POISON IN YOUR COFFEE

THE HIDDEN HUMAN AND ENVIRONMENTAL COSTS OF PESTICIDE-INTENSIVE COFFEE FOR FARMERS, DRINKERS, AND NATURE

CONTENTS

Deutsche Umwelthilfe COFFEE WATCH INKOTA PESTICIDE ACTION NETWORK UK

EXECUTIVE SUMMARY

THE HIDDEN COST OF COFFEE — WHY PESTICIDE USE DESERVES URGENT ATTENTION

Two billion cups of coffee are consumed every day. It is one of the world's most beloved beverages — and one of its most pesticide-intensive crops. Behind the familiar ritual of a morning coffee lies a story that too often goes untold.

Coffee production globally relies heavily on pesticides, including many that are classified as Highly Hazardous, linked to cancer, neurotoxicity, reproductive harm such as miscarriages, endocrine disruption, water contamination, and ecosystem collapse with loss of unique biodiversity.

These are chemicals that endanger the farmers and workers who apply them, contaminate soils and waterways around farms, and leave residues that can travel all the way to the consumer's cup.

Many coffee pesticides are already banned in the countries where that coffee is drunk, yet remain in use in the countries where it is grown.

This report provides the first comprehensive synthesis showing how structurally dependent the global coffee sector is on Highly Hazardous Pesticides (HHPs). It documents severe health impacts on farmworkers, including acute and chronic poisonings. It summarizes coffee pesticides' environmental harms as well. The report also exposes the regulatory double standard that allows pesticides banned in Western consuming countries to be exported to producing countries and re-imported as "toxic cocktail" residues in consumers' cups. To conclude, it outlines a path towards a safer, more just, and more sustainable coffee system.

SCALE AND FREQUENCY OF PESTICIDE USE

Where data exists, it reveals staggering chemical intensity in coffee.

- Brazil used 19.8 million liters of pesticides on coffee in 2015, more pesticides per hectare than maize or soy
- Vietnam has seen pesticide use increase 3–5× in 25 years, with coffee ranking second only to rice in pesticide use
- Kenya uses 27% of its national pesticide volume on coffee although coffee accounts for only around 0.5% of Kenya's total agricultural area
- Climate change intensifies pest pressure, driving even heavier chemical use and deepening farmers' dependency

A DOUBLE STANDARD IN GLOBAL TRADE

Pesticides banned in the EU and U.S. are still exported to coffee-producing countries, where regulation is weaker. This regulatory double standard shifts the health and environmental burden onto producing countries and the farming communities least able to bear it, while leaving consumers exposed to residues that are barely monitored and rarely disclosed.

HUMAN TOXICITY: HAZARDOUS CHEMICALS DOMINATE COFFEE PRODUCTION

Across Brazil, Kenya, and Colombia, at least 159 active ingredients are used in coffee production:

- 60–77% are Highly Hazardous Pesticides
- 59% are banned in the EU
- 14 ingredients are WHO Class 1A/1B (extremely or highly hazardous)
- 22 are carcinogenic or probably carcinogenic
- 40 are reproductive toxicants or endocrine disruptors
- 29 are neurotoxic

These chemicals are linked to cancer, miscarriages, infertility, endocrine disruption, and neurological disease.[1]

Glyphosate, classified as "probably carcinogenic", remains deeply embedded in coffee production, with 164 registered products containing glyphosate approved for use in Brazil alone.

RESIDUES: A "TOXIC COCKTAIL" IN CONSUMERS' CUPS

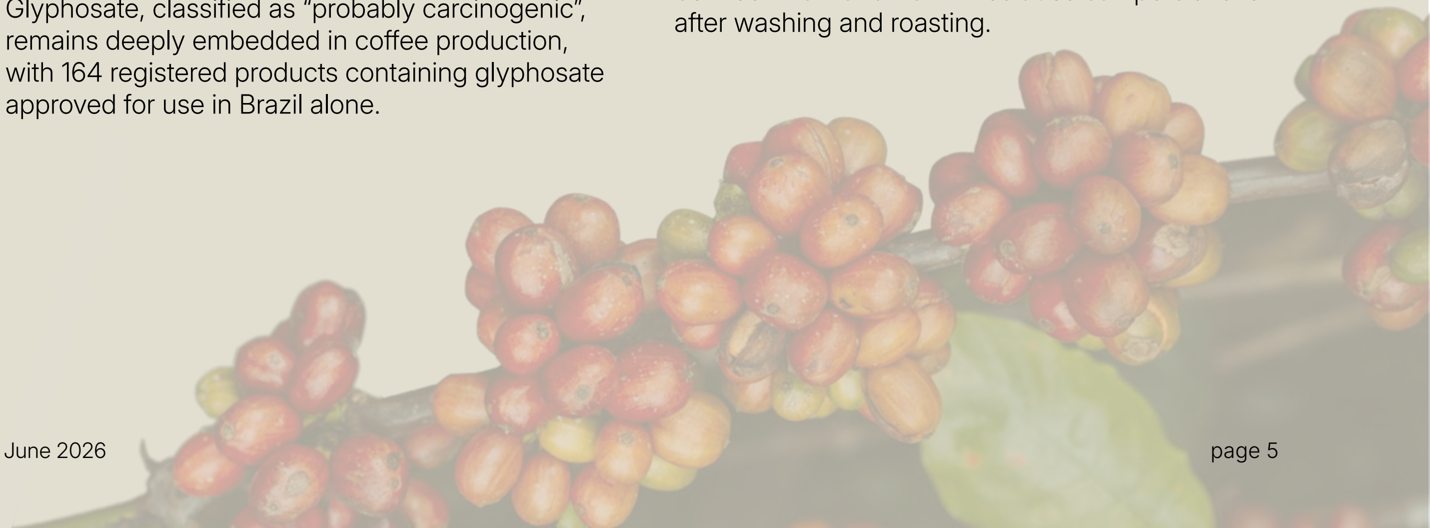
1 cup in 5 that coffee drinkers savor is likely contaminated with residues of pesticides.

Testing of coffee imports is minimal, yet available evidence is alarming:

- 19% of green coffee (unroasted coffee bean) samples contain pesticide residues
- 72% of roasted coffee in the US showed glyphosate leftovers (AMPA)
- 21% of roasted samples tested in Egypt contain residues

Many contain multiple residues simultaneously, forming a "toxic cocktail"

In 2022, 23% of coffee samples tested by the European Food Safety Authority (EFSA) contained pesticides banned in the EU, and the presence of banned pesticides in coffee increased tenfold between 2011 and 2022. Residues can persist even after washing and roasting.



FARMWORKERS ARE BEING POISONED

Farmers and farmworkers face the highest exposure through mixing, spraying, re-entry into treated fields, contaminated water, and drift.

Even their families are exposed, through residues carried home on clothing and skin, contaminated drinking water, and proximity to treated fields, with children particularly at risk.

Acute symptoms include vomiting, collapsing, respiratory distress, skin burns, and neurological effects; chronic exposure is linked to cancer, reproductive harm, and long-term organ damage.

Protective equipment is rare: in the Dominican Republic, 87% of farmers reported not wearing masks or gloves; in India, two-thirds used no protection at all.

Official poisoning statistics vastly undercount the true burden — studies suggest up to 88% of pesticide illnesses go undocumented.

Photo by Yevhen Smyk at Vecteezy.com

ENVIRONMENTAL DAMAGE: WATER, SOIL, BIODIVERSITY

Pesticides used in coffee are highly toxic to ecosystems and species[1]:

- 46 active ingredients are very toxic to bees, threatening pollination
- 48 are very toxic to fish, contaminating rivers and watersheds
- 18 are toxic to beneficial insects essential for natural pest control
- 11 are toxic to earthworms, undermining soil health

Water contamination is widespread: In Colombia, 81.3% of surface water samples from coffee regions contained pesticide residues.

Coffee wastewater also carries persistent pesticide loads. Chemical fertilizers add to the climate crisis, emitting nitrous oxide — 273× more potent than CO_2.

Soil contamination is a problem as well: Field data from major producing regions across four continents showing residues of HHPs at concentrations harmful to crucial soil life and biodiversity.

A PATH FORWARD

Real solutions exist, and they are already working in coffee-growing regions around the world. Integrated pest management, organic farming, agroforestry, and agroecological approaches can dramatically reduce pesticide dependence while protecting yields, farm incomes, and ecosystem health. Critically, the most effective results come not from any single approach but from combining multiple strategies: agroforestry creates the microclimate and habitat that makes biological control work; healthy soils support biopesticide performance; cultural controls reduce the pest pressure that natural enemies then suppress. These approaches do not simply swap one input for another — they rebuild the farm as a more resilient system, where pests and diseases are less likely to spread in the first place.

Regenerative farming can offer a meaningful entry point — healthier soils, lower input costs, greater resilience — but it carries a risk. Minimising Chemical Disturbance is widely recognised as a key component of regenerative agriculture but is overlooked by many so-called ‘regenerative’ standards. Applied to existing monoculture layouts without deeper structural change, it can become a corporate sustainability narrative that addresses symptoms while leaving the underlying vulnerability intact. It is most valuable as a first step toward agroforestry and agroecological design, not a destination in itself.

