

2. HOW PESTICIDES ENTER FOOD

Pesticides are used primarily to protect crops from harmful organisms, but their journey does not necessarily end where they are applied.

Once released into the environment, an active substance may settle on plant surfaces, penetrate plant tissues, reach the soil, be transported by water or air and, under certain conditions, enter the food chain.

The behaviour of each pesticide depends on its physical and chemical properties, the application method and environmental conditions. Some substances degrade relatively quickly, while others persist for longer. Some remain mainly on plant surfaces, whereas others are absorbed and transported within plant tissues.

Understanding these pathways is essential to explaining why pesticide residues may occur not only in fruit, vegetables and cereals, but also in foods of animal origin.

2.1 Direct treatments applied to crops

The most direct route by which pesticides may reach food is the application of plant protection products to agricultural crops. Treatments are intended to control insects, fungi, weeds and other organisms that may impair production.

Application methods vary: spraying leaves and fruit, treating soil, dressing seeds or distributing products through particular irrigation systems, where authorised.

During spraying, some of the product reaches the plant surfaces. Another portion may settle on the ground or disperse into the surrounding environment.

The amount of substance remaining on the crop depends on numerous factors: formulation type, application rate, characteristics of the plant surface, weather conditions and time elapsed since treatment.

Treating a crop does not necessarily mean that quantifiable residues will be present in the harvested product. The substance may degrade, be metabolised by the plant, be removed by environmental processes or become diluted as the plant develops.

For this reason, agricultural practice establishes specific intervals between the final treatment and harvest, depending on the plant protection product and crop. These intervals help ensure that residues at harvest comply with the conditions of authorisation.

2.2 Surface contamination of fruit, vegetables and cereals

When a pesticide is applied to the above-ground parts of a plant, some may remain on the surface of leaves, fruit, stems and other plant structures. Its persistence also depends on surface characteristics.

Many fruits and leaves are coated with a thin waxy cuticle that protects them against water loss and external agents. Some pesticides have a particular affinity for these waxes and may adhere to

or become distributed within the cuticle.

Consequently, exposure to rain alone does not necessarily remove residues completely. More water-soluble pesticides may behave differently and be more susceptible to washing off.

The physical structure of foods also affects residue retention. Rough, irregular surfaces, or surfaces covered with particular plant structures, may retain substances differently from smooth surfaces.

In cereals, residue distribution between the outer layers of the grain and its internal portions can vary considerably according to the substance and treatment type. This is particularly relevant to food processing, for example the production of wholemeal and refined flours.

The presence of a pesticide on the surface does not necessarily indicate its concentration throughout the food. Understanding its behaviour requires knowing where the substance was deposited and whether it can penetrate tissues.

2.3 Absorption and movement of pesticides inside plants

Some pesticides do not remain confined to crop surfaces. They can cross plant tissues and, under certain conditions, be transported inside the plant. These are known as systemic pesticides.

Absorption can occur through roots, leaves or other plant structures, depending on the active substance and how it is applied. Once absorbed, a pesticide may be distributed by the plant's transport systems.

Plants contain internal conducting tissues that comprise two main systems. Xylem transports water and mineral salts taken up by the roots towards leaves and other plant parts. It can be thought of as a network of pipes supplying primarily the upper parts of the plant.

Phloem, by contrast, distributes sugars produced in leaves by photosynthesis to the organs that need them, including roots, fruits and seeds. Unlike xylem transport, movement through the phloem can occur in different directions according to the plant's needs.

