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Department of Food Sciences

Course handouts

Intended for students of

MI CAE & MI CQAA

FUNDAMENTALS OF FOOD TOXICOLOGY

PRINCIPLES, MECHANISMS, RISK ASSESSMENT AND PREVENTION

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Preface

The continuous evolution of food sciences, together with the increasing demands for food safety, has placed toxicology at the forefront of scientific, industrial, and regulatory concerns. Understanding and managing the risks associated with food contaminants, chemical substances, and food contact materials has become a major challenge in protecting consumer health.

This course manual has been prepared to support Master's students in acquiring both the fundamental and applied knowledge required in food toxicology and the toxicology of food packaging materials. It provides an integrated approach to understanding the mechanisms of toxic substances, their fate within the body, the principles of risk assessment, and the interactions that may occur between food products and their packaging materials.

The manual is organized in a progressive manner to facilitate learning. It first introduces the fundamental concepts of general toxicology before addressing food contaminants, risk prevention strategies, genotoxicity, migration phenomena, and the regulatory aspects governing food safety. Figures, summary tables, and review questions are included throughout the chapters to enhance understanding and promote students' self-assessment.

Although this manual does not claim to be exhaustive, it has been designed as a pedagogical resource to complement classroom instruction. It aims to meet the educational objectives of the Master's programs in CAE and MICQA by providing students with the scientific foundations necessary to understand current challenges in food safety and the toxicological assessment of food contact materials.

It is my hope that this manual will facilitate students' learning and foster a scientific and critical approach, which is essential for their future careers in the fields of food science, quality control, research, and public health protection.

Table of contents

Chapter III: Mechanisms of action of toxic substances (toxicodynamics)

Chapter IV: Harmful substances in our food

Chapter V: Risk assessment

Chapter VI: Prevention in food toxicology

Chapter VII: Genotoxicity , mutagenicity and cancer

List of abbreviations

Abbreviation	Meaning
ADME	Absorption – Distribution – Metabolism – Elimination
BPA	Bisphenol A
CCP	Critical Control Point
DJA	Acceptable Daily Dose
DL50	Lethal Dose 50%
ED50 / DE50	Effective dose 50%
EFSA	European Food Safety Authority
GC	Gas Chromatography
HACCP	Hazard Analysis Critical Control Point
HPLC	High-Performance Liquid Chromatography
LOAEL	Lowest Observed Adverse Effect Level
MSG	Monosodium Glutamate (monosodium glutamate)
NOAEL	No Observed Adverse Effect Level
PCB	Polychlorinated biphenyls
SCGE	Single Cell Gel Electrophoresis (comet test)
THAT	Chromosomal Aberration
WHO	World Health Organization

List of figures

List of tables

In a context marked by the globalization of food trade, the intensification of industrial processes, and evolving consumption habits, food safety is a major public health concern. Chronic or acute exposure to potentially toxic substances, present in foodstuffs or originating from their packaging environment, raises considerable scientific, regulatory, and socio-economic challenges.

Food toxicology is thus an essential discipline for identifying, characterizing, and assessing the risks associated with contaminants of chemical, biological, or technological origin. It is based on the study of interactions between xenobiotics and biological systems, integrating the fundamental concepts of general toxicology, particularly toxicokinetics (absorption, distribution, metabolism, and excretion) and toxicodynamics (mechanisms of action and biological effects).

Furthermore, the increasing use of sophisticated packaging materials in the food industry, while essential for preserving, protecting, and enhancing the value of products, introduces new challenges related to the interactions between the container and its contents. The migration of chemical substances, which can alter the organoleptic properties of food or pose a risk to human health, constitutes a major area of research in modern toxicology.

Within this framework, the present work, through its various chapters, proposes an integrated approach to toxicology applied to food and packaging materials. It aims to analyze the main types of food contaminants, describe the mechanisms of their action within the body, and study the physicochemical and biological interactions between foodstuffs and their packaging. Consequently, a central question arises :

To what extent do food contaminants and interactions between food and packaging materials contribute to toxicological risk to the consumer, and how can these risks be assessed and controlled?

1. Introduction

Toxicology comes from the Greek word *toxicum,* meaning "poison." Toxic substances have been known and used since ancient times by the Egyptians, Greeks, Romans, and other civilizations.

The physician and philosopher **Paracelsus (1493–1541),** considered the father of toxicology, formulated a fundamental principle: ***"Everything is poison, nothing is poison, it is the dose that makes the poison."***

From the 19th century onwards, toxicology developed into a modern science based on solid experimental foundations. It draws upon several disciplines: biology, chemistry, pharmacology, physiology, and environmental science. Toxicology studies:

- The harmful effects of chemical substances on living organisms
- Their detection in various products (medicines, food, cosmetics, pollutants)
- Methods of preventing and treating poisoning

2. Terminologies

Poison or toxic substance: Any substance capable, after introduction into the body and depending on the dose, the route of entry, and the individual's condition, of disrupting certain vital functions, seriously damaging organic structures, or causing death. It may be of natural origin (e.g., dust, pollen) or artificial origin (e.g., formaldehyde), or of chemical (e.g., acetone) or biological (e.g., aflatoxins) nature.

Xenobiotic: A substance foreign to the organism that can induce harmful effects. Examples: pollutants, pesticide residues, medications, etc.

Toxin: a toxic substance of biological origin, synthesized by living organisms, such as bacterial toxins and mycotoxins.

Toxicity: The intrinsic ability of a substance to cause harmful effects at different levels: molecular, cellular, and organic.

Dose: quantity of substance administered.

Lethal dose (LD50): dose of a substance expected to cause death in 50% of a test population under specified experimental conditions.

Exposure: contact between an organism and a toxic substance.

Toxic kinetics: the study of the fate of a toxic substance in the body (absorption, distribution, metabolism, elimination)

Toxicodynamics : the study of the biological effects and mechanisms of action of toxic substances

Bioavailability: the fraction of the substance that reaches the bloodstream

Bioaccumulation: the progressive accumulation of a substance in the body

Acute effect: rapid effect after short exposure

Chronic effect: effect resulting from prolonged exposure

subchronic effect: intermediate between acute and chronic

Systemic toxicity: affects the entire body

Local toxicity: limited to the site of contact

Metabolism (biotransformation) : the transformation of the toxic substance in the body

Synergy: an interaction where two substances mutually increase their toxicity

Antagonism: one substance reduces the toxic effect of another

Ecotoxicology: the study of the effects of toxic substances on the environment

Clinical toxicology: the study of poisoning in humans

Analytical toxicology: identification and quantification of toxicants

Toxicity threshold: the minimum dose that produces a toxic effect

Safety factor: margin used to protect human health

3. Classification of toxic substances

Numerous classifications are proposed, the most important of which are those based on:

- The chemical nature of the compound (e.g., gaseous, mineral or organic toxins);

- The mechanism of toxic action (neurotoxic, hepatotoxic and nephrotoxic);
- According to usage (e.g., poisonings caused by insecticides, herbicides, etc.);
- The nature of the danger (based on various criteria: physico-chemical properties, nature and intensity of toxic effects, exposure conditions).

4. Routes of exposure and modes of penetration of toxic substances

The body is exposed to numerous toxins present in the environment. These toxins can enter the body through three main entry points:

4.1. Digestive tract

Toxins can be ingested through accidental ingestion, by consuming contaminated food or beverages, or by ingesting particles expelled through the respiratory tract. This is the most common route of transmission for toxins.

4.2. Respiratory route (Inhalation)

It is the main route of absorption of toxins, whether solid or liquid particles (aerosols and bio-aerosols, dust), gases and vapors suspended in the air, since they will be inhaled at the same time as the ambient air that contains them.

4. 3. Cutaneous route (skin)

The skin is an impermeable barrier that covers the entire surface of the body and protects it, but it can be penetrated by several toxins following contact with a liquid, a solid or vapors.

Regardless of the route of absorption, toxins reach the blood, lymph, or other bodily fluids. Blood is the primary vehicle for transporting toxins and their metabolites.

5. Toxicological interactions

The effects of a toxic substance can be modified by the simultaneous or separate administration of another toxic substance. Various terms exist to describe toxicological interactions occurring when two or more substances are combined (Table **I)**:

5.1. Synergy: the response is greater than the sum of the responses of the substances taken individually (the effect of two substances administered simultaneously is equal to or greater than the sum of the effects they produce when administered separately).

5.2. Addition (additivity): the response is equal to the sum of the responses of the substances taken individually; there is no interaction (the overall effect is equal to the sum of the partial effects. This occurs when the associated toxins act on the same receptors).

5.3. Potentiation: this occurs when a substance with little or no toxicity increases the response of another substance. It is present when the overall effect of the toxicants is greater than the sum of the separate effects of each of these toxic substances. Overall effect > A + B (the action of A is enhanced by the introduction of B)

5.4. Antagonism: the response is less than the sum of the responses of the substances taken individually. Antagonism exists when one substance partially or totally opposes the effects of another substance.