Achieving good reforms at scale requires:

- Investment in farmer training and agroforestry transitions
- Procurement policies that reward low-chemical production including labels
- Stronger regulation, including closing loopholes that allow export of banned pesticides
- Mandatory residue testing to protect consumers and farmworkers

Coffee’s pesticide crisis is systemic, global, and urgent. It harms farmers, ecosystems, and consumers, and is worsened by climate change and regulatory double standards. The alternatives are proven. The question is whether industry, governments, and consumers will create the conditions for farmers to actually use them.

WHO PRODUCES AND WHO CONSUMES?

PRODUCING COUNTRIES AND IMPORTANCE OF SMALL SCALE FARMERS

Behind each of the 2.2 billion cups of coffee consumed every day lies a human story.[2] Most begin on a smallholder farm. There are 12.5 million of them worldwide, 95% smaller than five hectares[3], spread across around 20 producing countries[4]. Brazil alone accounts for over a third of global production, followed by Vietnam, Colombia, and Indonesia, with significant production also in Ethiopia, Uganda, Honduras, and other countries.

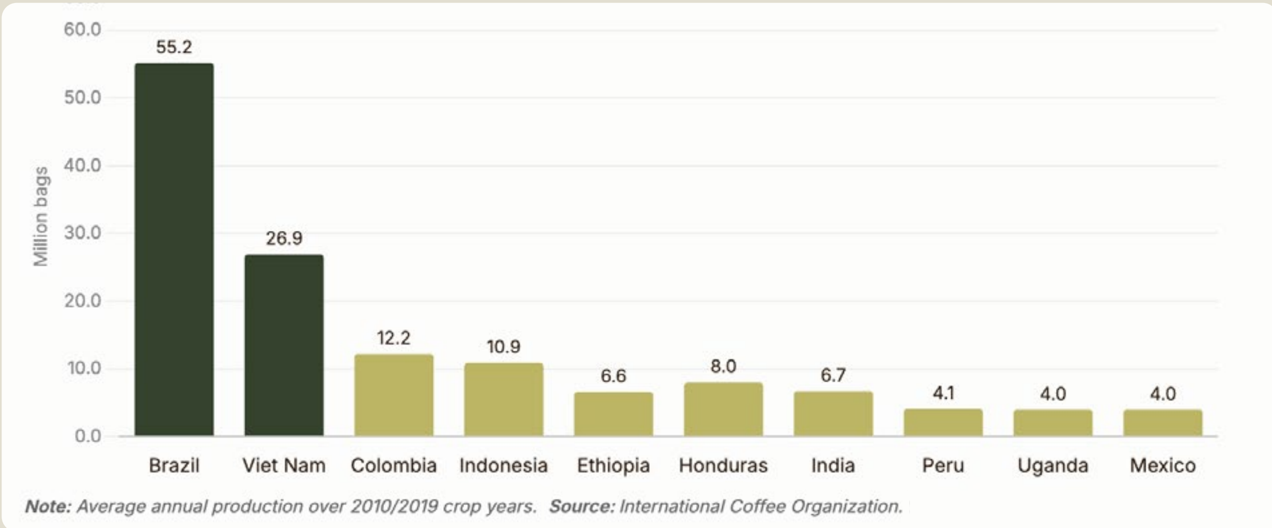


Figure 1: Top coffee-producing countries with different sizes of bars depending on their importance.[2]

Together, smallholders produce around 80% of the world's coffee — the foundation of a multi-billion-dollar industry. Yet at least 5.5 million of these farmers live below the international poverty line of $3.20 a day, navigating volatile prices, climate shocks, and limited institutional support with little margin to drive change.[4] Beyond these well-documented challenges, a largely overlooked burden remains that rarely makes headlines: many of these already vulnerable smallholder farmers, and the fragile ecosystems they depend on, are exposed to health and environmental risks of pesticide-intensive coffee production. The coffee industry's addiction to pesticides exacerbates existing vulnerabilities, reinforcing cycles of poverty, environmental degradation, and health inequity.

BRAZIL IN FOCUS

Approximately 300,000 producers cultivate coffee on nearly 2 million hectares. Family farms (small to medium farms owned by one family) contribute 30–38% of total national production. 90% of coffee produced by family farmers is grown in monoculture, a system that increases chemical dependency and leaves farmers more exposed to both market and climate risks.[5] Larger Brazilian coffee farms are globally notorious for their overwhelming use of monoculture systems.

Figure 2: The Coffee Farmers reality

THE WORLD'S TOP COFFEE CONSUMERS — AND THEIR RESPONSIBILITY FOR PESTICIDE USE

The majority of coffee is exported to wealthy consuming nations. The European Union, United States, and Japan together account for over 50% of global coffee imports.[6] The EU alone imports around 3 million tonnes of green coffee annually, making it the world's single largest coffee market.[7] The United States follows, consuming over 1.5 million tonnes per year. These markets shape the conditions under which coffee is grown, including the industry's devastating reliance on pesticides and their catastrophic impacts on human health and environment.

These consuming countries are often also the same ones supplying toxic pesticides. Many of the pesticides that are banned or tightly restricted in the EU and U.S. are still exported to coffee-producing countries.[8] They are exported by agrochemical companies that can no longer legally use them at home, and sold into markets where oversight is weaker and farmers have little choice. The same coffee, grown with those banned substances, is then legally returned to European and American supermarket shelves, as long as residue levels fall within specified limits (but with often limited and inadequate testing to protect coffee consumers). A chemical banned for use becomes a residue that is tolerated for import. That is a double standard at the heart of the coffee sector.

The double standard is not an accident. It is a system that exports health risks, environmental damage, and economic vulnerability to producing countries while consuming nations enjoy cheap coffee with little awareness of the hidden costs embedded in every cup.

This must change.

Consuming nations and their industries bear a direct responsibility: to close the loopholes that allow harmful pesticides on imported crops; to end the profit model built on exporting chemicals banned at home; and to back truly sustainable coffee through procurement policies, certification standards, and consumer education that prioritise pesticide reduction and agroecological practice.

The tools exist. What is needed is the political will to use them — and the consumer pressure to demand it.

CONSUMPTION ('000 BAGS)

1	EU (28)	46.799
2	United States	26.891
3	Brazil	22.830
4	Germany	9.490
5	Japan	7.806
6	Indonesia	5.429
7	France	5.340
8	Italy	5.203
9	Russian Federation	4.801
10	Canada	4.011

Note: '000 bags. ***Source:*** *ITC.*

Figure 3: Top 10 coffee consuming countries in 2018-2019[6]

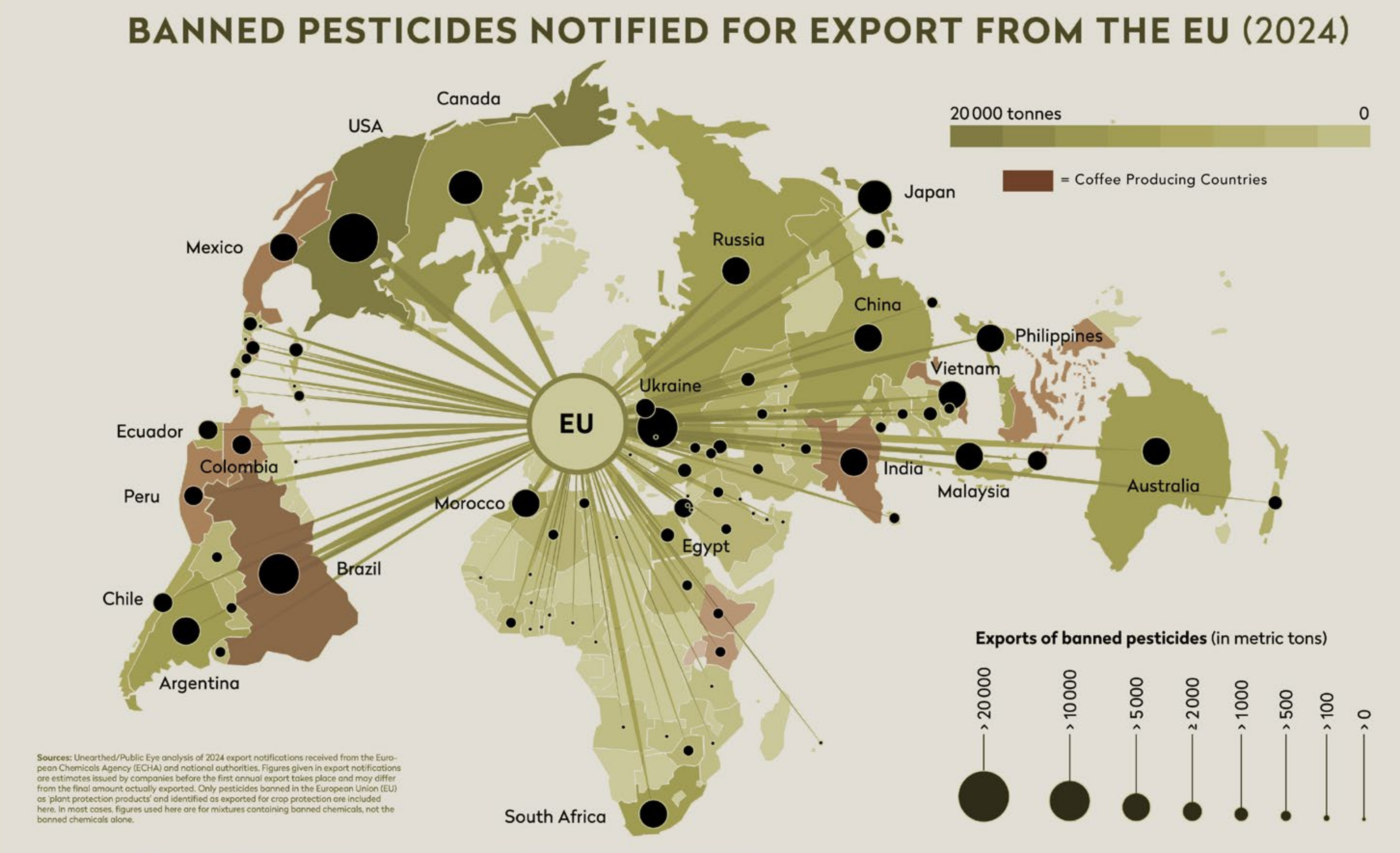


Figure 4: Banned Pesticides in Europe notified for export to coffee producing countries[8]

TWO TYPES OF BEANS THAT DOMINATE GLOBAL MARKETS

Of the more than 120 wild coffee varieties, just two dominate global production: Arabica and Robusta.[9] Arabica, prized for its complex flavours and bright acidity, accounts for roughly 55–60% of world supply.[10] It grows best at higher altitudes, where cooler temperatures slow the ripening of the bean and develop its distinctive taste. Those same conditions make arabica highly sensitive to pests, diseases, and climate change, pushing farmers toward more intensive pesticide use to protect their crop.

