Potential Contaminants in the Food Chain: Identification, Prevention and Issue Management

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Abstract

Contaminants are a vast subject area of food safety and quality. They are generally divided into chemical, microbiological and physical classes and are present in our food chain from raw materials to finished products. They are the subject of international and national legislation that has widened to cover more and more contaminant classes and food categories. In addition, consumers have become increasingly aware of and alarmed by their risks, whether rightly or not. What is the food industry doing to ensure the safety and quality of the products we feed our children? This is a valid question which this article attempts to address from an industrial viewpoint. Chemical food safety is considered a complex field where the risk perception of consumers is often the highest. The effects of chronic or acute exposure to chemical carcinogens may cause disease conditions long after exposure that can be permanently debilitating or even fatal. It is also a moving target, as knowledge about the toxicity and occurrence data of new chemical contaminants continues to be generated. Their identification, prevention and management are challenges to the food industry as a whole. A reminder of the known chemical hazards in the food chain will be presented with an emphasis on the use of early warning to identify potential new contaminants. Early warning is also a means of prevention, anticipating food safety concerns before they become issues to manage. Current best management practices including Hazard Analysis and Critical Control Points relating to the supply chain of baby foods and infant formulae will be developed. Finally, key lessons from a case study on recent contamination issues in baby food products will be presented.

Introduction

Contaminants are a vast subject area of food safety and quality. They are generally divided into chemical, microbiological and physical classes and are
present in our food chain from raw materials (RMs) to finished products. They are the subject of international and national legislation that has widened to cover more and more contaminant classes and food categories. In addition, consumers have become increasingly aware of and alarmed by their risks, whether rightly or not. What is our food industry doing to ensure the safety and quality of the products we feed our children? This is a valid question which this article attempts to address from an industrial viewpoint.

Stomach upsets and incidences of food poisoning have mainly been attributed to microbiological hazards such as *Campylobacter*, *Salmonella*, *Escherichia coli* 0157, etc. Infections of these and other pathogens can be food-borne, due to poor hygiene or even contracted from domestic or farm animals. Hazard Analysis and Critical Control Points (HACCP) is a very well established risk management tool in the food industry that has certainly led to an overall decrease in gastrointestinal infections from processed food. Physical contaminants like foreign bodies, glass and metallic fragments can be avoided by a strict management of supply chain and manufacturing processes and also by the use of instruments like X-ray detectors. Microbiological and physical contaminants have been the historical focus of the food industry for many decades and will continue to be the focus of attention and new approaches for their elimination. Indeed, this article could be solely dedicated to these types of contaminants. However, the purpose here is to focus on chemical contaminants.

Chemical food safety is considered a complex field where the risk perception of consumers is often the highest. The effects of chronic or acute exposure to chemical carcinogens may cause disease conditions long after exposure that can be permanently debilitating or even fatal. It is also a moving target, as knowledge about the toxicity and occurrence data of new chemical contaminants is continuing to be generated. Their identification, prevention and management are challenges to the food industry as a whole.

**Identification**

The field of chemical contaminants has undergone a certain evolution. In the early days and up to about two decades ago, research in food safety was mainly focused on the analysis and toxicity of active compounds like the class of organochlorine pesticides. Then it became understood that the degradation products or metabolites of some compounds could equally be found in foodstuffs and could have an even higher toxicological risk. Examples are, ethylenethiourea and propylenethiourea originating from dithiocarbamates or desulfylfipronil and fipronil sulfone from fipronil. More recently attention has been turned to understanding the fate of contaminants produced from industrial thermal processes, enzymatic processes, and those that can exist in a bound form linked to other constituents of the foodstuff such as proteins or
carbohydrates. Examples are: bound deoxynivalenol glucoside in fusarium-infected wheat and maize [1]; enzymatically formed 3-monochloropropanediol [2], and heat-induced acrylamide [3]. Andrews et al. [4], in Safety and Quality Research Priorities in the Food Industry, provide a good overview of the main areas of contaminants highlighting new avenues for research.

As an overview, the field of chemical contaminants can be broken down into several subclasses as presented in figure 1. The scope is quite large ranging from plant protection products to veterinary drugs and packaging migration compounds. Also, the points where a potential contamination could occur are all along the food chain. This gives an idea of the complexity involved when implementing a contaminant management program. Classical contaminants like pesticide residues, mycotoxins, heavy metals, etc., are well described in the literature and are routinely monitored in food analysis laboratories. To ensure low or the absence of contaminant residues in baby foods and infant formulae, agricultural RMs are or should be monitored. We will see later that combined with a strict upstream control of the supply chain is the best means to avoid contaminant residues from entering infant food.