Table I: Summary of different types of toxicological interactions

Type of interaction	**Definition**	**Overall effect**
Synergy	Combined effect greater than the sum of individual effects	**> A + B**
Additivity	The effect is equal to the sum of the individual effects.	**= A + B**
Potentiation	A non-toxic substance increases the toxicity of another	**>> A + B**
Antagonism	One substance reduces the effect of another	**< A + B**

In conclusion, toxicology is an essential discipline for understanding the effects of chemical substances on living organisms. It allows us to assess risks, prevent poisoning, and protect human health and the environment.

6. Review questions

1. What was Paracelsus' contribution to toxicology?
2. What is the difference between a toxic substance and a toxin?
3. Define a xenobiotic with an example.
4. Why is dose a determining factor in toxicology?
5. Compare the different routes of exposure to toxic substances.
6. Give examples of toxicological interactions in everyday life.

1. Introduction

After penetration, the toxic substance is distributed into different compartments of the body where it undergoes several metabolic transformations, especially in the liver, resulting in derivatives that are more water-soluble and easily excreted.

The chemical substance or its metabolites can bind reversibly or irreversibly to target molecules and sometimes can be eliminated in unchanged form.

2. Fate of a toxic substance in the body

2.1. Exposure phase: includes all the factors that will determine the necessary concentrations of the toxic substance for which the target organ will actually come into contact with the toxic substance.

2. 2. Toxicokinetic phase: this is the influence exerted by the body on a toxic substance, in other words, is the study of the pathway of the substance once it comes into contact with the body. It is based on four fundamental stages: ***Absorption, Distribution, Metabolism and Elimination*** **(ADME) (Figure 2, page 10):**

2.2.1. Absorption of toxic substances

This is the passage of a xenobiotic from its site of contact until it reaches the bloodstream.

The toxic substance can exert a direct toxicity (strong acid or strong base), or after its penetration into the body.

2.2.2. Distribution (transport)

After absorption, the xenobiotic reaches the bloodstream, where it can be stored or undergo initial metabolism. It will then be primarily distributed to the various body fluids, and subsequently to the tissues.

Xenobiotics in the blood can:

- Dissolve in plasma water,
- Bind partially to plasma proteins,
- Bind to the cell membrane or penetrate the cytoplasm of formed elements, in particular red blood cells (ex: lead).

The body has barriers that prevent the penetration of certain groups of toxins (especially hydrophilic ones) into organs and tissues.

Example: The placental barrier reduces the penetration of high molecular weight molecules and hydrophilic toxins from maternal blood to the fetus.

2. 2.3. Metabolism (biotransformation)

Biotransformation reactions. in other products: *metabolites.* These reactions take place in various tissues (liver, kidneys, muscle, intestine, lungs).

Toxins are transformed into more polar, more water-soluble compounds, which are therefore more easily eliminated and *less toxic: detoxification.* However, some metabolites may be *more toxic:*

Examples: - Oxidation of methanol into formic acid which is toxic to the optic nerve.

- Oxidation of ethylene glycol to oxalic acid which causes kidney damage.

A toxic substance A introduced into the body can follow one or more of three pathways:

1. Passage through and elimination in intact form (no change) **(A)**

2. Successive transformation into compound **B** and then into compound **C,** which will be eliminated

3. Transformation into compound **D** which will be eliminated.

Figure **2** illustrates the different biotransformation reactions and the stages of detoxification of a toxic substance.

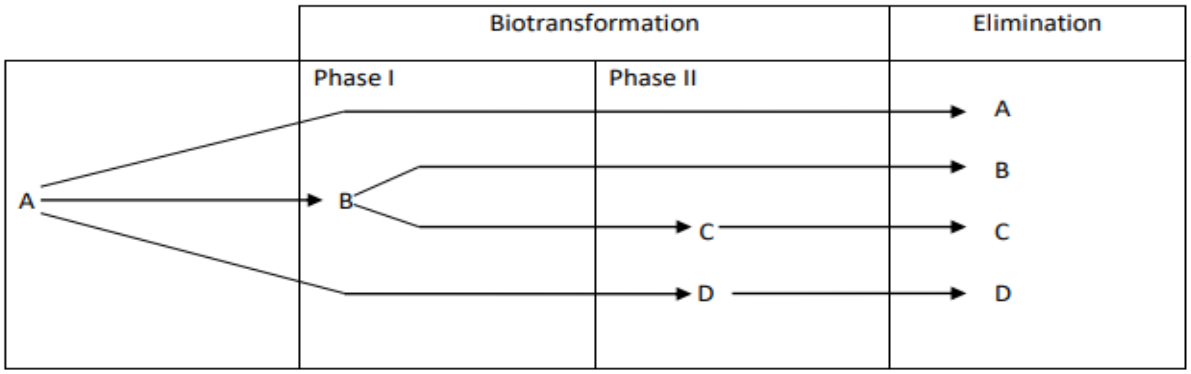

Figure 1: General diagram of xenobiotic biotransformation

During biotransformation, the xenobiotic can follow one and/or both of the following phases:

- **In phase I,** during the detoxification of xenobiotics, chemical modifications alter (generally reducing) the activity of these molecules, and therefore their toxicity. Occasionally, these reactions lead to more toxic products (more dangerous than the initial ones), but this is rare.
- **In phase II,** during detoxification, condensations of molecules modify (generally increasing) the solubility of these molecules, thus facilitating their excretion. Occasionally, these reactions lead to compounds that are less soluble (and therefore more dangerous) than the initial ones, but this is rare.

2. 2.4. Elimination or excretion

Xenobiotics and their metabolites (*unaltered product or its metabolites)* are primarily eliminated from the body via feces and urine, and, for some, via the respiratory or mammary routes. Other secondary routes include saliva, sweat, and hair, nails, and skin appendages.

A. The renal route: Blood transports many products, including several waste products from metabolism, to the kidneys where it is filtered and useless substances are eliminated.

B. The gastrointestinal route: It allows the elimination of molecules not absorbed (not dissolved) in the digestive tract as well as those that are excreted by saliva (e.g., alkaloids), gastric juice (nicotine) and bile.

C. The pulmonary route: It allows the elimination of gaseous or volatile toxins (e.g., volatile hydrocarbons, cyanide, carbon oxides, etc.).

D. Mammary route: It allows the elimination of lipid-soluble substances **(e.g.,** organophosphate insecticides and carbamates, heavy metals, etc.).

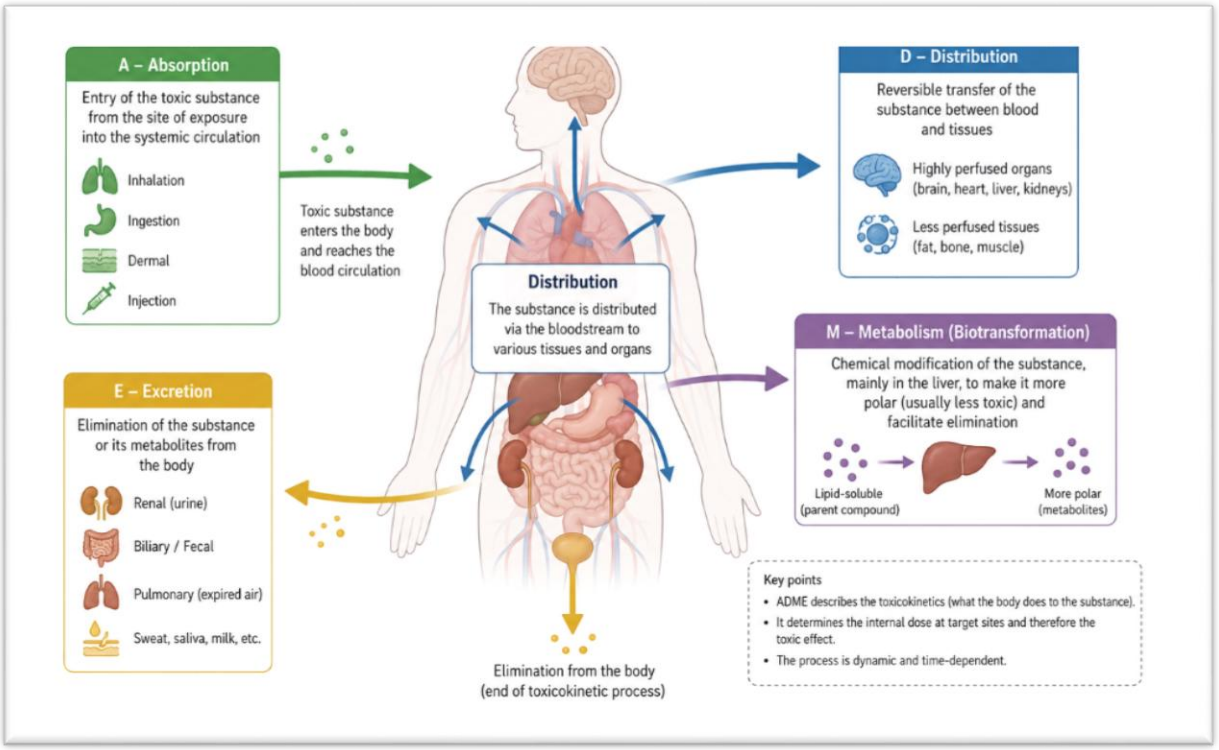

Figure 2: General diagram of the fate of a toxic substance in the body (ADME: toxicokinetics)

Toxic kinetics, therefore, allows us to understand ***how a toxic substance circulates and evolves in the body,*** which is essential for assessing toxic risk.

