed to become drier. Predictions about extreme events are highly uncertain, but heat waves are expected to be more intense, frequent, and longer lasting, whereas extreme precipitation events will increase in northern and Western Europe (EEA 2007).

In the literature, there is much focus on the effects of climate change on food security (Lobell et al. 2011), defined as when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life (WHO 2014). Additionally, climate change and related disturbances are considered important factors that can cause changes in the nature and occurrence of food safety hazards at various stages of the food chain, from primary production to consumption (Tirado et al. 2010). There are many pathways through which climate-related factors may impact food safety including changes in temperature and precipitation patterns, increased frequency and intensity of extreme weather events, ocean warming, and changes in the transport pathways of complex contaminants.

Temperature increases and changes in rainfall patterns have an impact on the persistence and patterns of occurrence of bacteria, viruses, parasites, and fungi and the patterns of their corresponding foodborne diseases and the risk of toxic contamination (Tirado et al. 2010). Climate change may alter the seasonal patterns and abundance of pests and diseases, which may affect pesticide use in plants (Boxall et al. 2009). Elevated temperatures may also lead to the emergence and reemergence of pathogens and vectors, resulting in greater use of biocides and veterinary medicines in livestock management (Kemper 2008). As an example, the recent emergence of bluetongue and Schmallenberg viruses in cattle in Northern Europe during the last years demonstrated the possibility for pathogenic agents to spread in areas where environmental conditions became favorable (Medlock and Leach 2015).

Responses will differ between crops and animal production systems and between geographical locations, but changes in pest and disease control measures may have implications for the presence of chemical residues in the food chain. Consequently, an increase in the prevalence of antibiotic-resistant pathogens in animal and human populations is likely (FAO 2008). The risk of emerging zoonosis may also increase due to climate-related changes in the survival of zoonotic agents in the environment, changes in migration pathways, carriers, and vectors, and changes in the natural ecosystems.

Extreme weather events such as floods and droughts may lead to contamination of soil, agricultural lands, water and food, and animal feed with pathogens, chemicals, and other hazardous substances, originating from sewage, agriculture, and industrial settings. Ocean warming and subsequent physicochemical changes of marine water may also affect the persistence and patterns of occurrence of pathogenic bacteria, harmful algal blooms, and chemical contaminants in fish and shellfish. Climate change may affect the transport of chemicals into food, including aerial inputs of volatile and dust-associated contamination, flooding, and increased bioavailability of heavy metals due to changing environments and soil properties (Boxall et al. 2009).

2 Climate Change and Biological Hazards

Climate change could affect existing pathogens or lead to the emergence of new pathogens in food through effects on animal husbandry and animal-to-animal transmission, pathogen survival, and other mechanisms (Tirado et al. 2010). The fact that most foodborne bacterial pathogens can grow at room temperature with faster growth favored at elevated temperatures means that increases in ambient temperatures may also speed up the rate of pathogen proliferation along the food chain with the subsequent increase in the number of cases (FAO 2008). Climate change may increase the demand for irrigation water, elevating pathogen risks by manure and sewage contamination. Particularly, temperature increase and changes in precipitation pattern have a close relationship not only with the fate and transport of enteric bacteria but also with their growth and survival. For instance, Liu et al. (2013), in a study of the impacts of climate change on the microbial safety of preharvest leafy green vegetables, predicted that the contamination risks by pathogenic *Escherichia coli* and *Salmonella* are likely to increase.

Some pathogens probably to be affected by climate change are those with low-infective doses (e.g., *Shigella*, *E. coli* serovars) where small changes in distribution or abundance could lead to large outbreaks. Other certainly affected pathogens are those with significant persistence in the environment (e.g., enteric viruses and parasitic protozoa) (FAO 2008). Pathogens with good stress tolerance responses to temperature and pH (e.g., *Salmonella*) may also compete better against other pathogens under climate change. Another aspect to consider is that gene transfer between bacterial species is a common contributor to pathogenicity and antibiotic resistance and is likely to be impacted by changes in the environment caused by climate change.

Gastroenteritis and diarrheal disease are important causes of illness in the world and they are climate sensitive, showing strong seasonal variations (Kovats and Tirado 2006). Higher temperature has been found to be strongly associated with increased episodes of diarrheal disease in adults and children worldwide.