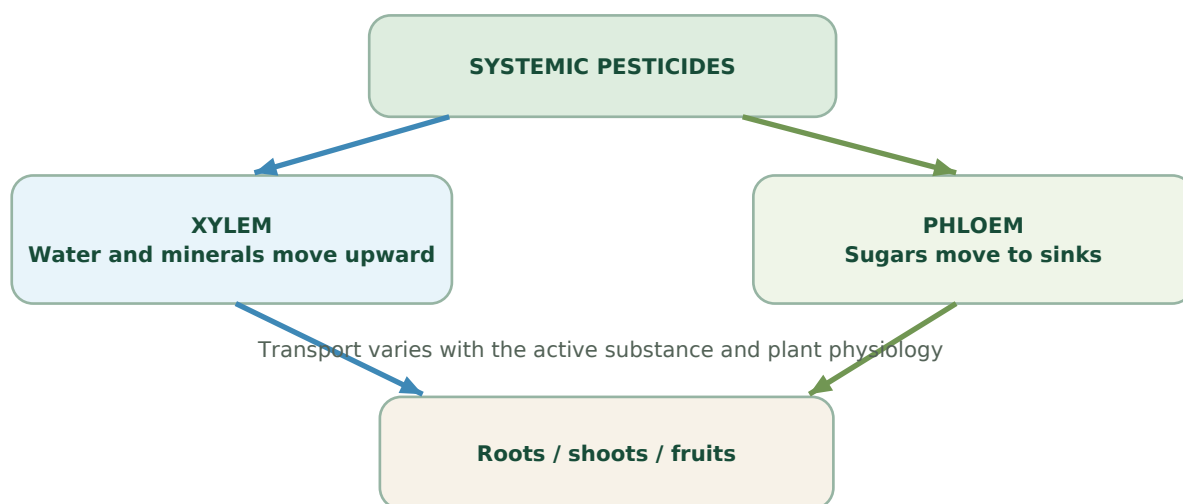
Some systemic pesticides can be transported through the xylem, the phloem or both. Their ability to reach edible parts depends on the chemical properties of the substance and the physiology of the plant.

Thus, a pesticide applied to leaves may reach other plant parts, including fruit, if it has the necessary properties. This can be agriculturally beneficial, because the active substance can act in tissues not reached directly by treatment.

For food residues, however, it introduces a crucial distinction: a pesticide absorbed into plant tissues cannot necessarily be removed simply by washing the surface.

Systemic action does not mean that every pesticide reaches fruit or edible parts at significant concentrations. Transport, metabolism and degradation differ considerably among substances.

Figure 1. Systemic movement through xylem and phloem (schematic)



2.4 Environmental dispersion: air, soil and water

After application, some pesticides can move away from the treated area. Physical and chemical processes determine their transfer among the atmosphere, soil and water.

Dispersion into air. During spraying, smaller droplets can be carried by the wind beyond the treated area. This is known as spray drift. Some substances can also volatilise after application, passing from soil or plant surfaces into the atmosphere.

Transport through soil. Once a pesticide reaches the soil, it may bind to mineral particles and organic matter, degrade or remain available for subsequent transfer. Its behaviour depends, among other things, on water solubility and adsorption capacity, meaning its tendency to adhere to particle surfaces.

Transport into surface waters. Rainfall can mobilise pesticides in soil and carry them towards ditches, canals, streams and rivers. This can occur through surface runoff—water flowing over the ground—or through the transport of eroded soil particles.