3. Review questions

1. Define toxic kinetics.
2. What are the steps involved in ADME?
3. What is the role of the liver in toxicity?
4. Why do certain toxins accumulate in the body?

1. Definition of the toxic effect

The toxic effect is the disruption and dysfunction of the balance of the body's adaptation processes towards of numerous situations of aggression (biological, chemical, physical). It is the result of a process that is often complex and can lead to various effects in a living organism, for example: skin irritation, eye irritation, digestive system irritation, abnormal heart rhythm, etc. Some toxic effects are reversible (they disappear more or less quickly after exposure stops) while others are irreversible (they persist or worsen after exposure stops).

Toxicodynamics studies the biological effects of toxins and their mechanisms of action at the molecular, cellular, and tissue levels and explains how and why a toxic substance causes biological effects, thus complementing *toxicokinetics.*

2. Types of toxic effects

The effects caused by a toxin can manifest themselves:

- Through functional changes (e.g., changes in respiratory rate during exposure to an asphyxiant) without creating lesions, and they are generally reversible.
- Through lesion changes (morphology) (e.g., pulmonary fibrosis caused by chronic exposure to crystalline silica) without the subject showing clinical signs and are often irreversible.
- Finally, biochemical alterations without being accompanied by apparent morphological changes (inhibition of cholinesterase’s caused by organophosphate insecticides).

3. Mechanism of action of toxic substances

Toxins act at cellular sites and target specific molecules, such as structural proteins (membranes), transporters (hemoglobin), lipids, nucleic acids, etc., which are frequently affected, unlike sugars, which are rarely impacted by toxic molecules. These effects result from the presence of receptors involved in the mechanisms of action of toxic molecules.

Toxic effects depend on the substance, the dose, and the duration of exposure, but also on various factors related to the individual: sex, age, nutritional status, etc. **Figure 3** illustrates the consequences and the mechanism of interaction between the toxic substance and the cell in the body.

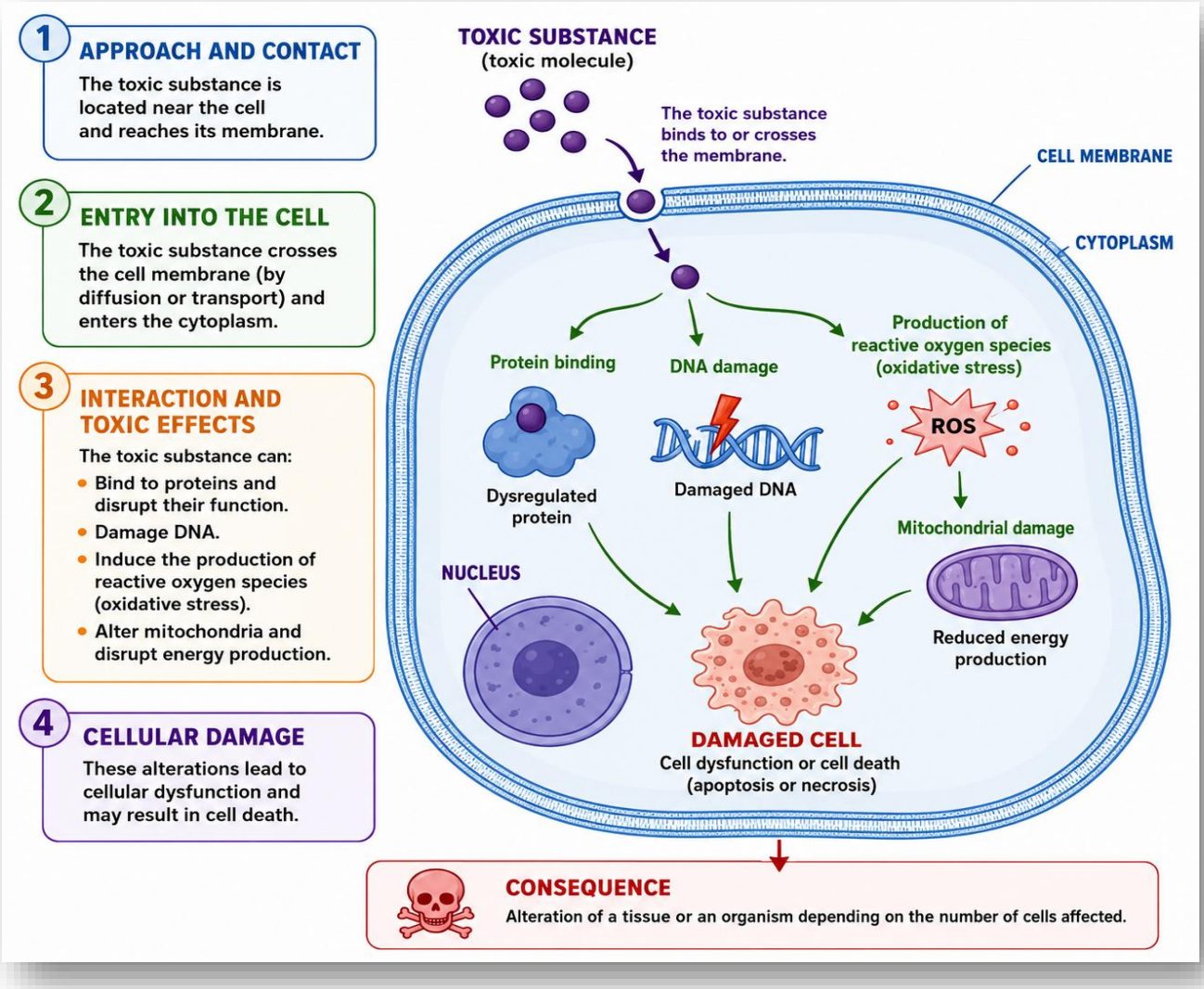

Figure 3: Consequences of interactions between the toxicant and the target cell

4. Classification of toxic effects

Toxic effects can be classified in various ways, according to, for example: the duration of onset (acute, subacute, chronic), the type of action (local, systemic), the mechanism of action (stimulant, inhibitor), the route of entry (respiratory, cutaneous, digestive), the tissue or organ affected (blood, liver, kidney), the chemical nature of the toxic substance, etc.

4.1. According to the nature of the toxic product

4.1.1. Direct toxicity: the toxic substance produces its harmful effects without any biotransformation; its chemical nature is responsible for its toxicity. Examples: strong acids and strong bases; oxidizing agents (ingestion of bleach); carbon monoxide (CO), etc.

4.1.2. Indirect toxicity: the toxic substance is not toxic in its current form, but requires biotransformation to reveal its toxicity, a metabolic reaction (hydrolysis, oxidation, etc.). Example: paracetamol.

4.2. According to the toxic effects or the duration of onset

4.2.1. Acute toxicity: this is defined as the various effects that occur very quickly after a high dose of a toxic substance enters the body. In this case, the signs of poisoning appear rapidly after ingestion, within 24 hours. These are effects that occur rapidly (generally in less than 24 hours) after limited exposure; they may be reversible or irreversible.

4.2.2. Subacute (medium-term) toxicity: the toxic substance is administered repeatedly over a longer period not exceeding three months. The aim is to determine which organs and functions are affected by this toxic substance.

4.2.3. Chronic toxicity (long term): this lasts for a sufficiently long period, more than three months. It is a toxicity that appears through the accumulation of toxins in the body and is called (cumulative toxicity). It can cause carcinogenic, mutagenic, teratogenic effects (genetic toxicity).

Very often, the repeated absorption of even minimal doses leads to much more severe poisoning. This is the case with cumulative poisons (arsenic, fluoride, heavy metals, mercury, lead, cadmium, etc.).

Table II characterizes the two types of poisoning, acute and chronic, according to the same comparison criteria.

Table II: Comparison between the two types of poisoning (acute and chronic).

Criteria	**Acute poisoning**	**Chronic poisoning**
Exposure time	Short	Long
Dose	High	Weak
onset of symptoms	Fast	Progressive
Gravity	Often severe	Variable
Accumulation	Rare	Frequent

Acute and chronic poisonings differ in their mode of exposure and their effects. Understanding them is essential for the prevention and management of toxicological risks.

5. Dose-effect and dose-response relationships

In toxicology, the two concepts are similar but not identical. The confusion arises from the fact that they both describe the relationship between a dose and what happens in the body, but at different levels.

5.1. Dose-effect relationship: refers to the relationship between the dose and the specific effect at the individual level. Increasing the dose can increase the intensity or severity of an effect. A dose-effect curve can be plotted for the whole organism, the cell, or the target molecule.