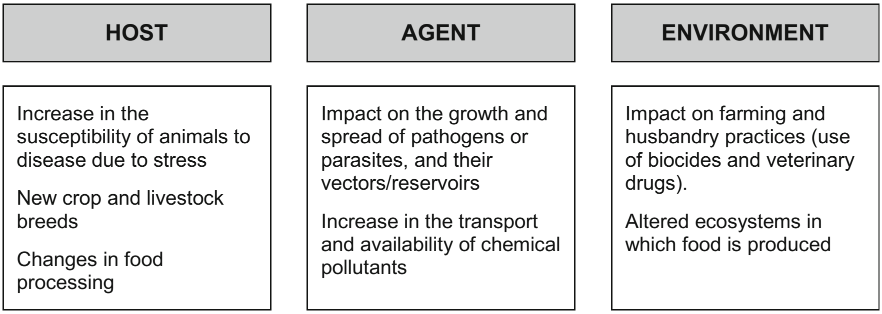

Fig. 1 Some pathways through which climate-related changes and variability may impact all three elements of the epidemiologic triad: host, agent, and environment (adapted from Tirado et al. 2010)

For instance, diarrheal reports in Peru increased 8 % for each degree of temperature increase (Checkley et al. 2000). Increased rates of water-borne diarrhoeal diseases such as cholera, cryptosporidiosis, and typhoid fever have been reported after flood events (Tirado et al. 2010).

As reviewed by Van der Spiegel et al. (2012), there are several ways in which climate change may affect infectious diseases (Fig. 1). First, hot and humid conditions can cause heat stress in livestock, which will induce a higher vulnerability to diseases. Climate change may bring about substantial shifts in disease distribution, and outbreaks of severe disease could occur in previously unexposed animal populations. Second, higher temperatures may increase the rate of development of pathogens or parasites, which may lead to larger populations. Changes to winds could affect the spread of certain pathogens and vectors. In turn, other pathogens that are sensitive to high temperatures and moist or dry conditions may have their survival compromised and decrease with climate warming. Also, there may be several impacts of climate change on the distribution and the abundance of disease vectors (e.g., flies, ticks, mosquitoes), as illustrated by the modification in the distribution of Chikungunya virus in Europe and the recent appearance of autochthonous cases reported in South-Eastern France (Fischer et al. 2013). Finally, farming and husbandry practices (including the use of veterinary drugs) will be affected due to climate-related changes.

Foodborne diseases that have been identified as a priority because of changing climate conditions include salmonellosis, campylobacteriosis, vibriosis, other bacterial infections, viral diseases, and parasitic infections (ECDC 2007).

2.1 Salmonellosis

Previous research has demonstrated that *Salmonella* infections in humans are positively associated with temperature. A time series analysis study on human salmonellosis in several European countries showed that, in general, cases of salmonellosis increased by 5–10 % for each one-degree increase in weekly ambient temperature (Kovats et al. 2004). Infection with *Salmonella* Enteritidis appeared to be more sensitive to the effects of environmental temperature, at least as compared with infections caused by *Salmonella* Typhimurium.

2.2 Campylobacteriosis

The role of climate-related parameters such as short-term increases in ambient temperature on human campylobacteriosis is unclear (Kovats et al. 2005). Although associations between human cases and weather exist, the seasonality is less pronounced and the biological mechanisms underpinning these associations are not fully understood, which makes it difficult to predict the effects of climate change on campylobacteriosis infection.

2.3 Vibriosis

Higher temperatures, flooding, and changes in water salinity may all have an impact on water microbiota including aquatic human pathogens such as the pathogenic *Vibrio* spp. (FAO 2008). Large outbreaks attributed to the consumption of oysters contaminated with *Vibrio parahaemolyticus* have been linked to higher mean water temperatures in the Gulf Coast of the USA. Additionally, changes in epidemiology have been noted since new serovars of *V. parahaemolyticus* such as O3:K6 have emerged and spread, even though a definitive relationship to global climate change has yet to be made (Tirado et al. 2010). The global epidemiology of foodborne *V. vulnificus* infection revealed a statistically significant increase in the number of cases when summer temperatures peaked. Infection by the enteric pathogen *Vibrio cholerae*, which is usually transmitted to humans through contaminated water, is endemic in certain tropical and subtropical regions of the world. In these areas, there are characteristic epidemic peaks which are frequently seasonal (Marques et al. 2010).