In addition to batch-to-batch analysis for infant food manufacturers, most governmental agencies also carry out yearly monitoring programs to assess the levels and risks associated with known contaminants in these sensitive food products. Today, baby food and infant formulae are the most tested of all food categories. Increased awareness and surveillance has led to improvements in agricultural practices and supply chain control leading to minimized

\[ \text{Fig. 1. Chemical hazard identification in the food chain.} \]
and safe levels in RMs. Published official surveys in developed countries have shown a consistent decline in contamination levels in both RMs and finished products. The British Food Standards Agency released results from a 2003 survey on dioxins and dioxin-like PCBs in 124 retail samples of baby foods and concluded a continued decrease of 85% in dietary intakes since they first started the surveys in 1989 [5]. Furthermore, for the food types where EU limits are in force, i.e. milk-, meat-, egg- and fish-based products, all concentrations of dioxins were within the appropriate EU limits.

What about emerging or unknown contaminants? For the last 2–3 years early warning has been the current trend where food companies and authorities attempt to take a proactive approach anticipating food safety issues rather than being obliged to work reactively when faced with a declared problem. Within Europe the European Food Safety Authority (EFSA) has commissioned a project to develop an early warning system, described in the EFSA Journal [6]. This is called the EU EMRISK Project.

Early warning systems if well designed and of high quality can identify new chemical risks before they become issues to manage. Figure 2 shows this underlying philosophy upon which Nestlé’s Early Warning System has successfully been built. Our early warning system proceeds through three main stages. Firstly, there is the collection of information. The outcome of early warning is only as good as the input to the system. In addition to other areas of importance to food safety like microbiology, in the case of contaminants the system mobilizes our key scientists in all fields of contaminant expertise corresponding to the scope along the food chain as shown in figure 1. They do

Fig. 2. Philosophy of Nestlé’s early warning system.
not act alone, as toxicologists, agronomists, RM buyers, analytical experts from testing laboratories, and our external consultants all contribute to enrich the quality and quantity of information that feeds the system. The second stage is to scientifically evaluate the information, weeding out the useful from the rest. The relevant valid information is then used to elaborate possible solution strategies for prevention or mitigation actions in the operational environment. Senior management commitment and their decisions on proposed recommendations is necessary for this system to function effectively. The system is based on a network approach where the company leverages all its resources to bring benefit to the company and to the consumer.

**Prevention**

Above, it was shown that an effective early warning system for food safety can be an instrument in the work of prevention. However, on a daily basis the greatest measures of prevention belong to the operational procedures used to control the industrial supply chain and production of baby foods and infant formulae. This is part of the overall quality assurance system that starts with written documents describing the controls on all the following critical areas:

- Selection of suppliers, farms, fields
- Agricultural practices (seeds, fertilizers, plant protection products)
- Harvesting
- Transport
- Storage
- Sampling procedures
- Analytical and monitoring programs
- Product release procedures
- Supplier audits, corrective actions
- Laboratories, performance tests, accreditation
- HACCP plan
- Distribution

It is quite an extensive program that encompasses all aspects related to the infant nutrition supply chain, production and distribution. For more information, Vasconcellos [7] provides a comprehensive review of all quality assurance aspects in the food industry. Finished products must also be compliant with national or international legislation. In this respect, standards and norms are also a means of prevention, obliging the producer to respect specific limits in finished products and taking the necessary actions to ensure those limits are respected through the entire industrial process. As mentioned earlier, for infant nutrition products, control of the supply chain is crucial.