For the dose-effect curve: it describes the intensity of an effect in an individual as a function of the dose; the higher the dose, the stronger or more pronounced the effect. For example, a progressive increase in blood pressure or the percentage of enzyme inhibition. It is characterized by its continuity (gradual), measured in a single individual or a biological system, as it allows the determination of parameters such as the maximum effect (E max) and the effective dose 50% (ED50).

5.2. Dose-response relationship (all-or-nothing): refers to the relationship between the dose and the percentage of individuals exhibiting a specific effect.

For the dose - response curve, the effect is considered to be present or absent (e.g., death, seizure, appearance of a tumor). It is characterized by its discontinuity (binary response: yes/no), its measurement on a population, and it allows the determination of the LD50 (lethal dose for 50% of individuals), and the ED50 (effective dose for 50% of individuals)**.**

A low-dose zone is generally observed where no response can be detected; with increasing dose, the response follows an upward curve, generally reaching a plateau at 100% response (**Figure 4)**. The dose is often expressed as the amount (mg/kg body weight) of xenobiotic that has entered the body.

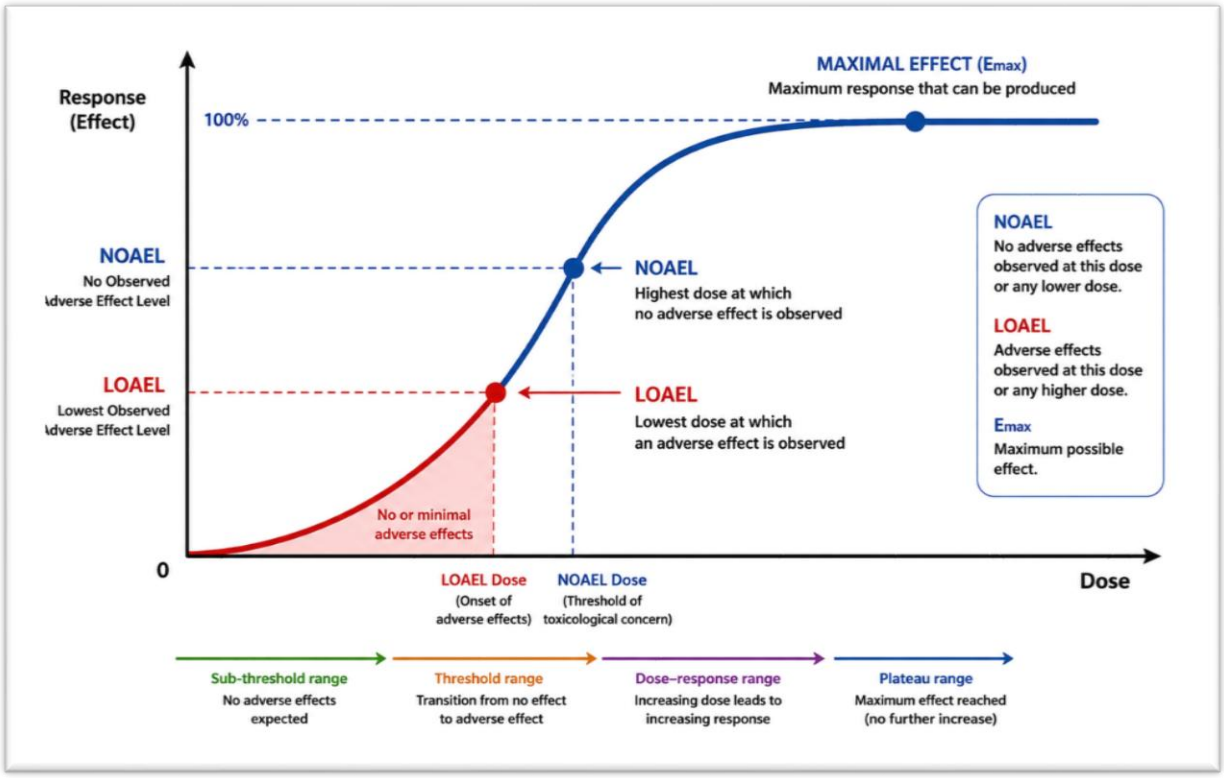

Figure 4: Curve showing the relationship between dose and response

The following table compares the two types of effects (dose-effect and dose-response).

Table III: Main differences between dose-effect and dose-response

Criteria	**Dose-effect**	**Dose-response**
Level of education	Individual	Population
Response type	Gradual (continuous)	Quantity (yes/no)
What we measure	Intensity of the effect	Frequency of the effect
Example	Intensity of pain	% of subjects with pain

6. Review questions

1. What are the differences between acute and chronic poisoning?
2. Give two examples for each type of poisoning.
3. What factors influence the severity of poisoning?
4. What is the difference between toxic kinetics and toxicodynamics?
5. List two mechanisms of action of toxic substances.
6. Explain the dose-effect relationship

1. Introduction

Food toxicology aims to assess the toxicological risk of a food. It determines the extent to which a food is or is not dangerous to health. This involves determining whether it contains pathogens (viruses, parasites, pesticides, harmful chemicals, etc.).

By definition, a food contaminant is any substance that is not intentionally added to a food product, but is nevertheless present in it, either as a residue of processing and handling during production (agriculture, livestock farming, veterinary medicine), or during preparation or during storage.

2. Food contaminants

2.1. Biological contaminants

They are foodborne illnesses caused by the ingestion of inedible or toxic products such as toxins from infectious agents, medicines, heavy metals, poisonous mushrooms, chemical compounds or other poisons, food additives, residues of plant protection products, etc.

Food poisoning can cause digestive problems such as diarrhea and abdominal pain. In the most severe cases, food poisoning absolutely requires medical attention and possibly hospitalization.

What is the difference between food poisoning and foodborne illness?

- **Poisoning** is a pathology caused by ingesting toxins secreted by bacteria or molds in food before it is eaten. For example: toxins secreted by *Clostridium botulinum.* causing botulism (a neurotoxic disease), and by *Staphylococcus aureus,* causing diarrhea, gastroenteritis, etc. or toxinogenic fungi such as *Aspergillus sp.* secreting aflatoxin (mycotoxins) which is carcinogenic, etc.
- **Foodborne illnesses occur when** microorganisms multiply in food and excrete toxins and toxic metabolites into the small or large intestine. The pathogenicity stems from the action of the infectious microorganism and the toxin it secretes.

2.2. Chemical contaminants

2.2.1. Food additives

Food additives are substances that are not normally consumed as food by themselves nor used as typical food ingredients but are intentionally added to foods to perform specific

technological functions, such as preservation, coloring, or stabilization. In the European Union, they are identified by an "E number" (the letter E followed by three or four digits), whereas internationally they are designated by the International Numbering System (INS) established by the Codex Alimentarius Commission, which uses the same numerical code without the letter "E".

Among the dangerous food additives (listed in **Table IV)**, these additives are often controversial or associated with potential adverse effects when consumed in large quantities or by certain sensitive individuals (allergies, asthma, sensitivities). All these additives are generally regulated in many countries and are regularly reassessed by health authorities (EFSA, WHO), but their safety is sometimes debated.

Table IV: Some food additives often associated with adverse effects

Additive	Name	Common use	Possible effects
E102	Tartrazine	Yellow coloring (candy, drinks)	Allergies, hyperactivity in some children
E110	Orange-yellow S	Coloring (sodas, snacks)	Allergic reactions, intolerances
E122	Azorubine	Red dye	Suspected hyperactivity, allergies
E124	4R Culvert	Red dye	Possible allergic reactions
E129	AC Allura Red	Sweets, drinks	Hyperactivity in sensitive children
E621	Monosodium glutamate (MSG)	Flavor enhancer (prepared foods)	Headaches in some sensitive individuals (controversial)
E951	Aspartame	Sweetener (diet drinks)	Controversies surrounding neurological effects (not confirmed at normal doses)
E320	BHA (butylhydroxyanisole)	Preservative (chips, cereals)	Suspected of having carcinogenic effects at high doses in animals
E321	BHT (butylhydroxytoluene)	Conservative	Suspected effects on the liver and immune system (high doses)
E220–E228	Sulfites	Preservatives (wine, dried fruit)	Asthma attacks in sensitive individuals

2.2.2. Pesticide residues

Pesticide residues (fungicide, herbicides, insecticides) are chemical substances, or mixtures of substances, which present risks of toxicity, which may remain in food intended for human or animal consumption as a result of phytosanitary treatments carried out either during the growing season or after harvest (Figure **5)**.

Their effects can manifest immediately or in the short term (acute effects) (e.g., skin and eye irritation, headaches, nausea, etc.) or as chronic effects following repeated absorption of low doses of pesticides, which can cause liver, prostate, and blood cancers, fertility problems, neurological disorders, etc. Figure 5 shows the mode of exposure of humans and their environment to pesticides.