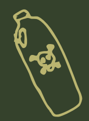
Robusta is tougher and more heat-tolerant, it naturally resists many of the pests that plague arabica and typically requires fewer chemical inputs. Long dismissed as inferior — the bean behind instant coffee and budget blends — robusta is quietly gaining ground. As climate pressures make arabica harder to grow at traditional altitudes, more farmers are shifting toward robusta for its resilience. Its share of global production is rising, and with it, questions about how cultivation practices — and pesticide use — may evolve as the industry adapts to a warming world.[4]

ROBUSTA

Coffee canephora (Robusta):

Low altitude, typically between 0 to 800 meters above sea level in hotter, humid conditions able to withstand higher temperatures, which can range from 24°C to 30°C

E.g. Vietnam, Indonesia, West-Central Africa



Pest & disease resistant
Less pesticide use needed

Coffea canephora (Robusta) requires cross-pollination, meaning pollen must be transferred between different plants — typically by insects like bees or by wind. This promotes genetic mixing and results in a broader range of genetic traits within Robusta populations. Because of this higher genetic variability, Robusta plants tend to be more resilient to environmental stressors, including pests, diseases, and climate fluctuations, which contributes to their greater hardiness and disease resistance compared to C. arabica.[11]

Robusta's higher concentration of caffeine (nearly double the amount found in Arabica) and Chlorogenic Acids acts as a natural defense mechanism against pests and diseases.[12] The bitterness of caffeine deters insects[13] and the level of Chlorogenic Acids is toxic to many fungi[14] , therefore lower pesticides are needed.

VS.

ARABICA

Coffee arabica:

High altitude typically ranging from 600 to 2,000 meters above sea level in cooler climates where temperatures range from 15°C to 24°C

E.g. Brazil, Ethiopia (country of origin to Arabica coffee), Colombia

Pest- and disease-sensitive
Higher pesticide need

Coffea arabica is primarily self-pollinating (its flowers can fertilize themselves without relying on insect or wind pollinators). This is an advantage where pollinator activity is low and helps ensure fruit set and non-changing flavour. However, this reproductive strategy also results in low genetic diversity, which limits the species' ability to adapt to new stresses. As a result, Arabica is especially vulnerable to diseases and environmental change, including threats like coffee leaf rust, and presents challenges for breeding greater resilience.[11]

Coffea arabica has less caffeine and Chlorogenic Acids, that can act as natural defense against pests and diseases.

Figure 5: Robusta vs. Arabica - Difference in sensitivity to pests and deseases

THE COFFEE INDUSTRY'S ADDICTION TO PESTICIDES

Reliable data on the types, volumes, and application rates of pesticides used in coffee production are hard to come by for many producing countries, a gap that makes comprehensive assessment difficult and reflects a broader lack of transparency in global supply chains. However, existing data tells a concerning story.

Coffee farming has become heavily reliant on pesticides, many of them classified as Highly Hazardous Pesticides, with some chemicals applied up to 20 times per season. For the farmworkers, rural communities, and ecosystems living with those application rates, the risks are real — and likely greater than the incomplete data suggests.

SHEER SCALE: THE VOLUME OF PESTICIDES IN COFFEE

Coffee is one of the most pesticide-intensive crops globally: Pesticides are sprayed in high volumes and alarming rates across major producing regions:

In Brazil the scale of pesticide use is impossible to ignore. In 2015, coffee farming consumed 19.8 million litres of pesticides, 3.8% of all pesticides sold in the entire country[15], generating US$246.5 million in revenue for the agrochemical industry.[16] Coffee fields are treated with an average of 10 litres of pesticide per hectare, more than maize (7.4 L/ha) or soy (4.8 L/ha) - crops notorious for chemical intensity.[17] And the trend is moving in the wrong direction: in 2020, Brazil recorded a 11% increase in pesticide sales over the previous year.[18]

Vietnam is the world's second-largest coffee producer and has seen pesticide use in agriculture increase three- to five-fold over roughly 25 years. Coffee ranks second only to rice in the country's total pesticide consumption, a striking fact given that the sector accounts for only about 10% of land use compared to rice.[19]

In Kenya, coffee accounts for an estimated 27% of national pesticide use, despite being grown on only 5% of the area dedicated to maize, Kenya's dominant crop. That stark disproportion signals just how chemically intensive coffee farming has become relative to other crops.[20]

Photo by Asih Wahyuni at Vecteezy.com

HIGH TOXICITY: THE WIDESPREAD USE OF HIGHLY HAZARDOUS AND BANNED PESTICIDES

The concern lies not only in the quantity and rates of pesticide application, but also in the toxicity of substances used.

Our analysis—based on peer-reviewed literature and official pesticide registration data—covers coffee production in Brazil, Kenya, and Colombia, three countries representing different continents and for which such data were available. Across these, we identified at least 159 different active ingredients registered for use on coffee.

Brazil had the highest number in active use. The chemical profile was broadly similar across all three countries, and the findings are difficult to ignore:

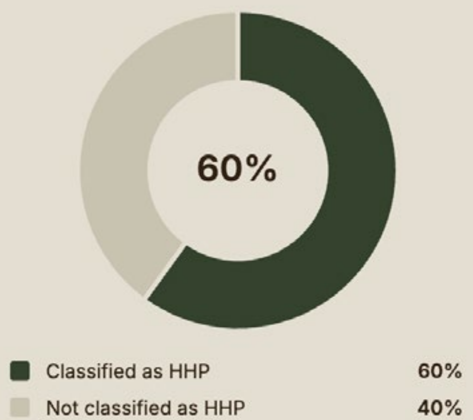


Figure 6: Pesticides classified as Highly Hazardous (HHPs)[21]

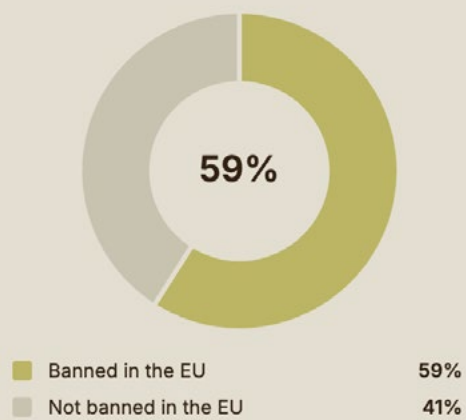


Figure 7: Pesticides banned in the EU[22]

HIGHLY HAZARDOUS PESTICIDES (HHPS)

HHPs are pesticides that pose particularly high levels of acute or chronic risks to human health or the environment.

According to the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organisation (WHO), this classification includes pesticides listed under international conventions such as the Stockholm[23] and Rotterdam Conventions[24], those classified by WHO as extremely or highly hazardous,

- Known or probable human carcinogens (causing cancer),
- Mutagens (damage the DNA in cells),
- Reproductive toxicants (affect fertility, the ability to have children, or the healthy development of an unborn baby)
- Endocrine disruptors (disturb the body's natural hormone balance),
- Substances that are very persistent (stay in the environment for a long time)
- Bioaccumulative and those causing severe or irreversible harm to the environment.[25]

Pesticide Action Network (PAN) subsequently developed an international HHP list based on these FAO/WHO criteria, while also expanding the approach to include additional environmental toxicity indicators and broader human health concerns.[21]

60% of the documented substances are classified as Highly Hazardous Pesticides (HHPs) according to criteria established by the Pesticide Action Network (PAN)[21] and 59% are already banned in the EU.[22]

These substances are banned in the EU because they pose severe risks to human health or the environment through their acute or chronic toxicity, long-term health impacts, or environmental persistence. A 2023 study from Kenya showed that even 77% of pesticides used in coffee production are classified as HHPs.[20]