Different sourcing strategies exist depending on the nature and safety risk of the RM. Some RMs are sourced through the trade channels, others directly from farmers. The Nestlé approach involves adaptation of growing systems,
contract growing and development of full traceability meeting legislation and internal norms. Contract growing is used for sensitive RMs with high risk and difficult supply; supplier contract growing for relatively high risk RMs where the supplier guarantees supply and safety through their own competence. Selective purchasing is used where risk is relatively low and the supplier guarantees supply and safety from their own controls. Finally open market trading can be used for relatively low risk RMs and where availability is high. This entails a methodological work of selecting suppliers, farmers and farms applying restrictive instructions with contractors and farmers. It can also involve contracting before start of season. Application of good agricultural practices is key. For example, an approach to avoid mycotoxin problems in cereals involves:

- Selection of growing areas
- No maize in crop rotation
- Control of fusarium toxins (implies choice of fungicides)
- Choice or resistance varieties
- Correct grain drying before storage
- Selection of storage facilities
- Analyses to identify critical control points

Consequences of this approach encourages suppliers and farmers to act as experts guaranteeing measurable quality and safety, participating in sustainable agricultural programs, increasing added value if requirements are met. These measures will in turn increase the responsibility of the primary production sector.

Agronomists follow up with agricultural advise and control during the growing season using defined analytical procedures that meet analytical specifications on representative samples taken from homogeneous lots. Representative samples are the key to quality assurance. These need to be obtained taking all risks into account. These may be taken over different stages, e.g. cereals at the field, storage, transport, or vegetables at the field and harvest. The range of contaminants analyzed depends on the reliability of information. Taking pesticides for example, information on registered pesticides, spray plans and illegal use allow a hit list of pesticides to be identified. This can then be used to establish analytical programs carried out in the Nestlé laboratories.

Processing RMs into finished products is considered a safety factor but, on its own, not a solution. Careful management of growing systems aims to reduce the range of contaminants. Once within the factory environment HACCP is ‘the’ tool for assisting in the prevention of safety issues. It requires an in-depth knowledge of processes and products from start to finish. Simply put, potential hazards are identified by specialists (in cross-functional teams) and controls are implemented to monitor them with the system documented and continuously improved. More information on HACCP can be found in Mortimore and Wallace [8].
The above measures are designed to give confidence that food safety is being managed properly and professionally allowing the manufacturer to focus on producing a safe product.

**Issue Management**

Zero risk does not exist! Food companies and legislators are obliged to manage the issues in order to minimize risks. Chemical risk assessment is a tool for issue management. The principles of risk assessment of food and human health care are well described in the ILSI monograph series [9]. Schilter [10] also described the risk assessment approach in the ‘Assessment and Management of Pesticides Toxicological Risk in Baby Food Manufacturing and New Product Development’. Figure 3 shows the approach used to perform a risk assessment.

One of the first tasks is to establish safe levels. Paracelsus is attributed with stating that the poison is in its dose. The identification of a chemical hazard has to be based on scientific facts that either declare the potential hazard to be real or not. If toxicological and occurrence data exist for a known contaminant in a RM or finished product then assessing the risk is reasonably straightforward (fig. 4). However, when confronted by new chemical molecules for which there are no toxicity data then estimations have to be made (fig. 5). These are usually based on molecular structure and calculated reactivity. Modelization tools, such as quantitative structure activity relationships or computational toxicology, are useful for estimating toxicity. Once past this...
filter then the job of assessing its occurrence in food is required. Risk assessors then use experimental or modeled exposure data. Most available toxicological data on contaminants is often at high doses. Due to the general low levels found in food, a current area of research is to develop risk assessment approaches for contaminants at low doses and over long periods of time.

Fig. 4. Ensuring food safety in existing products.

Fig. 5. Ensuring food safety in new products.
A conservative approach often used in Europe for contaminants of unknown toxicity is the threshold of toxicological concern [11]. In risk assessments for infants and children the nature of their food consumption is most important. Infants are restricted to similar diets everyday offering little variety when compared to adults, and this consumption is very high when related to body weight. Furthermore, their diet is consumed for a relatively short time period until the infant starts to consume a greater variety of foods.

The recent case of the hydrazine compound semicarbazide (SEM) found in baby food jars in 2003–2005 illustrates an example of issue management. SEM is a known metabolite of nitrofuran antibiotics which are prohibited in the EU and should not be found in baby foods. These antibiotics are allowed for veterinary use and residues can be found in animal products such as meat, eggs, shrimp, honey, etc. In early 2003, SEM was found in baby foods not containing animal RMs. At first difficult to understand, the presence of SEM in the vegetable-containing baby food was attributed to the migration from the azodicarbonamide blowing agent used to manufacture the air-tight seal of the jar closure. IARC classifies SEM as group 3 meaning ‘not classifiable as to its carcinogenicity to humans’. As there was a concern about possible carcinogenicity risk, a safety assessment was performed. The approach is shown in figure 6. From the literature there were some indications that SEM has a weak genotoxicity and a weak carcinogenicity. Therefore during June–July 2003 the Nestlé Research Center focused on the safety assessment on non-threshold, carcinogenic effects. The basis of the exposure assessment was the following:

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**Fig. 6.** Safety assessment of semicarbazide (SEM).
A lifetime exposure was assumed with variations according to life stages.