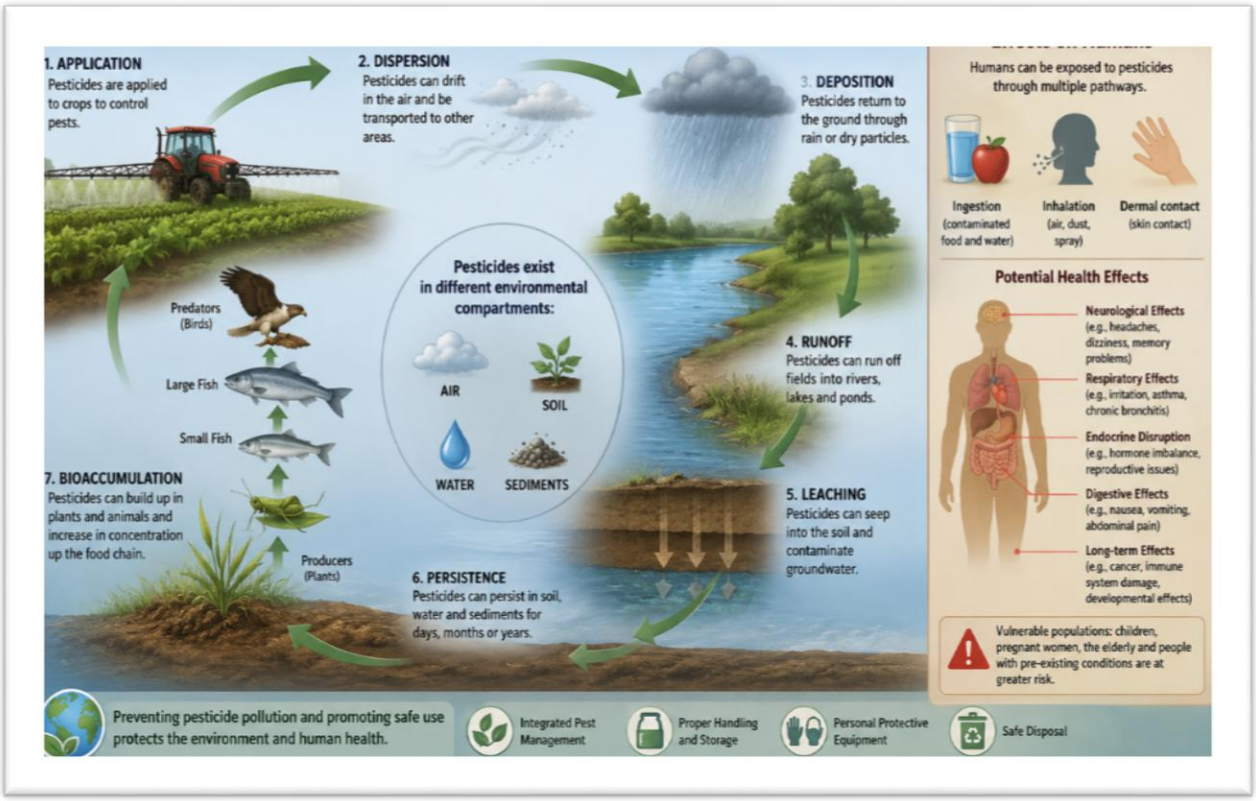

Figure 5: The pesticide cycle in the environment and its effects on humans.

2.2.3. Veterinary drug residues

Veterinary medicine is an essential tool for protecting animal health and well-being. It therefore also contributes to preserving public health by participating in the prevention and control of animal diseases transmissible to humans. Veterinary medicines can include antibiotics, antiparasitics, anabolic steroids, and more.

2.2.4. Heavy metals

Heavy metals are naturally occurring elements. They are found in the air, water, soil, sediments, and consequently in plants, animals, fish, and all elements of the human diet. They can be:

- **Essential:** elements indispensable to metabolism of carbohydrate metabolism, lipids and enzymatic reactions (dehydrogenases, etc.), such as Cu, Zn, Fe, Mg, etc., but at high concentrations become toxic to living organisms.
- **Toxic:** heavy metals are toxic and have harmful effects on living organisms even at low concentrations. They have no known beneficial effects on cells. Their toxicity develops through bioaccumulation along the food chain. This is the case for lead (Pb), mercury (Hg), and cadmium (Cd).

Their toxicity varies depending on the dose and duration of exposure. Short-term exposure to high concentrations causes acute syndromes, while long-term exposure to low concentrations causes chronic disorders.

In humans, these compounds can affect the nervous system, kidney, liver, and respiratory functions. Some are carcinogenic, such as cadmium, nickel, and chromium. etc.

2.2.5. Dioxins and Polychlorinated Biphenyls (PCBs)

Dioxins and Polychlorinated Biphenyls (PCBs) are chemicals that are particularly toxic to humans and the environment. They are products of incomplete combustion of organic substances (waste, cigarettes, etc.) and industrial processes (metallurgy, etc.). These toxic substances accumulate in living organisms and are no longer eliminated, having harmful effects on

reproduction and possibly carcinogenic effects. They cause chronic toxicity, the full extent of which is still poorly understood.

3. Food allergens

By definition, an allergen is the substance responsible for an allergic reaction. Following contact, ingestion, or even inhalation, the body's immune system manifests numerous inflammatory signs. The symptoms can vary in severity depending on the individual and the intensity of the allergy.

It is important to know that any product containing allergens is subject to mandatory labeling that clearly indicates the name of the allergens.

Most triggers for an allergic reaction are plant or animal proteins, such as those found in chicken eggs, fish, bananas, or celery. Nut and peanut allergies are the most severe and can even be fatal in rare cases. The most common symptoms of a food allergy usually appear within two hours of ingestion: swelling of the lips, eyelids, and ears, diarrhea, and vomiting, etc.

4. Packaging material residues

The interaction between container and contents can affect the organoleptic and nutritional qualities of food, and consumer safety. This is known as the migration of hazardous chemicals from the container to the contents. Materials must be inert with respect to food to limit this migration. Bisphenol A (BPA), a mixture of phenol and acetone, a common component of plastic packaging, is strongly suspected of being a dangerous endocrine disruptor for both animals and humans.

Several other potentially harmful substances can be found in food **(Table V).** Indeed, it is not the mere presence of these substances that poses a problem, but rather the quantity and frequency of consumption**.** A varied diet, with plenty of fresh foods, naturally reduces the risks.

Table V: Impact of certain harmful substances on humans

Substance	Kind	Where can we meet her?	Health effects
Lead	Heavy metal	Old paint, contaminated water	Neurological disorders, especially in children
Mercury	Heavy metal	Some fish (tuna, swordfish), pollution	Damage to the nervous system
Arsenic	Toxic metalloid	Contaminated water, some soils	Carcinogenic, digestive and nervous system disorders
Carbon monoxide	Toxic gas	Faulty heating, cars	Prevents blood oxygenation (life-threatening danger)
Asbestos	Mineral fiber	Old buildings	Causes serious lung disease
Benzene	Chemical compound	Cigarette smoke, fuels	Carcinogenic (blood, bone marrow)
Formaldehyde	Chemical product	Building materials, furniture	Irritant, probable carcinogen
Pesticides (some)	Chemicals	Agriculture, food waste	Hormonal and neurological disorders
Dioxins	industrial pollutants	Food chain (animal fats)	Highly toxic, long-term effects
Cyanide	Chemical poison	industry , certain plants	Blocks cellular respiration
Alcohol (ethanol)	Psychoactive substance	Alcoholic beverages	Toxic to the liver and brain in excess
Nicotine	Alkaloid	Tobacco	Addictive, cardiovascular effects

5. Review questions

1. What is food toxicology and what is its main objective?
2. Give the definition of a food contaminant and cite two examples.
3. What is the difference between food poisoning and foodborne illness? Give an example for each.
4. What are the main types of chemical contaminants found in food?
5. What are the short- and long-term effects of pesticide residues on human health?
6. What is a food allergen and what are the most common symptoms of a food allergy?

Risk assessment is a rigorous scientific process used to estimate the probability and severity of adverse effects resulting from exposure to a toxic agent. It is widely used in food toxicology, public health, and by regulatory authorities to ensure consumer safety. It relies on a structured approach that integrates experimental, epidemiological, and statistical data.

Risk assessment is a fundamental tool in modern toxicology. It allows us to transform complex scientific data into concrete decisions aimed at protecting public health. It relies on a cautious approach that incorporates safety margins to account for uncertainties and individual differences.