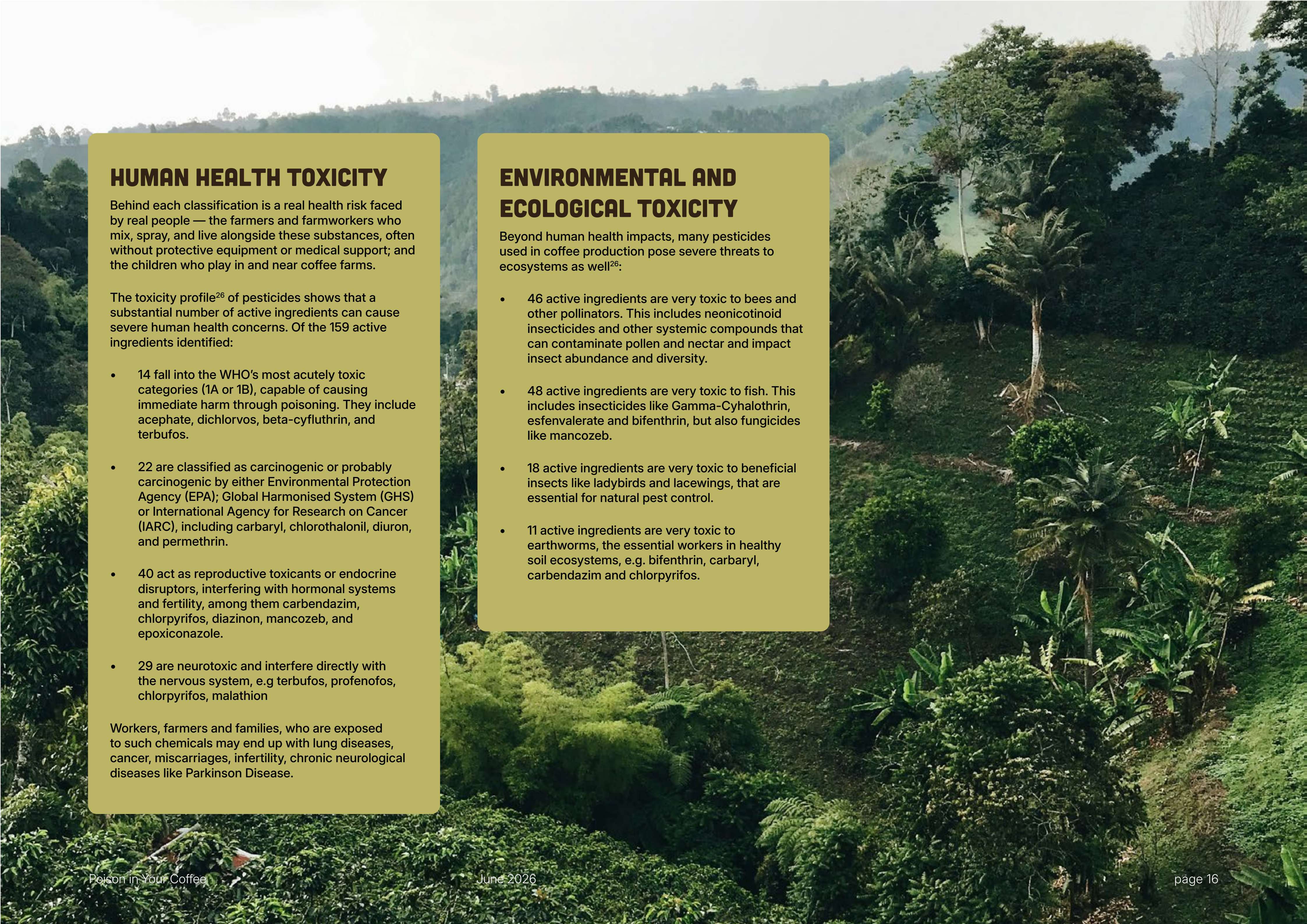
Of the 159 active ingredients identified, 12 appear on the Rotterdam Convention's Prior Informed Consent list — meaning they can only be exported if the receiving country has been fully informed of the risks and explicitly agrees to accept them.

This discrepancy exemplifies the "double standard" in global pesticide regulation, where substances that are too dangerous for use in coffee consuming countries continue to be marketed and applied in coffee producing countries.

THE DOUBLE STANDARD

The pesticide "double standard" refers to the practice whereby agrochemical corporations—predominantly based in Europe and North America—continue to manufacture, export, and profit from pesticides that are banned or severely restricted in their home countries due to health and environmental risks.

Weak regulatory systems and limited enforcement capacity in many producing countries allow these hazardous chemicals to be sold and used, effectively transforming parts of the Global South into dumping grounds for pesticides deemed unacceptable elsewhere.



HUMAN HEALTH TOXICITY

Behind each classification is a real health risk faced by real people — the farmers and farmworkers who mix, spray, and live alongside these substances, often without protective equipment or medical support; and the children who play in and near coffee farms.

The toxicity profile[26] of pesticides shows that a substantial number of active ingredients can cause severe human health concerns. Of the 159 active ingredients identified:

- 14 fall into the WHO's most acutely toxic categories (1A or 1B), capable of causing immediate harm through poisoning. They include acephate, dichlorvos, beta-cyfluthrin, and terbufos.
- 22 are classified as carcinogenic or probably carcinogenic by either Environmental Protection Agency (EPA); Global Harmonised System (GHS) or International Agency for Research on Cancer (IARC), including carbaryl, chlorothalonil, diuron, and permethrin.
- 40 act as reproductive toxicants or endocrine disruptors, interfering with hormonal systems and fertility, among them carbendazim, chlorpyrifos, diazinon, mancozeb, and epoxiconazole.
- 29 are neurotoxic and interfere directly with the nervous system, e.g terbufos, profenofos, chlorpyrifos, malathion

Workers, farmers and families, who are exposed to such chemicals may end up with lung diseases, cancer, miscarriages, infertility, chronic neurological diseases like Parkinson Disease.

ENVIRONMENTAL AND ECOLOGICAL TOXICITY

Beyond human health impacts, many pesticides used in coffee production pose severe threats to ecosystems as well[26]:

- 46 active ingredients are very toxic to bees and other pollinators. This includes neonicotinoid insecticides and other systemic compounds that can contaminate pollen and nectar and impact insect abundance and diversity.
- 48 active ingredients are very toxic to fish. This includes insecticides like Gamma-Cyhalothrin, esfenvalerate and bifenthrin, but also fungicides like mancozeb.
- 18 active ingredients are very toxic to beneficial insects like ladybirds and lacewings, that are essential for natural pest control.
- 11 active ingredients are very toxic to earthworms, the essential workers in healthy soil ecosystems, e.g. bifenthrin, carbaryl, carbendazim and chlorpyrifos.

GLYPHOSATE: A POSTER CHILD OF THE COFFEE PESTICIDE CRISIS

Glyphosate is a substance whose harms are scientifically documented, but one that remains deeply embedded in coffee production worldwide.

In 2015, the World Health Organization's International Agency for Research on Cancer (IARC) classified glyphosate as "probably carcinogenic to humans" (Group 2A).[27] Since then, courts around the world have heard thousands of cases brought by farmworkers who developed Non-Hodgkin lymphoma (a type of cancer that starts in the lymphatic system) after years of exposure. In landmark U.S. rulings, juries found that manufacturers knowingly failed to warn users of cancer risks, awarding billions in damages to workers and their families.[28]

Despite this evidence, glyphosate use in coffee production has not declined. Farmers apply it routinely to suppress weeds between coffee trees, to save labour, reduce costs, and achieve rapid weed suppression. In Brazil alone, 164 registered glyphosate-containing products are approved for use in coffee cultivation.[29] In Kenya, glyphosate ranks second by volume among all pesticides used in the sector.[20] As a result of the heavy use, studies have detected glyphosate residues in green coffee beans across multiple producing countries.[30]

Repeated glyphosate applications also undermine long-term sustainability:[31] they degrade soil organic matter,[32] disrupt soil microbial communities, 42 harm non-target organisms, and accelerate the evolution of herbicide-resistant weeds[34] making coffee and other crops harder to grow. Meanwhile, farmers lose ecosystem services provided by managed ground cover, such as erosion control, moisture retention, and habitat for beneficial insects. The irony is stark: an herbicide marketed to improve agricultural productivity is undermining the long-term biological foundation that coffee cultivation depends upon.

Vietnam, the world's #2 coffee producing country, demonstrates that change is possible. Responding to mounting health and environmental concerns, authorities banned glyphosate from manufacture, import, sale, and use from 2021 onward.[35] Monitoring data showed that glyphosate residues in exported green coffee, previously widespread, declined sharply in the years that followed.[36] When regulators act, farmers adapt, and the harm decreases. The question is whether other governments will follow.

SOME HAZARDOUS PESTICIDES USED IN COFFEE THOUGH BANNED IN THE EU

FUNGICIDES

- **Chlorothalonil:** A broad-spectrum fungicide used against coffee leaf rust (Hemileia vastatrix) and brown eye spot (Cercospora coffeicola)[37], is classified as a probable human carcinogen (Group B2) by the US EPA based on animal tumour evidence[38]. The EU banned it in 2020 due to unacceptable groundwater contamination risks from its metabolite and genotoxicity concerns. It is highly toxic to aquatic organisms.[39]

- **Epoxiconazole:** a fungicide used to fight coffee leaf rust (Hemileia vastatrix), is classified as a probable human carcinogen (Group B2) by the US EPA. Additionally it disrupts hormone production and liver enzymes in humans, with Brazilian coffee workers showing lower testosterone levels after exposure.[40] It acts as a strong hormone disruptor, blocks important cell channels, and can irritate skin; animal tests show damage to liver, kidneys, adrenals, and ovaries.