2.4 Viral Foodborne Diseases

Viruses do not grow in foods and many of the viruses that cause gastroenteritis in humans do not have a readily demonstrated relationship to ambient temperature. Three major routes of viral contamination of foods have been identified: human sewage and feces, infected food handlers, and animals for zoonotic viruses

(FAO/WHO 2008). All these routes may be influenced by climate-induced changes. For example, flooding can result in the overflow of untreated human sewage, resulting in increased likelihood of enteric virus contamination during the production of fresh produce and molluskan shellfish.

2.5 Parasitical Agents and Foodborne Diseases

There is a causal relationship between climate change and emerging parasitic diseases (Poulin and Mouritsen 2006). Several studies in different geographical regions of the USA and Europe show that climate-related variability, such as changes in precipitation, affects the incidence of parasitical foodborne and waterborne diseases transmitted by protozoan parasites such as cryptosporidiosis and giardiasis (ECDC 2007). Likewise, global warming and increased temperature may affect the transmission cycle of foodborne trematodes of public health significance such as Fasciola, Clonorchis, Schistosoma, and Paragonimus (Poulin and Mouritsen 2006), which are transmitted by the consumption of raw or undercooked freshwater fish, crabs, crayfish, and plants. All trematodes use mollusks (generally snails) as first intermediate hosts for the production of infective cercariae, and an increase in temperature is almost invariably coupled with a larger cercarial output.

3 Climate Change and Chemical Hazards

The chemical safety of food (toxins, contaminants, residues) varies by food type and where it is produced, making it difficult to assess associated changes in food safety when consuming different types of food produced in different geographical areas. Mycotoxins, an important public health concern, are formed through complex interactions between fungi and crops and are affected by weather conditions such as temperature, humidity, and precipitation. A recent review indicated increasing problems of aflatoxins in parts of temperate Europe and the USA as climate change-associated temperature rises approach the optimal level for production of aflatoxins, one of the most important mycotoxins from a public health point of view (Paterson and Lima 2010).

Freshwater and coastal environments are likely to be especially vulnerable to climate change because aquatic ecosystems are fragile (FAO 2008). A number of human illnesses are caused by consuming seafood (especially shellfish) containing natural toxins produced by algal blooms, which are predicted to be more common and more widely distributed in the coming decades (FAO 2008).

It is generally accepted that climate change may lead to altered chemical inputs to food. Greater use of biocides, pesticides, and veterinary medicines is likely in some areas, increasing the presence of chemical residues as well as the prevalence of antibiotic-resistant pathogens. Changes in transport pathways may also affect contaminant inputs to agricultural systems and food (Miraglia et al. 2009). Flooding is one mechanism for transporting chemical contaminants onto agricultural land and may increase due to climate change (Boxall et al. 2009). In addition, altered contaminant inputs to surface waters may have impacts upon aquatic species that are subsequently consumed. Increases in the aerial inputs of volatile and dust-associated contamination may also occur, posing increased risks for human health and the environment.

3.1 Mycotoxins

Mycotoxins are secondary metabolites produced by fungi during their development. As a consequence, the worldwide distribution of mycotoxins is directly related to climatic conditions since temperature and humidity are key factors for the development of toxigenic molds. As illustrated on Fig. 2, in tropical and subtropical regions, where temperature and humidity are favorable for the development of *Aspergillus* species, aflatoxins (Afla) are the main mycotoxins. These mycotoxins represent a serious health hazard as aflatoxin B1 is classified in IARC Group 1 of carcinogenic compounds for humans (Iqbal et al. 2013). This imposes an additional threat to human health since a metabolized but still toxic form of the toxin (AFM_1) is transferred to milk when lactating dairy cattle are fed with aflatoxin B_1-contaminated feedstuffs (van der Spiegel et al. 2012).