1. Risk assessment steps: Risk assessment comprises four fundamental, interconnected steps**:**

1.1. Hazard identification

Hazard identification involves determining whether a given substance has an intrinsic potential for toxicity. This step relies on the analysis of scientific data from experimental studies (*in vitro, in vivo*) and human observations. It allows for the identification of the nature of the contaminant (chemical, biological, or physical), the cataloging of associated toxic effects, and the determination of target organs. For example, lead is known for its neurotoxicity, particularly in children, and some mycotoxins also have carcinogenic potential. This step answers the essential question: *is the substance capable of causing a harmful effect?*

1.2. Characterization of the danger

Hazard characterization aims to quantify the relationship between the administered dose and the observed effect. It allows the assessment of the severity, frequency, and nature of toxic effects. It includes the study of dose-effect and dose-response relationships, the identification of a threshold dose (if one exists), and the determination of toxicological indicators such as NOAEL (No Observed Adverse Effect Level), LOAEL (Minimum Observed Adverse Effect Level), and LD50. It also allows the identification of reversible or irreversible effects, acute or chronic effects, and sensitive populations (children, pregnant women). This step helps answer the question: *at what dose and with what intensity does the hazard manifest itself?*

1.3. Exposure assessment

Exposure assessment involves estimating the amount of a substance to which a population is actually exposed. It takes into account: the concentration of the contaminant in food, dietary habits (quantity and frequency of consumption), routes of exposure (primarily ingestion in food toxicology), and the characteristics of the population (age, weight, physiological state). Exposure can be chronic (long-term exposure to repeated low doses) or acute (single exposure to high doses). For example: regular ingestion of pesticide residues in fruit and consumption of fish contaminated with mercury. This step answers the question*: how much of the toxic substance is actually absorbed?*

1.4. Risk characterization

Risk characterization is the synthesis of the preceding steps. It aims to estimate the actual risk to human health by comparing exposure levels to toxicological thresholds. This involves comparing the estimated exposure with reference values (ADI, NOAEL) and analyzing uncertainties (biological variability, study limitations). For interpretation: if the exposure < ADI → low or negligible risk, and if the exposure > ADI → potential risk requiring action. This step helps answer the question: *does the hazard represent a real risk under current exposure conditions?*

2. Standards in toxicology

Toxicological standards are established to guarantee a high level of protection for human health. They are based on experimental data and incorporate significant safety margins.

2.1. ADI (Acceptable Daily Intake)

The Acceptable Daily Intake (ADI) is the amount of a substance that an individual can ingest daily, throughout their life, without appreciable risk to their health. It is expressed in mg/kg of body weight /day.

The ADI is calculated from the NOAEL by applying a safety factor (generally 100), which takes into account: differences between species (animal → human), and variability between human individuals. It is determined according to the following formula:

DJA = NOAEL / safety factor

The role is to establish maximum limits in food, to regulate the use of additives and pesticides, and to protect vulnerable populations.

2.2. NOAEL (Acceptable Daily Intake)

The NOAEL corresponds to the highest dose of a substance at which no adverse effects are observed under controlled experimental conditions. It is determined from toxicological studies in animals and short- or long-term studies. Its importance lies in providing an essential scientific basis for risk assessment, allowing the definition of safety margins, and serving directly in the calculation of the ADI.

Table VI: Summary of the different stages with their objectives.

Stage	**Objective**
Hazard identification	Detect harmful effects
Dose-effect	Understanding the dose/toxicity relationship
Exposure	Assess contact with the toxic substance
Characterization	Estimate the overall risk

3. Review questions

1. Define the toxicological risk.
2. What are the steps involved in its evaluation?
3. What is the DJA?
4. What is the purpose of the DL50?
5. Why is exposure important in risk assessment

Food toxicology prevention encompasses all measures implemented to avoid, reduce, or eliminate risks associated with food contaminants. It is a crucial pillar of food safety and relies on an integrated approach involving producers, manufacturers, regulatory authorities, and consumers.

1. Quality control and contaminant detection

Quality control refers to all the procedures implemented to verify that food products comply with health and regulatory requirements. It is carried out at every stage of the food chain, from the production of raw materials to the distribution of the finished product. This control relies on microbiological analyses (detection of pathogenic bacteria such as Salmonella or Listeria), chemical analyses (measurement of pesticides, heavy metals, and additives), and physical analyses (detection of foreign bodies). It can be preventive (monitoring of raw materials), in-process (monitoring of processes), or final (verification of the product before marketing). The objective is to guarantee that food products are safe, compliant, and of consistent quality, while respecting regulatory requirements.

2. Methods of analysis

Analytical methods play a crucial role in quality control and the characterization of chemical substances. High -Performance Liquid Chromatography (HPLC) is widely used to separate, identify, and quantify non-volatile compounds in complex matrices, particularly in the pharmaceutical and food industries. Gas Chromatography (GC), on the other hand, is especially well-suited for the analysis of volatile and semi-volatile compounds, such as solvents or organic residues. Spectrophotometry relies on the interaction between matter and electromagnetic radiation, allowing the measurement of a substance's absorbance or transmittance to determine its concentration. These techniques are often complementary and provide accurate and reliable results.

The HACCP (Hazard Analysis Critical Control Point) system is a systematic, preventative approach to identifying, assessing, and controlling significant food safety hazards. It is based on seven fundamental principles:

1. *Identify the dangers*
2. *Determine the critical control points (CCPs)*

3. *Set critical limits*
4. *Set up a monitoring system*
5. *Define corrective actions*
6. *Check the system*
7. *Ensure document traceability*

HACCP allows for the anticipation of risks rather than their correction, improving product safety and quality and strengthening consumer confidence. It is now mandatory in many food industries and is an international standard.

3. Compliance with standards

International standards play a fundamental role in regulating food safety and product quality. The World Health Organization (WHO) establishes guidelines to protect public health worldwide, particularly with regard to contaminants in water and food. For its part, the European Food Safety Authority (EFSA) The Authority assesses risks related to the food chain in the European Union and provides scientific advice to support regulations. These standards set maximum limits for contaminants, chemical residues, and microorganisms. They ensure a high level of food safety, harmonize regulations between countries, and facilitate international trade. Other reference bodies include the Codex Alimentarius Commission and World Health Organization. Organization, etc.

Failure to comply with standards can lead to serious consequences, including legal sanctions, product recalls, and health crises.

4. Traceability

Traceability refers to the ability to track a food product throughout its entire production, processing, and distribution chain. It allows for the identification of the origin of raw materials, the monitoring of the various manufacturing stages, and the location of products in circulation. A distinction is made between upstream traceability, which traces the product back to its origin, and downstream traceability**,** which tracks its distribution to the consumer. Traceability plays a crucial role in the event of a health crisis, enabling the rapid withdrawal of contaminated products, limiting consumer exposure, and identifying the sources of contamination.

Modern technologies (barcodes, databases, digital systems) have significantly improved traceability efficiency. The following figure summarizes the steps to follow in risk management in the agri-food sector.

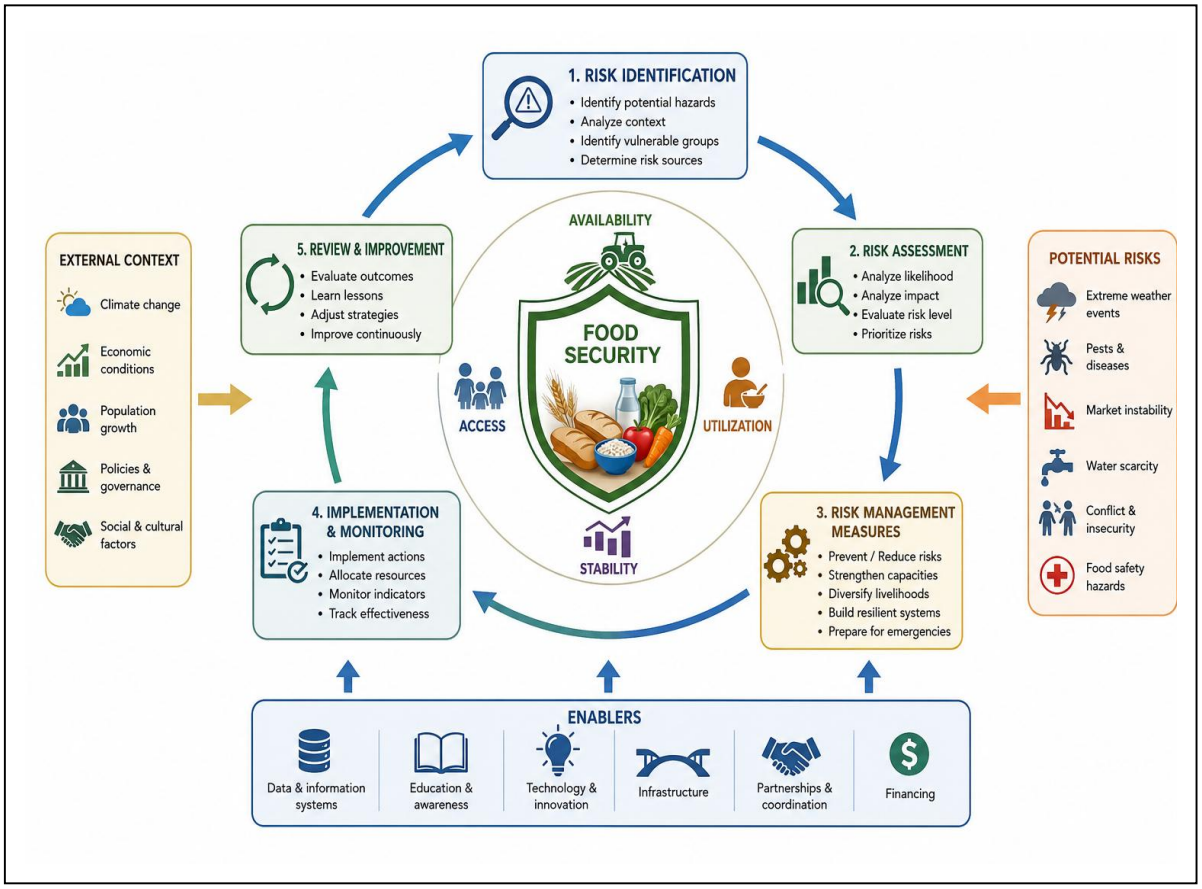

Figure 6: Risk management for food security

Prevention in food toxicology relies on a coherent combination of measures, including quality control, compliance with standards, and the application of HACCP system and the Traceability. These tools make it possible to control risks at each stage of the food chain and to guarantee a high level of food safety in a context of globalized production and trade.