HERBICIDES

- **Diuron**: A herbicide, classified as carcinogenic. The U.S. EPA labels it as a "known/likely" human carcinogen, citing studies that show tumours in the urinary bladder, kidneys, and mammary glands in laboratory animals.[41] Meanwhile, the European Chemicals Agency (ECHA) lists it under its harmonized classification as "may cause cancer" (H351), with proposals even classifying it as Category 1B—meaning "presumed to have carcinogenic potential in humans".[42] Nevertheless it's still used in coffee production in Brazil and registered in 28 different products.

INSECTICIDES

- **Chlorpyrifos**: Chlorpyrifos, an organophosphate insecticide used against coffee pests like the coffee berry borer (Hypothenemus hampei) and leaf miners, inhibits acetylcholinesterase affecting the nervous system.[43] The US EPA banned it from all food crops in 2021 because prenatal exposure harms children's brain development. The EU banned it in 2020 for the same reason. Key studies of children show it causes lower IQ scores (by up to 3 points), poorer memory, and attention problems that last into school age[44].

- **Imidacloprid**: Imidacloprid, a neonicotinoid insecticide used against coffee leaf miners (Leucoptera coffeella) and other sucking pests, is banned for outdoor agricultural use in the EU since 2018 due to severe risks to bees and other pollinators.[45] It harms insect nervous systems and persists in soil and water, killing bees and disrupting aquatic ecosystems.[46] Human studies involving neonicotinoids generally link exposure before birth to potential neurodevelopmental risks.[47]; animal studies show prenatal imidacloprid impairs memory and increases anxiety in offspring.

IMPLICATIONS AND THE NEED FOR SYSTEMIC CHANGE

Even the industry has acknowledged the scale of the pesticide problem. The Coffee Sustainability Reference Code, developed by the Global Coffee Platform (GCP), has published a list of pesticides to be phased out, some immediately, others by 2026 or 2030.[47] The Code requires 15% of active ingredients be prohibited immediately, with a further 40% to be phased out by 2030.

GCP's 2030 commitment to phase out all PAN HHPs was ambitious, and PAN UK was pivotal in securing it. But resources to scale up alternatives have not followed, and a critical gap remains: GCP does not appear to mandate the same phase-out in its recognition of 'equivalent schemes'. Phasing out many currently used pesticides by 2030 leaves farmers navigating increasing pest and disease pressure with a shrinking chemical toolkit, in an already fragile monoculture system.[48]

This striking admission demonstrates just how far current practice has drifted from what is considered acceptable. This gap likely underestimates the true scale of the problem as, in many producing countries, reliable pesticide use data simply does not exist, making it impossible to fully account for what is being applied, by whom, and at what risk to human health and the environment. The gap between commitment and reality on the ground remains wide — and for the farmers and farmworkers already living with the consequences, five more years is a long time to wait.

What is needed is accelerated, major investment by industry and governments in agroecological approaches, biological controls, and diversified farming systems that build natural resilience from the ground up.

Photo by Oleg Gapeenko at Vecteezy.com

HUMAN HEALTH IMPACT

Pesticides in coffee may be affecting millions if not billions of consumers, but the heaviest burden falls on the 25 million farmers and 100 million farmworkers who grow it.

Across Latin America, Africa, and Asia, people mix pesticides, spray fields in tropical heat, harvest recently treated cherries, and return home in contaminated clothing, most without adequate training, protective equipment, or access to safer alternatives.

Many of the pesticides they handle every day have been banned in coffee-consuming countries precisely because of the risks they pose to human health.

Despite coffee commanding some of the highest pesticide applications of any commercial crop, only a few studies focus specifically on the health of coffee farmers or farmworkers.

PATHWAYS OF EXPOSURE IN COFFEE PRODUCTION

Coffee farmworkers face pesticide exposure at every stage of the production cycle. The highest-risk moments include when workers ***mix, load, and apply chemicals by backpack sprayer*** or motorised equipment, when skin contact and inhalation of spray mist are most intense. But exposure does not stop when the sprayer does. Workers who return to treated plantations for weeding, pruning, or harvest come into contact with residues on foliage, soil, and coffee cherries, often long before any recommended waiting period has passed.[49]

Those who handle freshly picked cherries during washing, pulping, and fermentation touch residues that remain on the fruit.

During dry processing and hulling, pesticide-contaminated dust rises as dried husks and parchment are mechanically removed. Even roasters may inhale residues that volatilise at high temperatures.[50]

For many smallholder families, the farm and the home are the same place. Spray drift reaches living areas, gardens, and water sources.[51] Workers carry contaminated clothing and boots indoors, and children play in spaces where chemicals have settled.[52] Tools and containers used for pesticide application are sometimes reused to carry water or store food.[53]

Last but not least, runoff from treated fields contaminates streams and aquifers that entire communities rely on for drinking water, cooking, and irrigation.[54] The result is a chemical environment with no clear boundary between work and home life, one in which health consequences accumulate across years, and across generations.

THE PROTECTION GAP

The vast majority of coffee farmworkers handle pesticides without adequate personal protective equipment (PPE).

In the Dominican Republic, 87% of coffee farmers reported not wearing masks or gloves when they spray.[55] In India, two thirds of coffee workers used no protective measures at all during pesticide application.[56]

Investigative reporting from Brazil found workers on large commercial plantations, where toxic, carcinogenic substances are frequently applied, spraying wearing only their own clothes, without the protection the law requires.[57] Even where Brazilian labour law mandates that employers provide it[58] enforcement is weak and compliance sporadic.

This gap exists for reasons that reinforce each other. Protective equipment is often unavailable or simply unaffordable for smallholder farmers and wage workers.

Standard product labels recommend long sleeves, gloves, hats, goggles, face masks, and boots, equipment that is genuinely impractical in tropical heat and can result in health effects from heat stress. Workers improvise: plastic bags instead of gloves, handkerchiefs tied over their mouths.[57] The result is a false sense of security that may be more dangerous than wearing nothing at all. And even proper equipment offers incomplete protection against substances whose chronic health effects[59], including endocrine disruption, can be driven by small doses accumulated over many years.

The coffee industry compounds this failure through neglecting the monitoring of worker's health. Unlike the cut flower industry, where acetylcholinesterase testing to detect organophosphate exposure is increasingly standard,[60] coffee production has no comparable biological monitoring despite widespread use of the same insecticides. Industry attention focuses almost exclusively on residue limits in exported beans and on product quality and trade compliance, while the health of the people who produce those beans goes unmonitored, unmeasured, and unreported. The true burden of occupational illness for farmers and farmworkers remains invisible.

ACUTE HEALTH EFFECTS

ACUTE HEALTH EFFECTS: THE IMMEDIATE TOLL OF PESTICIDE EXPOSURE

Acute pesticide poisoning strikes within hours or days of exposure. Symptoms range from dizziness, nausea, vomiting, and headaches to abdominal pain, blurred vision, skin rashes, and respiratory distress.[61] Severe cases produce tremors, convulsions, confusion, and loss of consciousness.[56] Organophosphate and carbamate insecticides, both widely used in coffee production, are particularly dangerous: they inhibit the enzyme acetylcholinesterase, sending the nervous system into dangerous overstimulation.[62] In the most severe cases, especially with high-dose exposure to acutely toxic chemicals, pesticide poisoning can be fatal.

EVIDENCE FROM COFFEE-PRODUCING COUNTRIES

Brazil's coffee heartland tells the story with uncomfortable clarity: In 2012, official records from Minas Gerais, the state that produces roughly half of Brazil's coffee, recorded 21 pesticide deaths and 817 agricultural poisonings.[52] Those numbers almost certainly underestimate reality. A Danwatch survey of 412 coffee workers in the same area found that 59% reported at least one acute poisoning symptom.[52] Danwatch investigations captured what the statistics miss: workers collapsing in fields after spraying, vomiting, struggling to breathe, some hospitalised after organophosphate exposure — then returning to work as soon as they physically could, because their families depended on it. Similar findings were reported in a study by a Brazilian research team.[63]

Broader research estimates that up to 88% of farmworker pesticide illnesses go undocumented.[64]

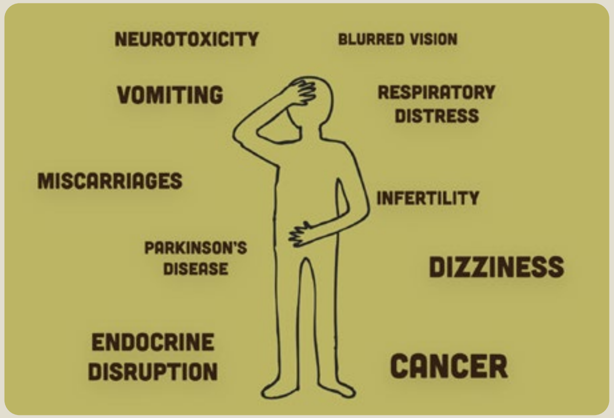


Figure 8: Acute and chronic health effects due to pesticide exposure

The pattern documented in Brazil repeats across every major coffee-producing region. Research in Vietnam,[65] Nicaragua and Costa Rica[66], Tanzania[62] and the Dominican Republic[67] consistently finds high rates of acute poisoning symptoms among coffee workers. In the Dominican Republic, those with higher pesticide levels in their blood and urine experienced more frequent and more severe symptoms.[55] In Nicaragua and Costa Rica, researchers measured significant cholinesterase inhibition, the biochemical signature of organophosphate poisoning, with the most severe enzyme depression found in workers showing the worst neurological symptoms.[66]