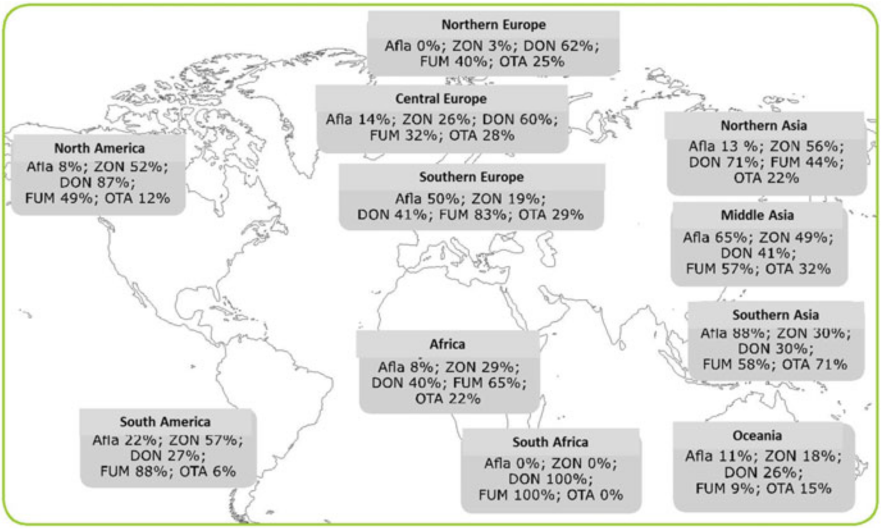

Fig. 2 Worldwide distribution of main mycotoxins in crops (adapted from Rodrigues and Naehrer 2012)

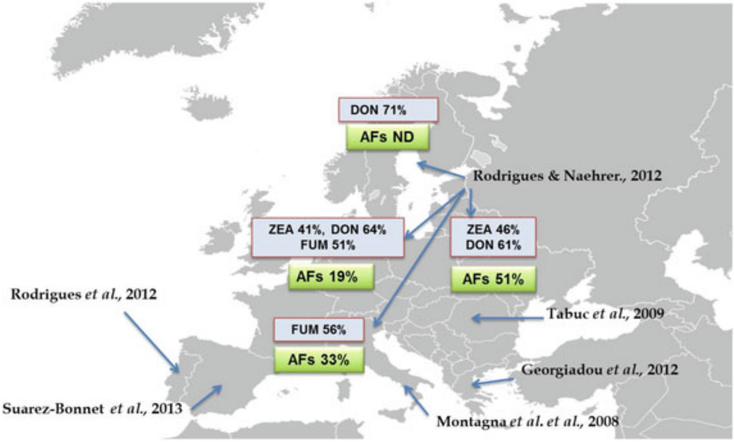

Fig. 3 Alerts signaling aflatoxin B_1 contamination of European productions

By contrast, the European climate was, until now, not considered to allow aflatoxinogenesis, whereas it is ideal for the development of *Fusarium* species on crops. That is why the major toxins that contaminate maize and small grain cereals (wheat, triticale, barley) produced in Europe are deoxynivalenol (DON) and zearalenone (ZON), as well as fumonisins (FUM); type-A trichothecene mycotoxins T_2 and HT_2 affect mainly oats and barley.

However, climate change may have several consequences on mycotoxin distribution. First of all, for several years, alerts signaling aflatoxin B_1 contamination of European productions increased, suggesting that Europe may not be AFB_1 free, which may have strong consequence on risk management strategies (Fig. 3). Thermotolerant fungal species that are adapted to warmer climate, such as *Aspergillus flavus* (i.e., aflatoxins), may therefore become more problematic than *Penicillium verrucosum* (i.e., ochratoxin A—OTA) in temperate Europe (Paterson and Lima 2010).

Moreover, recent studies by Van der Fels-Klerx et al. (2012a, 2013) indicated that climate change could also increase deoxynivalenol contamination of wheat in north-western Europe by up to three times, while for maize, an overall decrease in deoxynivalenol contamination was projected. However, variability between regions and crop years was large, illustrating the need of carefully considering both direct and indirect effects when assessing climate change impacts on crops and related food safety hazards.

An important indirect factor is that the feeding rate of many arthropod vectors (i.e., corn borers) increases at higher temperatures, thus increasing exposure of crops to mycotoxigenic fungi (i.e., *Fusarium* spp.), and hence the spread of mycotoxins.

As another example of the effect of climate on fungal disease, increasing atmospheric CO_2 concentration will directly increase the amounts of *Fusarium* Head Blight and the subsequent risk of trichothecene mycotoxins (Chakraborty and

Newton 2011). This increased susceptibility is probably due to changes in the host physiology and morphology rather than a more infective pathogen.