5. Review Questions

1. At what stages of the food chain does quality control intervene?
2. Why is quality control essential for food safety?
3. What is the role of analytical methods in food toxicology?

4. Why is HACCP considered a preventive approach?

5. What are the advantages of HACCP for the food industry?

6. What do the standards stipulate regarding contaminants?

7. What can be the consequences of not complying with the standards?

8. Explain the link between quality control and food safety risk prevention.

1. Introduction

Genotoxicology involves demonstrating the toxic potential of physical or chemical agents on DNA and identifying the mechanisms involved, distinguishing in particular between primary DNA damage, mutagenic, clastogenic, and aneugenic actions (Figure 7). Characterizing these hazards then allows for risk assessment based on the characteristics of the exposure (drug treatment, accidental exposure, etc.) and the target tissues involved. Its primary aim is to prevent the risks of cancer, transmissible genetic alterations, and even infertility.

Thus, the objectives of Genotoxicology are: the determination and application of biosafety principles in the laboratory, the identification of genotoxic agents, and the determination of their mechanisms. molecular and cellular involved in the phases of bio activation, interaction with DNA, repair of primary lesions, and assessment of the initial consequences of these lesions

The study of genotoxicology allows for the development of several genotoxicity tests to detect primary DNA damage (comet assays, adduct detection, etc.), gene mutations (Ames test), chromosomal mutations, and genomic mutations (micronucleus assay). Toxicogenetics also enables the biological monitoring of exposures. professional has of the environments potentially carcinogens in applying strategies including genotoxicity tests and therefore it allows to initiate certain actions of prevention of occupational cancers in order to optimize prevention actions.

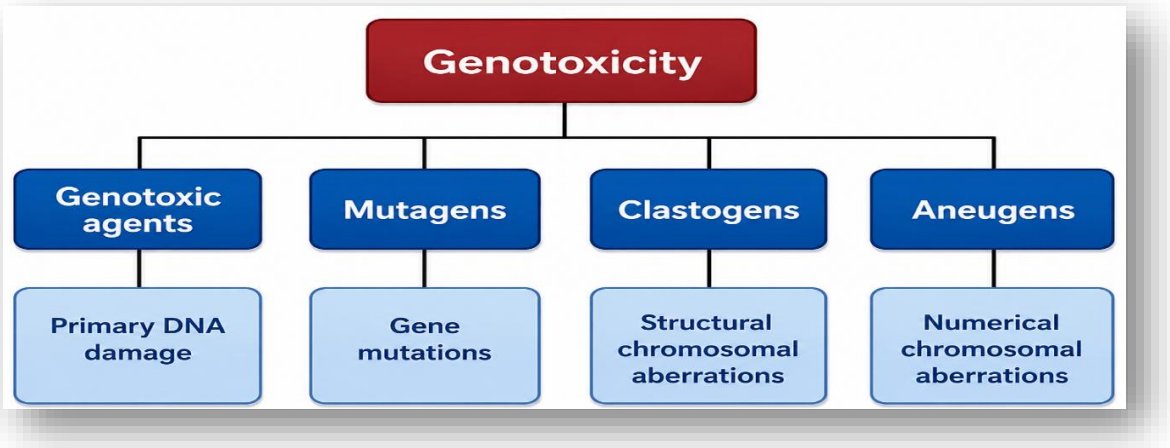

Figure 7: Different types of lesions of DNA and their consequences

2. Tests of valuation of genotoxicity

Genotoxicity, called also toxicity genetic, represents the ability of some physical agents, chemicals or organic to provoke the appearance of DNA has which can lead has of the mutations irreversible of material genetic, if these lesions born are not repaired. These agents are qualified of mutagens. The tests of genotoxicity aim has assess the impact of a substance, of a preparation, or of an extract, potentially mutagenic in measuring their ability to induce gene or chromosomal aberrations in bacteria or eukaryotic cells. The most commonly used laboratory tests are: the Ames test, the comet test, the micronucleus test, and the chromosomal aberration test.

2.1. Test of Ames: this is a test of toxicology genetic *in-vitro* which consists of examine if a chemical substance or a physical agent east able to induce a specific mutation in different strains of *Salmonella typhimurium.*

2.2. Comet test: this test called for Single Cell Gel Electrophoresis (SCGE) is a method based on microscopy fluorescent that is fast and very sensitive for the detection and the quantification of primary DNA lesions, including DNA breaks, which represent one of the lesions with a high probability of occurring after exposure to mutagenic agents.

2.3. Chromosomal aberration assay: CA on mammalian cells is frequently used to evaluate there genotoxicity, in student the damages of DNA induced by miscellaneous agents chemical and environmental factors, and has been adopted as a genotoxicity index. It identifies agents that cause structural abnormalities (chromosomal or chromatidal breaks), or abnormalities in chromosome number (aneuploidy, polyploidy).

3. Mutations and mutagenic

A mutation is a change that occurs in the genetic material of DNA. The consequences of these changes depend on the type of cell affected. A mutagen is a physical or biological agent, or a chemical substance, capable of causing mutations, thus altering the genetic information (usually DNA) of an organism. It increases the frequency of certain mutations, often involving insertion.

4. Types of mutagens agent: the mutagens agent can be classified in:

4.1. Chemicals mutagens: can be the analogues of base (tautomers), of the agents which react with DNA (without replication), intercalating agents (flat molecules), or oxidative reactions. Chemical mutagens are distinguished by their mode of action. Some act through mechanisms similar to spontaneous mechanisms, while others act more like radiation. Three types are distinguished:

a. Base analogues: their chemical structure is similar to purines and pyrimidines. They can be incorporated into DNA during replication.

b. Chemical substances that alter the structure and pairing of bases: nitrous acid comes from the digestion of nitrites (food preservatives), it is the cause of deamination, (loss of a band NH_3). Theire degradation can go until theire production of sites without databases, which, upon replication, generates mutations.

c. Intercalating agents such as acridine, proflavin, and ethidium bromide are molecules that insert themselves between the bases of DNA, this results in DNA stretching.

d. Agents that alter the structure of DNA: certain large molecules bind to the bases that become thus " no coding » (eg: NAAAF). Others agents cause of the intra- and inter-strand bonds (e.g., psoralen found in plants and used in treatments of the skin).

Of the products chemicals cause of the breakups In DNA (eg : peroxides). These agents do not induce without doubt not directly THE mutations but induce of the process of repairs that are mutagenic.

4.2. Physical mutagens radiation is a physical mutagen. It is a physical process by which energy flows through space. There are two main forms of this energy:

a. Electromagnetic: described as waves of electrical energy. For example: gamma rays, X-rays, ultraviolet rays.

b. Corpuscular that is made up of atomic and subatomic particles that move at high speeds. Speed and cause damages when they enter collision with other particles, in particular of the molecules biological. By example: THE particles alpha and the particles beta. Both are known as

ionizing radiation because they produce ions capable of reacting physically and chemically upon contact with biological molecules.

4.3. Biological Mutagens Possible sources of biological mutagens include all preparations of a biological nature used in prophylactic or therapeutic medicine. such that vaccines antitoxins, blood, serum and antigens. THE agents Potential mutagenic biological agents can be microorganisms, particularly viruses, and certain chemical agents.

5. Cancer and cell cancerous

Cancer stay Today moon of the diseases the most formidable despite the progress made in matter of prevention, detection and treatment. It is responsible of a death on eight in worldwide, and more than 12 million new cases are diagnosed each year.

Several studies have shown that tumorigenesis in humans is a complex process involving several steps. These steps reflect the alterations genetics that sudden a normal cell to transform into a cancerous cell.

A cancer cell is an abnormal cell with the power to multiply indefinitely and uncontrollably, tending to destroy and invade neighboring tissues. The cancer cell appears generally different of the cells normal. His characters allow off to identify it, both in isolation and within tumor tissue.

6. Relationship mutation – cancer

Cancer remains one of the leading causes of mortality worldwide. Extensive evidence has demonstrated that genetic mutations within cellular DNA are critical events in cancer initiation and progression. Moreover, germline mutations inherited within families can increase susceptibility to the development of certain cancers.