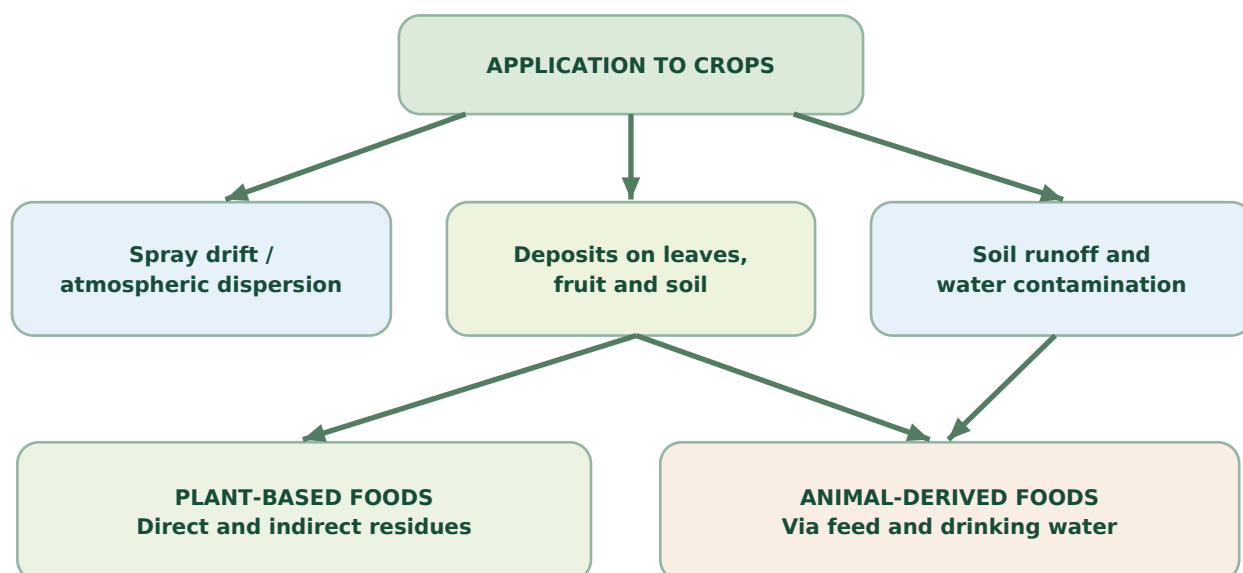
Transport into groundwater. Substances that are sufficiently mobile and persistent may infiltrate through soil and reach aquifers. Certain degradation products may also be highly mobile.

Water contamination is particularly important when the water is subsequently used to irrigate crops or provide drinking water to livestock.

Environmental transfer is not uniform: two substances applied to the same soil may follow very different pathways. Soil properties, temperature, rainfall, depth to groundwater and organic matter strongly influence these processes.

Assessing these phenomena is an important part of the environmental risk assessment undertaken by European scientific authorities.

Figure 2. Principal pathways from pesticide application to the food chain (schematic)



2.5 Contamination of crops that were not directly treated

A crop may come into contact with pesticides even when it has not been treated directly. For example, substances used in one field may be carried by wind towards neighbouring crops. Spray drift can deposit small quantities of product on nearby plants.

Another possible exposure route is irrigation water containing pesticide residues originating from other agricultural areas.

Soil can also be a contamination source, especially when it contains residues of previous treatments or long-persisting substances. Under certain conditions, some of these substances can be taken up by the roots of subsequent crops.

This is particularly relevant to organic production. Organic farming rules strictly limit the use of plant protection products and prohibit numerous substances allowed in conventional agriculture.

Nevertheless, organic certification does not amount to an analytical guarantee that pesticide residues are completely absent. Accidental contamination can arise from external environmental sources even where agricultural management is correct.

Of course, the possibility of contamination does not imply that every untreated crop contains measurable residues. The extent depends on distance from sources, environmental conditions, the type of substance and many other variables.

A label describes how a food was produced, but cannot describe everything it encountered in the environment. The distinction matters: knowledge of farming practices is not equivalent to complete knowledge of the final product's chemical composition.

2.6 Transfer through feed and drinking water to farm animals

Pesticides can also enter the food chain through feed consumed by animals raised for meat, milk and eggs. Cattle, pigs, poultry and other farm animals consume feed largely made from agricultural products such as cereals, forage, oilseeds and their derivatives.

If these raw materials contain pesticide residues, the animals may ingest them. Drinking water is another potential exposure route when it contains substances arising from environmental contamination.

Grazing animals may also accidentally ingest soil particles, which can contain residues of persistent substances.

Once ingested, a pesticide may follow different pathways. Some may be eliminated without substantial transformation. Another fraction may be absorbed through the digestive tract, distributed among tissues and metabolised, particularly by the liver.

The speed of these processes varies greatly with the animal species and chemical properties of the substance. For certain compounds, especially persistent and lipophilic ones, elimination may be relatively slow and accumulation in tissues may occur.