3.2 Algal Toxins

Some algal species (mainly dinoflagellates and diatoms) produce toxins usually when they bloom, and these marine biotoxins can accumulate in filter-feeding shellfish and some fish species and cause food poisonings in humans, which can be very serious. The most common illnesses associated with algal toxins are ciguatera fish poisoning (CFP), paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), azaspiracid shellfish poisoning (AZP), diarrhetic shellfish poisoning (DSP), and neurotoxic shellfish poisoning (NSP). Global increase of harmful algal blooms in recent decades has been linked to eutrophication of water bodies, the transport of harmful algae species in ships' ballast water, and climate changes (Marques et al. 2010). The observed increase in frequency, duration, and geographic scope of algal blooms has been associated with warmer than usual conditions, so projected warming is likely to result in even greater problems in the future. A study of climate change projections for the years 2030–2050 (van der Fels-Klerx et al. 2012b) reported that the frequency of harmful algal blooms of *Dinophysis* spp. may increase, but consequences for contamination of shellfish with diarrhetic shellfish toxins are uncertain.

3.3 Chemical Contaminants

Human activities have resulted in the release of several chemical contaminants into the environment in the last decades. These include toxic metals (e.g., mercury, cadmium, lead) and persistent organic chemicals, like dioxins and polychlorinated biphenyls (PCBs), among others (Marques et al. 2010). For instance, chemical contaminants enter marine ecosystems via direct discharges from land-based sources (e.g., industrial and municipal wastes), atmospheric deposition from local and distant sources, and ships (Schiedek et al. 2007). Many contaminants accumulate in sediments, where they can remain for very long periods, and in the food web where they can reach high concentrations in top-level predators and ultimately affect human health. Climate change impacts on hydrographic conditions are expected to directly influence the availability and toxicological effects of chemical and biological contaminants. Warmer water temperatures and changes to precipitation and stream flow patterns may exacerbate many forms of water pollution with toxic metals and persistent organic chemicals.

The salinity of coastal and estuarine systems will experience fluctuations arising from changes to precipitation and stream flow patterns. Salinity may affect the toxicity of various classes of toxic metals due to either bioavailability or physiological factors. In particular, metals like cadmium and mercury are taken up more rapidly by mollusks and crustaceans at reduced salinities (Hall and Anderson 1995). Likewise, temperature-related increases in the uptake, bioaccumulation, and toxicity of metals have been reported for crustaceans, echinoderms, and mollusks (Wang et al. 2005). Warmer water temperatures facilitate mercury methylation, and the subsequent uptake of methyl mercury by fish and mammals has been found to increase by 3–5 % for each 1 °C rise in water temperature (Booth and Zeller 2005). Similarly, cadmium bioaccumulation by blue mussel *Mytilus edulis* was higher at 12 °C than at 2 °C, as well as lead uptake increased at 26 °C as compared to 6 °C.

4 Conclusions

In the future, food systems are likely to change for a number of reasons, including climate change as a very important factor. An altered climate will mean that food will be produced under different environmental conditions and, coupled with adaptations to and mitigations against climate change, food production will be very different in the future. These changes will result in emerging pathogens and altered use of pesticides and veterinary medicines and will likely affect the main transfer mechanisms through which contaminants move from the environment to food, with implications for food safety.

Some pathogens and chemicals are transferred from animals to humans, so monitoring of animal health may enable us to detect threats before human infection occurs. Development of rapid detection methods for pathogens and chemicals in food, and surveillance systems to report these quickly, may enable action to be taken in a timely manner. Furthermore, it is recommended to closely monitor levels of mycotoxins and marine biotoxins, in particular related to risky situations associated with favorable climatic conditions for toxin producing organisms.

The common theme arising for food safety is altered risks and increasing unpredictability and change (Jacxsens et al. 2010). Greater unpredictability suggests the need for increased surveillance to identify potential hazards before they occur and greater speed in addressing emerging threats. Risk managers are encouraged to pay attention to the continuity of collecting the right data, the availability and accessibility of databases, as well as the harmonization of terminology and data collection. The situation demonstrates the need for scientific research and development of improved tools, techniques, and practices to adapt the current risk management systems.

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