- Highest exposure was assumed in infants with a peak at 6–12 months.
- 95th percentile intake of baby foods was taken.
- 20 ppb level was taken for all products.
- Highest exposure = 1.05 μg/kg birth weight/day in 9-month-old infants.

Such an exposure is likely to decrease over time, e.g. a 60-kg adult consuming 100 g products (e.g. sauces, dressings) contaminated at 15 ppb, is exposed to SEM at about 0.025 μg/kg body weight/day.

Exposure to 1.05 μg/kg body weight/day is unlikely to be of concern for non-cancer threshold toxicity (i.e. osteolathyism, vasculopathy, neurotoxicity) since the reported lowest observed adverse effect levels for these effects are about 50–100 mg/kg body weight/day.

The assumptions for non-threshold carcinogenicity were:
- No safe level assumed, use of quantitative risk assessment.
- Quality risk assessment models express risk (i.e. probability) as function of dose.
- When assuming simple linear proportionality of risk as a function of dose and extrapolating this risk at the highest estimated SEM exposure.
- SEM exposure of 1.05 μg/kg body weight/day leads to a theoretical increased risk of about 2.3 extra cancer cases in a million persons exposed over lifetime.
- Conservative assumptions: (1) linear dose-response (several authors note that use of simple linear models to low-dose extrapolation is very conservative and may exaggerate risk by about 2 orders of magnitude); (2) absence of detoxification and repair processes, and (3) constant upper-bound exposure over lifetime.

Therefore, the theoretical risk was considered low – it is usually considered that exposures resulting in risk <10^{-6} are virtually safe. SEM from food in jars is unlikely to present appreciable carcinogenic risk to human health.

At that time in July 2003, the EFSA was informed through the European Confederation of Food Industries. The food and packaging industry started a joint working group to find solutions to the potential problem. The EFSA also commissioned a genotoxicity study. In October 2003, EFSA publicly recommended reducing SEM in baby foods but also advised not to change eating habits. In January 2004, an EU directive was published banning the use of azodicarbonamide as a blowing agent in seals. Then in March 2004, the EFSA study revealed SEM not to be genotoxic. The joint industry group was starting to have promising results and by November 2004 was praised by EFSA and the EU for their progress. In February 2005, commercial alternatives existed to replace azodicarbonamide. Finally, in July 2005, the EFSA scientific panel concluded that there is no health concern from SEM at levels currently found in food, even for infants. SEM acts through a genotoxic threshold effect.

- SEM-induced genotoxicity has been shown to be mediated by reactive oxygen species, and inhibited by antioxidants or metabolic systems.
Therefore, a practical/apparent threshold for carcinogenicity may be applied, suggesting that SEM is unlikely to be of concern for carcinogenicity [12, 13].

It is generally considered that issue management is a combination of three factors: risk assessment, risk management and risk communication (fig. 7). While important to assess the safety of contaminants in foods, the SEM case shows that it is important to keep into perspective the relevance of the risk and weigh it against the benefits. In the SEM case, the blowing agent was providing a microbiologically safe product whose benefits far outweighed any potential risk of adverse effects.

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**References**

Discussion

**Dr. Haschke:** For most pediatricians this is new, but not for me because I have been involved several times. It shows how a company, and I think Nestlé is not alone, takes care in the safety of food. You showed us the case of semicarbazide where you could manage the risk from the first to the last step. There was only one critical issue when an issued statement was a little bit preliminary, but there are other issues which are more or less not manageable that way, they end up being an emotional issue. You have mentioned the ITX issue; it was clear from the beginning that there would be no health risk, but on the other hand it ended up as a highly emotional thing which appeared on the internet within a few days and of course was used by several organizations to criticize the quality of commercial products. What is the percentage of the problems which become emotional, where you really have a comparison tool with which you can manage the whole value chain of risk management? In the case of ITX, was there no chance to come up with a sound scientific statement before it became emotional and politicians picked up the issue and brought it to the surface? Would there not have been a chance to handle that differently?