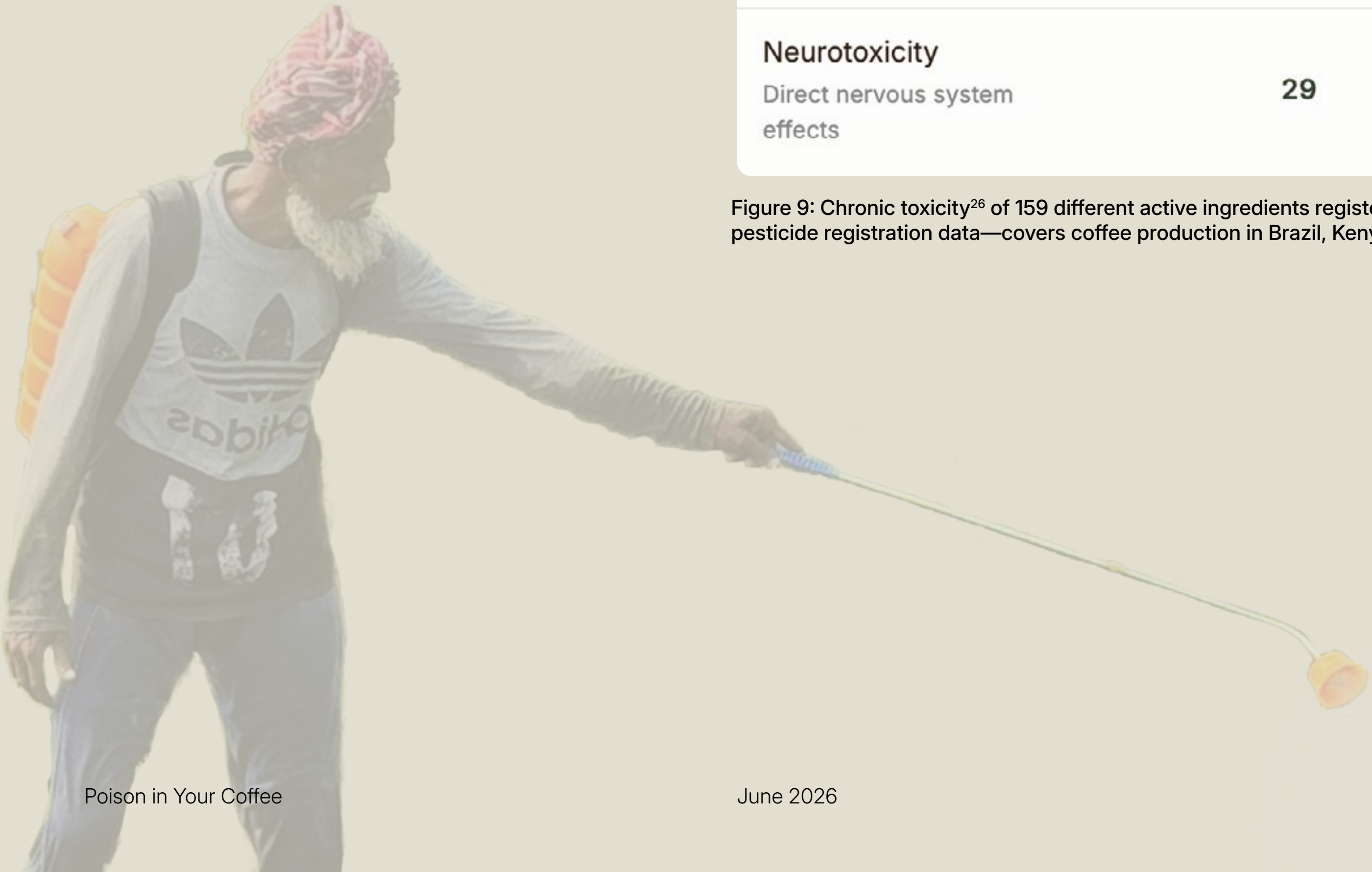
Across all these countries, the same factors recur: workers without protective equipment and with limited access to medical care continue through acute poisoning because stopping means lost income.[68]

CHRONIC HEALTH EFFECTS

Workers handle pesticides repeatedly: mixing, spraying, and returning to treated fields, often without precautions, for years, and even across entire careers. Chronic health damage accumulates over months and years of repeated exposure and by the time it becomes visible, it is often irreversible.

HEALTH CONCERN	CONFIRMED	POSSIBLE	SHARE OF ALL PESTICIDES
Carcinogenicity Known or probable carcinogens	22	—	14%
Reproductive toxicity Endocrine disruptors & reproductive toxicants	40	61	64%
Neurotoxicity Direct nervous system effects	29	23	32%

Figure 9: Chronic toxicity[26] of 159 different active ingredients registered for use on coffee. (Peer-reviewed literature and official pesticide registration data—covers coffee production in Brazil, Kenya, and Colombia)



CANCER

14% of the pesticides used in coffee production are classified as probable or known human carcinogens. Glyphosate as one example, is classified by IARC as "probably carcinogenic to humans," with epidemiological evidence linking it to non-Hodgkin lymphoma.[69] Other examples of probable carcinogens include the insecticide diazinon and the fungicide epoxiconazole.
To establish a direct link between pesticide exposure and cancer is difficult but has been established by various researchers: Farmworkers in Brasil who declared having been exposed to pesticides had a risk of almost four times higher for the development of lymphomas, leukemias, and multiple myeloma cancer compared to those who did not declare exposure.[70]

NEUROLOGICAL DISEASES

Chronic exposure to organophosphates and neonicotinoids has been linked to serious and lasting neurological damage among farmworkers.

There is a bitter irony at the heart of coffee and neurological health. Research suggests that drinking coffee may reduce the risk of Parkinson's disease[71] but some of the pesticides used to produce it can cause the very condition that coffee appears to help prevent.

France recognised pesticide-induced Parkinson's disease as an occupational illness in the agricultural sector years ago. Germany followed only recently.[72] Pesticides linked to the diseases are paraquat, glyphosate, chlorpyrifos, diazinon.[73] A long-term study in Brazil found that coffee farmers with long-term exposure to organophosphate pesticides (which are neurotoxic) had a higher incidence of Parkinson's disease compared to the general population.[74] Farmers in Costa Rica's Zarcero County, a major coffee-producing region, have reported memory problems, difficulty with motor coordination, and persistent neurological symptoms that continue even when they are not actively spraying.[75] These issues reflect ongoing damage to the nervous system built up through years of repeated contact with organophosphates: cognitive impairment, chronic dizziness, and difficulty concentrating.

REPRODUCTIVE AND DEVELOPMENTAL TOXICITY

Some pesticides (like neonicotinoids, glyphosate, and fungicides like triazoles) function as endocrine disruptors, interfering with hormonal systems that regulate reproduction and development. In the Dominican Republic, coffee farmers exposed to pesticides have shown a possible reduction in male fertility linked to early life exposure.[76] Triazole fungicides have documented effects on male hormones and reproductive function.[40] No studies specifically focused on female coffee farm workers and reproductive health, despite acute risks.

RESPIRATORY DISEASE

Long-term exposure to pesticides can impair lung function and lead to chronic respiratory conditions like asthma, and increased susceptibility to bronchitis among farmers.[77] Workers in coffee production environments often inhale airborne pesticide residues leading to cumulative respiratory damage over time. However, no study has been found to look at these possible long term effects.

KIDNEY DISEASE

While chronic kidney disease is documented in agricultural regions where coffee is grown (e.g. El Salvador),[78] research specifically examining kidney disease among coffee farmers remains limited. Pesticides like paraquat and atrazine have been linked to kidney damage[79] that progresses to chronic forms, particularly when combined with dehydration

MENTAL HEALTH EFFECTS

An emerging area of concern is the relationship between chronic pesticide exposure and mental health conditions. Studies in Brazil's coffee growing area have found validated correlations between pesticide exposure and depression among coffee farmers.[80] While depressive symptoms can result from many factors, research indicates that pesticide exposure increases depression risk.

VULNERABLE POPULATIONS

COFFEE PESTICIDES' THREATS TO WOMEN, MATERNAL, AND NEONATAL HEALTH

Women and children are disproportionately exposed to pesticides in coffee production but their specific vulnerabilities remain largely invisible in industry sustainability efforts and occupational health policy.

Women wash contaminated clothes and make up a substantial part of the coffee workforce, from planting and weeding to harvesting and post-harvest processing. According to a survey by the International Coffee Organization (ICO), between 20 per cent and 30% of coffee farms are run by female leaders and women account for up to 70% of the production workforce, depending on the region.[81] In southern Minas Gerais, Brazil, pesticide poisoning symptoms were particularly prevalent among rural women.[82] In northern Tanzania, nearly 29% of reported acute poisoning cases occurred among adolescent girls.[83]

Pesticides used routinely in coffee farming disrupt hormones, threaten fertility and menstrual health, and harm unborn children.[84] Prenatal exposure to organophosphates, including chlorpyrifos and diazinon, both widely applied on coffee farms, has been linked to reduced birth weight, preterm birth, and serious neurodevelopmental damage.[85] Children exposed to chlorpyrifos before birth show reduced IQ scores, working memory deficits, attention problems, and measurable changes in brain structure.[86]

Neonicotinoids such as imidacloprid can cross the placental barrier, adding further neurodevelopmental risk.[87] The developing brain is extremely sensitive: doses that cause minimal harm in adults can permanently alter the trajectory of a child's cognitive development.