It is important to emphasise that residues in feed do not automatically mean that they will be transferred to food of animal origin. This depends on actual absorption, metabolism, tissue distribution and the organism's capacity to eliminate the substance.

Assessing contaminants in feed is therefore an important part of food-chain safety.

2.7 Transfer of pesticides into foods of animal origin

When an animal absorbs a substance, it may be distributed among tissues according to its chemical properties. A particularly important parameter is lipophilicity, or the tendency of a substance to partition preferentially into fats rather than water.

Some lipophilic pesticides can accumulate in animal adipose tissue, especially when they are highly persistent and metabolised slowly. Under certain conditions, residues may therefore occur in meat, animal fat, milk and eggs.

In milk, certain lipophilic substances may transfer into the fat fraction. Similarly, in hen's eggs, some lipophilic contaminants may preferentially partition into the yolk, which contains a significant amount of lipid.

This phenomenon does not apply to all pesticides. Many plant protection products are metabolised and eliminated by animals without substantial accumulation.

Two concepts should therefore be distinguished. Bioaccumulation occurs when an organism takes up a substance faster than it eliminates it, increasing its concentration over time.

Biomagnification occurs when the concentration of a substance increases from one trophic level to the next. A trophic level is an organism's position in the food chain: plants form the first level, herbivores that feed on plants occupy the next, and carnivores feeding on herbivores occupy a higher level.

For example, a persistent substance can be absorbed by small organisms, pass to animals that eat them and reach higher concentrations in predators at upper food-chain levels.

These processes are particularly relevant to certain persistent organic pollutants, but they are not universal properties of pesticides. Understanding them helps explain why some substances can still

be detected in foods of animal origin even after they are no longer used directly in agriculture.

2.8 Contamination during storage and after harvest

The journey of pesticides towards food does not necessarily end at harvest. Certain agricultural commodities may be treated with plant protection products at later stages to protect against insect pests or fungal diseases during transport and storage.

Specific post-harvest treatments may, for example, be authorised for certain fruits and vegetables. Some fungicides are used to prevent moulds responsible for the deterioration of citrus fruit and other fruit in storage.

Stored cereals may also, where permitted, undergo treatments intended to control storage insect pests. Residues in the final product can therefore originate not only from treatments during cultivation but also from later stages of the supply chain.

Accidental contamination is another concern. Equipment, containers, vehicles and storage facilities may be sources of cross-contamination if they are not properly managed. In such cases, residues need not result from intentional treatment of the food product.

Monitoring raw materials and storage conditions is therefore as important as monitoring farming practices.

Subsequent food-processing operations can also change residue concentrations and distribution. Drying, milling, refining, extraction and other treatments can reduce, concentrate or transform substances, depending on the pesticide and the process involved.

2.9 Legacy pesticides: contamination persisting for decades

Some pesticides widely used in the past had chemical characteristics that made them particularly resistant to environmental degradation. Examples include organochlorine pesticides such as DDT, aldrin and dieldrin.

Many of these substances have been banned or severely restricted because of their persistence, potential to accumulate in living organisms and possible effects on health and ecosystems.

However, stopping their use does not necessarily cause them to disappear immediately from the environment. Soil may act as a reservoir in which some contaminants remain for many years.

Their persistence depends on molecular chemistry, environmental conditions and degradation rates. For some substances, transformation products can also remain highly persistent. DDE, one of the main degradation products of DDT, is an example.

Such substances can still be present in soil, sediments and living organisms decades after their use ended. They may enter the food chain through environmental uptake or animal feeding.

A more fundamental point is that degrading a pesticide does not necessarily mean that it ceases to be an environmental concern.

The parent molecule can be transformed into other substances, known as degradation products or metabolites. In certain cases these retain toxicologically relevant properties or are more mobile and persistent than the original substance.

Therefore, the disappearance of the parent pesticide from an analysis does not necessarily demonstrate the absence of its transformation products.