This is notably the case with mutations in the BRCA1 and BRCA2 genes, which predispose individuals to breast and ovarian cancers. The proteins produced by these genes are directly involved in protecting genetic information, as they participate in repairing breaks that occur in the carrier of this information: DNA.

DNA can be damaged by various lesions, but the most destabilizing to genetic information are double-strand breaks. In order to protect its genome, the cell possesses of numerous

mechanisms of repair of which their recombination counterpart Who It allows for faithful repair, that is, without loss or alteration of genetic information, thus preventing the onset of cancer.

Teratology is the branch of embryology that studies developmental anomalies (malformations), whether structural, functional or biochemical, present at birth, with their typical manifestations such as insufficient fetal development, abortion or there dead in-utero their carcinogenesis and THE malformations.

Today, it is clear that 90% of malformations congenital ones are caused by of the factors of the environment (identified or not), and are therefore generally not transmissible.

7. Relationship between mutagenesis and teratogenesis

Teratogenesis refers to the process by which structural or functional abnormalities arise during embryonic or fetal development, leading to congenital malformations or developmental defects. Mutagenesis, on the other hand, is the process by which mutations are generated, resulting in permanent alterations in the nucleotide sequence of the genetic material (DNA or RNA).

Mutations may occur spontaneously as a result of errors during DNA replication and cell division or may be induced by exposure to mutagenic agents such as ionizing radiation, chemical compounds, or certain viruses. Under normal physiological conditions, the vast majority of replication errors are rapidly corrected by highly efficient DNA repair mechanisms. Consequently, only a small fraction of these errors escape repair and become permanent mutations that can be transmitted to daughter cells during subsequent cell divisions.

When mutations occur in somatic cells, they remain confined to the affected individual and may contribute to the development of diseases such as cancer. In contrast, mutations arising in germ cells (sperm or oocytes) are heritable and can be transmitted to future generations, potentially resulting in inherited genetic disorders or increased susceptibility to disease.

Although mutagenesis and teratogenesis are distinct biological processes, they are closely related. Exposure to mutagenic agents during pregnancy may induce genetic alterations in embryonic cells, disrupting normal development and increasing the risk of congenital anomalies. Therefore, many chemical and physical agents possessing mutagenic properties also exhibit

teratogenic effects, depending on the timing of exposure, the dose, and the stage of embryonic development.

This relationship highlights the importance of evaluating the mutagenic potential of chemicals and environmental contaminants as part of reproductive and developmental toxicity assessments.

8. Example of a quiz for effective practice

Quiz 1 – Multiple Choice Questions (definitions): Genotoxicity refers to:
A. Protein destruction B. An agent's ability to damage DNA C. Cell reproduction D. Enzyme synthesis

Quiz 2 – True or False

Mutagenic agents always cause irreversible mutations.

Quiz 3 – Open Question

Give **two main objectives of genotoxicology** .

Quiz 4 – Multiple Choice Questions (tests)

The Ames test is used to:
A. Observe human chromosomes B. Detect mutations in bacteria C. Measure cell size D. Detect proteins

Quiz 5 – Match

Match each test to its function:

1. Comet testing
2. Micronucleus testing
3. Ames Test

a. Gene mutations

b. DNA breaks

c. Chromosomal abnormalities

Quiz 6 – Multiple Choice Questions (mutagens)

Intercalating agents:

A. Directly destroy chromosomes B. Insert themselves between DNA bases C. Repair DNA D. Prevent replication

Quiz 7 – True or False

Ionizing radiation can cause mutations.

Quiz 8 – Open Question

Name **two types of physical mutagens.**

Quiz 9 – Multiple Choice Questions (cancer)

A cancer cell is characterized by:

A. Controlled division B. Unlimited multiplication C. Rapid death

D. Absence of DNA

Quiz 10 – Thought-provoking question

Explain in one or two sentences the link between **mutation and cancer.**

corrections with explanations for better understanding

Quiz 1 – Multiple Choice Questions

Correct answer: B. The ability of an agent to damage DNA.

Explanation: Genotoxicity specifically concerns damage to DNA that can lead to mutations.

Quiz 2 – True or False

Answer: False.

Explanation: Mutations are not always irreversible, as some DNA damage can be repaired by cellular mechanisms.

Quiz 3 – Open Question

Possible answers:

- genotoxic agents
- Studying the mechanisms of DNA damage and repair
- Assess the risks of cancer or genetic abnormalities

Explanation: Genotoxicology is mainly used to prevent serious effects such as cancer.

Quiz 4 – Multiple Choice Questions

Correct answer: B. Detecting mutations in bacteria

Explanation: The Ames test uses bacteria to see if a substance causes mutations.

Quiz 5 – Matching

Answers:

1 → b (DNA breaks) 2 → c (chromosomal abnormalities) 3 → a (gene mutations)

Explanation:

- Comet testing → detects breaks
- Micronucleus testing → chromosomal abnormalities
- Ames test → gene mutations

Quiz 6 – Multiple Choice Questions

Correct answer: B. Insert themselves between the bases of DNA. Explanation:
Intercalating agents modify the structure of DNA by inserting themselves between the bases.

Quiz 7 – True or False

Answer: True.
Explanation: Ionizing radiation (X-rays, gamma rays) can break DNA and cause mutations.

Quiz 8 – Open Question

Possible answers:

- X-rays
- Gamma rays
- UV rays
- Alpha or beta particles

Explanation: These are forms of mutagenic physical radiation.

Quiz 9 – Multiple Choice Questions

Correct answer: B. Unlimited multiplication
Explanation: Cancer cells divide uncontrollably and invade tissues.

Quiz 10 – Thought-provoking question

Expected answer:
DNA mutations can affect genes that control cell division. This can lead to uncontrolled cell proliferation, resulting in cancer.

Explanation: Certain mutations (such as those in the BRCA1/BRCA2 genes) prevent DNA repair, which promotes the development of cancer.

- ## Example of synthesis questions

1. What is the main role of genotoxicology?

Genotoxicology aims to detect agents capable of damaging DNA in order to prevent serious diseases such as cancer, hereditary mutations, and infertility.

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2. How do genotoxicity tests help evaluate the danger of a substance ?

Tests such as the Ames test, comet assay, and chromosomal aberration test identify DNA damage, mutations, and chromosomal abnormalities, helping to assess the toxicity and risk of a substance.

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3. What is the difference between a mutation, a mutagen, and mutagenesis?

A mutation is a changé in DNA.
A mutagen is an agent that causes mutations.
Mutagenesis is the process through which mutations occur.

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4. Compare the different types of mutagens.

Chemical mutagens directly modify DNA (e.g., intercalating agents).
Physical mutagens such as radiation cause DNA breaks.
Biological mutagens (e.g., viruses) can alter or integrate into genetic material.

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5. Why do DNA damages not always lead to mutations ?

Cells have DNA repair mechanisms that correct most damage before it becomes a permanent mutation.

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6. Explain the link between DNA damage and cancer.

DNA damage can affect genes that control cell division, leading to uncontrolled cell proliferation and the development of cancer.

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7. What is the role of DNA repair mechanisms?

DNA repair systems maintain genome integrity by correcting damage, preventing the accumulation of mutations and reducing cancer risk.

8. How do BRCA genes increase cancer risk when mutated ?

BRCA1 and BRCA2 genes are involved in DNA repair. When mutated, they impair repair processes, increasing the risk of cancers, especially breast and ovarian cancer.

9. What is the relationship between mutagenesis and teratogenesis ?

Mutagenesis involves changes in DNA, while teratogenesis refers to developmental abnormalities in embryos. They may be related but are distinct processes.

10. Why is genotoxicity assessment important ?

It is essential for protecting human health, preventing cancer, controlling environmental chemicals, and ensuring the safety of food and pharmaceuticals.

This work concludes that food toxicology and packaging material toxicology are closely interconnected fields, central to current food safety issues. The analysis of exposure mechanisms, the fate of xenobiotics in the body, and their biological effects highlights the complexity of the interactions between contaminants and living systems.

The study of the various categories of toxic substances present in food, including chemical contaminants, biological toxins, pesticide and veterinary drug residues, and heavy metals, underscores the importance of a multidisciplinary approach integrating chemistry, biology, and food science. These contaminants can induce a range of effects, from acute manifestations to chronic, sometimes irreversible, pathologies, depending on the dose, duration of exposure, and individual characteristics.

Furthermore, packaging materials, while essential for the preservation and distribution of food products, can be a significant source of contamination. Migration phenomena, influenced by numerous physicochemical and environmental factors, illustrate the need for rigorous control of interactions between materials and foodstuffs.

In this context, regulatory frameworks, improved analytical techniques, and the development of safer, innovative materials are fundamental levers for reducing health risks. Furthermore, a thorough understanding of toxicological mechanisms helps guide risk prevention and management strategies.

Looking ahead, scientific advances in analytical toxicology, exposure biomarkers, and smart materials should contribute to strengthening food safety and better protecting consumer health. Food and packaging toxicology is therefore emerging as a strategic research field at the interface between science, industry, and public health.

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