CHILDREN EXPOSED TO PESTICIDES ARE IN HAZARDOUS CHILD LABOR

Recent ILO and UNICEF data place coffee fourth among sectors associated with child labour globally.[88] In eastern Uganda's coffee regions, 48% of children aged 5 to 17 work in the coffee supply chain, with 43% engaged in hazardous tasks that include direct agrochemical exposure.[89] Children pick cherries on recently sprayed plants, help clean sprayer tanks, and in some cases apply pesticides themselves. Even children who never enter the fields are exposed through contaminated clothing and equipment brought home by working parents, transferring residues to surfaces, toys, and food preparation areas.

Children are biologically more vulnerable than adults. Their higher exposure relative to body weight, less developed blood-brain barriers, and immature detoxification systems leave them poorly equipped to handle the chemicals adults struggle to manage.[90] A recent study from South African farming communities detected pesticides commonly used in coffee production, including chlorpyrifos, hydroxy-tebuconazole, mancozeb, and 2,4-D, in over 98% of children tested.[91] Higher pesticide levels were directly associated with poorer cognitive flexibility and inhibitory control: the brain functions that underpin learning, attention, and self-regulation.

RESIDUES IN COFFEE

– HOW DANGEROUS PESTICIDES ARE MOVING FROM FIELD TO CUP

Evidence suggests that pesticides applied to coffee farms thousands of kilometres away travel to your cup far more often than consumers realise. Studies consistently find pesticide residues in green coffee beans from almost every major producing region. The same HHPs that threaten farmers' health and damage local ecosystems show up again and again in traded beans across different continents. This is not a story of isolated incidents. It is a systemic pattern that puts not only farmers and ecosystems at risk, but potentially consumers at the end of the chain as well.

Photo by Asih Wahyuni at Vecteezy.com

EVIDENCE OF PESTICIDE RESIDUES ON GREEN BEANS

Green, unroasted coffee beans are the primary product traded internationally. They are not consumed directly and are classified as a processed commodity, and as a result, regulators in many countries have treated them as low-risk, exempting them from mandatory residue testing.

Most coffee-consuming nations do not systematically test green or roasted coffee for pesticide residues. Monitoring tends to be sporadic, reactive, and triggered only by alerts or scandals rather than routine oversight.

Even the current approach of sporadic monitoring paints a troubling picture. Between 2020 and 2024, the EU's Rapid Alert System for Food and Feed (RASFF) recorded chemicals as the most frequently reported hazard in coffee.[92] Pesticides accounted for 41% of all hazard notifications, with chlorpyrifos alone responsible for 66% of pesticide-related alerts.[93]

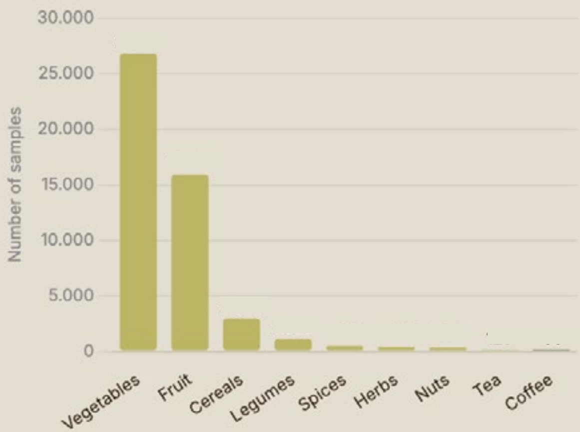


Figure 10: Number of samples of all origins for each food category[94]

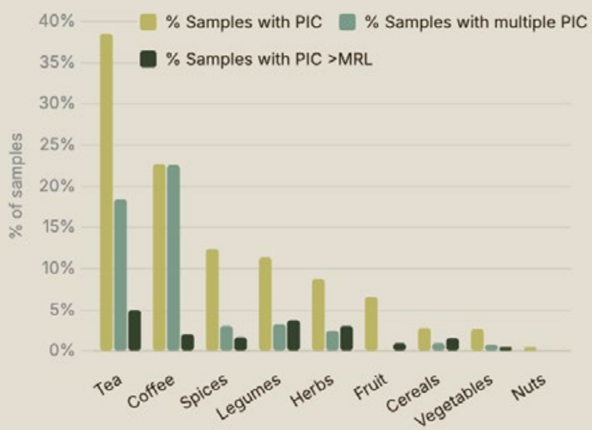


Figure 11: % of samples contaminated by PIC* pesticides[94]

The Rapid Alert System for Food and Feed (RASFF) is an EU safety network that allows authorities to quickly warn each other when food or feed may pose a health risk to consumers. It helps ensure that products with hazardous substances, such as pesticide residues, can be identified and allows for rapid alerts, border rejections, and follow-up actions, including product withdrawals or recalls.

Residue analyses from the official control programmes of EU Member States, collected by the European Food Safety Authority (EFSA) and analysed by PAN Europe, tells a similar story. Despite only 44 coffee samples being analysed in 2022, compared to 27,000 vegetable samples, 23% of tested coffee samples contained pesticides banned in the EU, placing coffee second only to tea among the most contaminated.[94]

*PIC pesticides are active ingredients that are listed under the Rotterdam Convention (PIC-list)

Substances detected included carbendazim, a mutagenic fungicide, alongside neonicotinoid insecticides such as clothianidin, thiamethoxam, and imidacloprid. Although only 2–3% of coffee samples exceeded individual legal Maximum Residue Limits (MRLs), every contaminated sample contained multiple pesticide residues simultaneously, a pattern that sets coffee apart from other analysed foods and raises serious questions about the adequacy of single-substance safety thresholds.

Perhaps most alarming: the presence of EU-banned pesticides in coffee samples increased tenfold between 2011 and 2022.

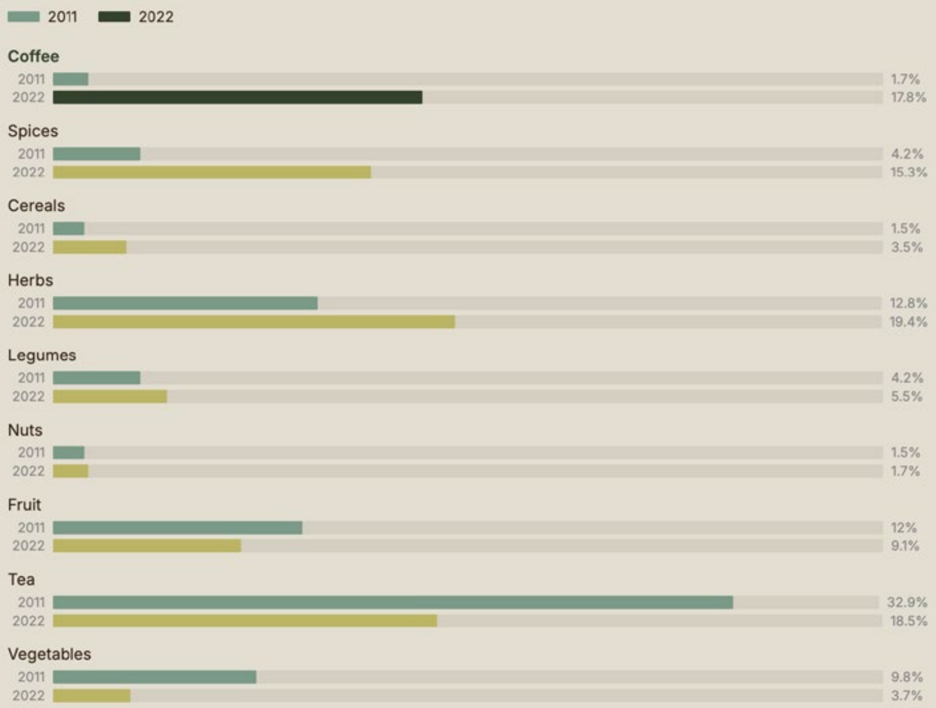


Figure 12: EU-banned pesticides in coffee samples increased tenfold between 2011 and 2022[94]

A comprehensive study by CIRAD with data collected in 2020-21 found the herbicides glyphosate and its breakdown product AMPA and the insecticides imidacloprid, thiamethoxam, clothianidin, and chlorpyrifos all present in green beans from Arabica and Robusta farms in Brazil, Mexico, Nicaragua, and Vietnam.[95] Many samples exceed the MRL set by the EU.

A 2021 analysis of 80 green coffee bean samples found pesticide residues in 19% of them. Imidacloprid, thiamethoxam, clothianidin, and triadimenol appeared regularly in Brazilian samples, while chlorpyrifos was present in every sample from Colombia, Kenya, and India — three of the world's most important coffee-producing countries.[96]

A single coffee sample could realistically contain glyphosate,and various insecticides at once, many of them neurotoxic, probably carcinogenic, or harmful to the human reproductive system. That is not a trace contamination issue. It is a toxic cocktail.