**Dr. Scanlan:** I don’t have a value or any figures about the number of incidences that occur where there is the emotional side to it. For the last few years the handling of these issues has become more professional, and because there is more awareness on the regulator side, they are being managed better. Remember the case of acrylamide a few years ago that went directly to the media, and it created a real snowball effect. In the case of furan, the most recent one, there has been no snowball effect. It has been handled much better. There has been an improvement in that but different people, journalists for example, have their own interest, they want to sell newspapers, so when it comes to things like ITX they will jump on the wagon and create a big issue. At the time of the ITX story, we actually did a risk assessment which was provided to the Italian authorities, but it didn’t lead to resolving the problem at the time. We shared all our information about any potential concern with them, and actually it wasn’t found to be any kind of threat; this was also communicated to European Food Safety...
Association (EFSA) at the time, and they agreed with us by the way. I don’t know if you know this, but the EFSA actually came out and said that our risk assessment was correct and there was no concern about ITX but the Italian authorities decided otherwise. Of course it was in the hands of the judges who were applying a very black and white approach to it, presence, no presence; they weren’t really concerned with the state of the assessment.

Dr. Calçado: I think people have a lot of misconception about food, not only in Brazil but worldwide. They think that non-processed foods are all healthy and not contaminated by bacteria or toxins. Otherwise, industrialized foods are thought to be not the best and full of dangerous additives.

Dr. Scanlan: That is true, processing is healthy, it is not the only means of course but it is healthy. The statement can be made that processed foods today have never been as safe; if you go back 100 years, today the food is far safer than it was then. I hope the next speaker will talk about the microbiological aspects and bring that up.

Dr. Jongpiputvanich: According to the actual WHO recommendations the sugar content should be less than 10% of the total calories. But in commercial baby food or commercial complementary food, the sugar content is more than 10% of the total calories. Why do the manufacturers do that? Are they only concerned about the taste of the food rather than healthy food?

Dr. Scanlan: I would imagine that there are regulations about how much sugar can be put in the food. Dr. Gailing, do you want to comment?

Dr. Gailing: Yes, a specific regulation in Thailand asks that sucrose not be added to infant formula. In the new Codex standard for infant formula it is the same, but for cereal-based baby food the new Codex standard allows up to 20% of added sugar in the components because there is no scientific base to ban sugar from the food of children, they need some calories. We just probably need to limit the consumption of sugar, but nevertheless the higher level is 20% of the total calorie intake in the cereal formula. Globally in our products we are between 10 and 15% when we add sugar.

Dr. Turck: It is generally considered that risk assessment and risk management at the regulatory level should be conducted by two different institutions. In my experience at the French Food Safety Agency, I am not sure that this is the ideal solution. What is your opinion on the experience of the EFSA which finally has a quiet opinion on the contaminant whereas DG Sanco decides exactly the reverse?

Dr. Scanlan: I would agree with you that the two bodies should act independent from one another in the sense that there are two different bodies; there are the risk assessors and the risk managers, but they need to have a very good communication. Don’t forget that in 2003 EFSA was brand new and had just started their operations, and they were also engaged in a learning curve on how to deal with these types of issues, not only with DG Sanco but also with the different national regulators in the different countries of the EU. I remember discovering at the time that there wasn’t very good communication between EFSA and France, UK, Germany, it was quite scattered, and then we saw with DG Sanco that there was a very poor communication going on. I would hope that it has improved since then, but I think it was more to do with a learning curve.

Dr. Gailing: It is not the problem of having separate risk assessment and risk management because they can talk together. It is more a problem of the application of the precautionary principle that the risk managers very often use because they want to go very quickly to protection because it is the aim of the precautionary principle to protect the public, even if it is not useful.

Dr. Scanlan: That’s a good remark.

Ms. Darira: There is a growing perception among consumers that organic foods are actually safer. In your opinion, as a chemist, is this true or not?
Dr. Scanlan: That is not a simple question. I wouldn’t want to get into the debate between organic food and processed food. It all depends on the hazards in the food, whatever it happens to be, and how that is managed. I have seen a lot of surveys of naturally grown organic food where the pesticide residue levels were far higher than whatever is found in the processed food. I have also seen cases where it is very clean and very good. So it all depends on the supply chain, how it is managed, how the whole production is taken care of. So there is no easy answer to your question.