Nature can transform a molecule without automatically rendering it harmless. This is why assessing chemical contamination cannot be limited to searching only for the substances originally applied.

2.10 Can a food contain residues of several pesticides?

A food may contain residues of several active substances at the same time. Multiple plant protection products may be used during cultivation to control different harmful organisms.

A crop may, for example, receive fungicide treatments to prevent disease and insecticide treatments to control particular pests. In other cases, simultaneous residues may arise from a combination of direct treatments, environmental contamination and previous applications.

Some compounds found in the final product may also be metabolites or degradation products of pesticides originally applied. The result can be a mixture of chemically different residues within a single food.

This situation is commonly described as multiple residues or, in popular discussion, a pesticide cocktail. The scientific issue is particularly complex.

A food may comply with every legal limit established for individual pesticides while containing residues of numerous active substances simultaneously.

Compliance of each individual residue does not in itself constitute a complete evaluation of potential combined effects. Substances in a mixture may act independently, produce cumulative effects when they affect the same organs or biological systems or, in certain conditions, interact with one another.

Interactions may be synergistic when the overall effect is greater than predicted from the substances considered separately, or antagonistic when it is smaller.

This does not mean that every mixture necessarily produces harmful or synergistic effects. Risk depends on the substances involved, their concentrations, exposure duration and characteristics of the exposed individuals.

How much do we really know about the effects of pesticide mixtures on human health? The answer is that scientific knowledge remains incomplete.

The European Food Safety Authority (EFSA) has studied simultaneous exposure to multiple pesticides for years and developed specific methods for cumulative risk assessment.

Assessments have already been carried out for groups of substances that can affect the nervous system and the thyroid. Assessments completed so far have not identified cumulative risks requiring regulatory action under the scenarios examined.

However, many aspects remain under investigation, notably effects on other organs, interactions among different substances and the consequences of chronic exposure to complex mixtures.

EFSA is progressively expanding these assessments to other organ systems, including the liver, kidneys and reproductive system. The European programme envisages completing the necessary cumulative assessments for pesticide residues by 2030.

At present, we therefore cannot predict and quantify with certainty every possible health effect arising from prolonged exposure to the many combinations of pesticides that may be present in food.

This does not establish that these combinations are necessarily dangerous. It means that scientific assessment of mixtures is not yet complete.

A food can therefore be fully compliant with the law while containing a set of chemical residues of which the consumer is unaware. This information is not normally provided on its label.

Consumers may know that a food complies with the law without necessarily knowing which pesticide residues it contains or in what quantities.

This is where a fundamental distinction emerges between what is legally permitted and what someone may wish to know before choosing a food. Directly analysing a product and making the results accessible provides additional information beyond what is normally available.

The point is not to automatically challenge the safety of foods that comply with legislation, but to recognise that legal compliance, knowledge of chemical composition and absence of detectable residues are three different concepts.

Conclusion to Chapter 2

The pathways by which pesticides reach foods can be much more complex than the simple image of a crop being treated in the field.

Substances can reach food through direct applications, absorption into plant tissues, environmental dispersion, contaminated feed, transfer within animal organisms and post-harvest treatments.

In some cases, residues may even derive from environmental contamination dating back many years. Each substance follows a specific pathway determined by its chemical properties, environmental conditions and the organisms with which it comes into contact.

Knowing how a pesticide may reach a food does not tell us whether that particular food actually contains it. Answering the second question requires directly examining the product and determining any residues present.

This is precisely where the following chapter begins: the occurrence of pesticide residues in foods of plant and animal origin.

Scientific references

EFSA - Pesticides — <https://www.efsa.europa.eu/en/topics/topic/pesticides>

EFSA - Chemical mixtures — <https://www.efsa.europa.eu/en/topics/topic/chemical-mixtures>

EFSA - Environmental risk assessment —
<https://www.efsa.europa.eu/en/topics/topic/environmental-risk-assessment>

Regulation (EC) No 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin.

Regulation (EC) No 1107/2009 concerning the placing of plant protection products on the market.