COUNTRY	PESTICIDES DETECTED	KEY FINDINGS	REFERENCE
Brazil	Glyphosate, AMPA	13% exceeded MRL EU (0.1 mg/kg)	CIRAD [156] Villain, L.[95]
	Imidacloprid, Thiamethoxam, Clothianidin, Chlorpyrifos	47% exceeded MRL 0.01 mg/kg for imidacloprid; 17% exceeded MRL 0.01 mg/kg for chlorpyrifos	CIRAD [156]
	Glyphosate, Imidacloprid, Chlorpyrifos, Bifenthrin, Azoxystrobin, Endosulfan, Cypermethrin	47% of samples exceeded EU MRL for imidacloprid; 17% for chlorpyrifos; glyphosate exceeded EU MRL; 22% of 158 samples contained 12 different pesticides	Government Brazil[97]
Nicaragua	Imidacloprid, Thiamethoxam, Clothianidin, Chlorpyrifos	20% exceeded MRL 0.01 mg/kg for imidacloprid; 10% exceeded MRL 0.01 mg/kg for chlorpyrifos	CIRAD [156]
Ethiopia	DDT*, Cypermethrin, Permethrin, Deltamethrin, Chlorpyrifos, Endosulfan	DDT (a persistent organic pollutant) detected at levels above Japanese MRL; concentrations 0.01–1.12 mg/kg	Mekonen et al.[98]
	DDT	DDT detected at levels above Japanese MRL; concentrations 0.01–0.08 mg/kg	Dinsa et al.[99]
Indonesia	Carbaryl, Carbofuran, Diazinon, Dichlorvos, Dimethoate, Imidacloprid, Malathion, Profenofos, + others	Diazinon and imidacloprid most frequent. Carbaryl, diazinon, dichlorvos, dimethoate, malathion and propoxur exceeded EU or Japanese MRLs	Harmoko et al.[100]
Vietnam	Glyphosate, AMPA	10% exceeded MRL EU (0.1 mg/kg)	CIRAD [156]
	Imidacloprid, Thiamethoxam, Clothianidin, Chlorpyrifos	8% exceeded MRL 0.01 mg/kg for imidacloprid; 8% exceeded MRL 0.01 mg/kg for chlorpyrifos	CIRAD [156]
India	Chlorpyrifos	—	Mathrubhumi[101]

**Concentrations from the very persistent DDT are not from actual use but from long term environmental contamination.*

Figure 13: Pesticide residues in green coffee beans in various countries

THE TOXIC COCKTAIL: MORE THAN THE SUM OF PARTS

Current food safety regulations primarily assess single-substance toxicity. The cocktail effect, namely what happens when multiple pesticide residues are present together, is largely not considered. When multiple residues occur simultaneously, their combined toxic effects may be additive (effects sum up, as with organophosphates and triazoles), synergistic (effects multiply, as with chlorpyrifos and glyphosate), or antagonistic. Mixture toxicity can also interact with so called 'inert' ingredients in the product formulation, additives such as surfactants, emulsifiers and dispersants, or other contaminants naturally present or created during coffee processing, including acrylamide, mycotoxins and furans.

Looking only at individual threshold levels almost certainly underestimates real health risks to coffee consumers.

The finding that 100% of contaminated EU coffee samples contained multiple residues makes this not a theoretical concern but an urgent practical one. Regulations must address this issue to properly protect consumers.[93]

DO PESTICIDES REMAIN IN YOUR CUP OF COFFEE AFTER IT'S ROASTED AND BREWED?

Does the coffee in your cup still carry the pesticides used to grow it? The industry's standard reassurance is that high roasting temperatures destroy residues, leaving the final product safe.

Scientific evidence tells a more complicated, less comfortable story.

Photo by Narong Khueankaew at Vecteezy.com

FROM FARM TO CUP: WHAT HAPPENS ALONG THE WAY

Before coffee reaches you, it passes through a long chain of processes. Farmers spray pesticides on plantations, workers harvest the cherries, and the beans are peeled, washed, fermented, and dried before export as green coffee. They are then roasted at temperatures typically between 200 and 240°C. Finally, the coffee is brewed. Each stage can reduce pesticide residues through different mechanisms: heat breaks down some chemicals, volatile substances evaporate, water washing removes some surface residues, and the silverskin, a thin layer covering the bean, is shed during roasting, taking some contaminants with it.





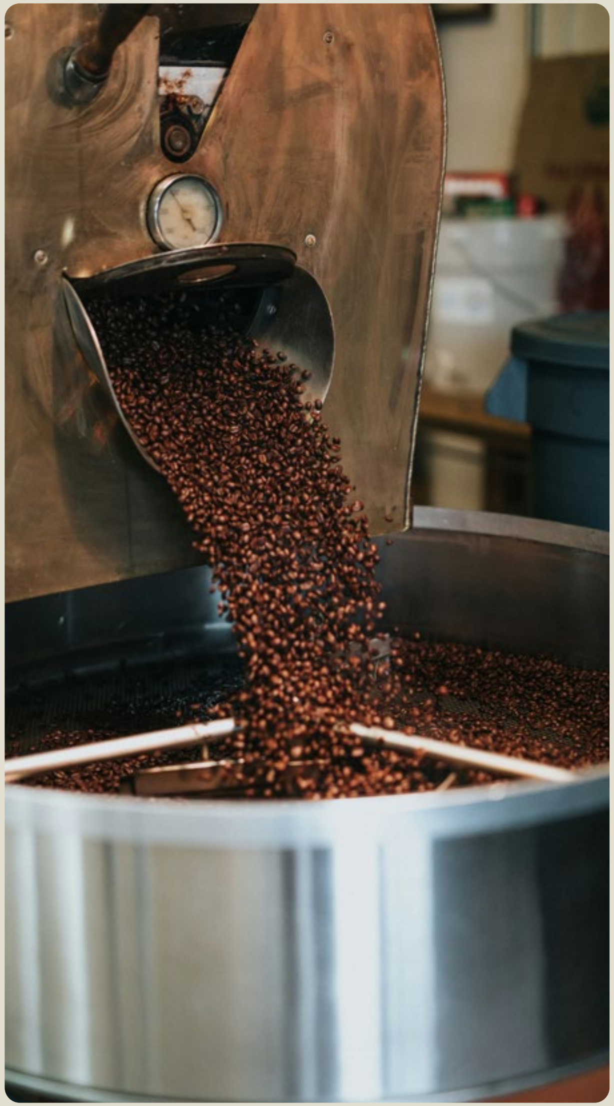

Studies report pesticide reductions ranging from 44% to nearly 100 % through washing and roasting,[102] with some research showing washing alone reduces residues by 15–58% and roasting by up to 99.8%.[103] These figures form the basis of regulatory assumptions in many countries: that coffee arrives in the cup effectively clean of pesticides. That belief is frequently used to justify the absence of routine monitoring and the lack of maximum residue limits (MRLs) for roasted coffee in many jurisdictions. ***But is this the truth?***

NOT ALL PESTICIDES BEHAVE THE SAME

Recent research challenges the reassuring narrative that coffee processing eliminates pesticide residues. The central flaw in that argument is that it treats all pesticides as identical.

They are not.

How much a residue survives depends on the chemical nature of the substance, the processing conditions, and how long the residue has bonded to the bean. Water-soluble substances respond well to washing, if temperature, duration, and method are optimal. Heat-sensitive pesticides break down or evaporate during roasting. But pesticides with low volatility and high thermal stability can and do persist, particularly when the molecule binds tightly to the bean matrix.[104] The evidence from roasted coffee makes this impossible to ignore: 21% of roasted samples tested positive for pesticide residues, with chlorpyrifos, imidacloprid, and cypermethrin among the most commonly detected.[105] These are not trace anomalies. They are pesticides surviving every stage of processing and reaching the finished cup.



ROASTING CONDITIONS MAKE A DIFFERENCE

Different roasting techniques, temperatures, durations, and bean types produce fundamentally different outcomes. Even for a single pesticide, results vary dramatically. A study on glyphosate, the herbicide most frequently cited by industry to demonstrate residue elimination, illustrates this perfectly.[106] Research commissioned by Nestlé and Tchibo found reductions that ranged from 35% to 90% depending on roasting conditions. Arabica beans showed stronger and more consistent reduction than Robusta. Fast roasting outperformed slow roasting. Most surprisingly, medium roast sometimes achieved greater glyphosate reduction than dark roast — directly challenging the assumption that darker always means cleaner. Crucially, the same research found hardly any complete elimination in any scenario tested: residues persisted to varying degrees across all processing methods.

A health risk assessment based on that study concluded that glyphosate levels in five cups of coffee per day remained well below the EU Acceptable Daily Intake (ADI) threshold of 0.5 mg per kilogram of body weight. But that assessment considered glyphosate in isolation. It did not account for the reality that coffee samples routinely contain multiple pesticide residues at once and current regulatory frameworks have no answer for what that combination does to human health.

WHAT INDEPENDENT RESEARCH ACTUALLY FINDS

The Nestlé and Tchibo study reported significant glyphosate reduction during roasting and found no AMPA, glyphosate's main breakdown product, in the final product.[106] Independent research tells a strikingly different story. The Clean Label Project analysed 57 coffee products from 45 brands and detected AMPA in 72% of samples, including organic coffees.[107] Studies from Egypt found organophosphate and neonicotinoid residues in 21% of roasted beans, with chlorpyrifos exceeding legal limits in some cases.[105] Another study found multi-residue contamination in up to 79% of roasted coffee samples, including toxic substances such as mepiquat chloride, permethrin, and methiocarb sulfone.[108]

Glyphosate is not representative of the full spectrum of pesticides found on coffee farms. Pesticides vary widely in their properties, such as solubility, thermostability, and more, and a focus on glyphosate reduction creates a false sense of reassurance. It tells us almost nothing about whether the pesticides regularly detected in green coffee survive through to the cup. For many of them, the honest answer is: we simply do not know.

THE ANALYTICAL CHALLENGE

Testing coffee for pesticide residues is far from straightforward. Modern multi-residue analysis demands sophisticated laboratory infrastructure: Gas Chromatography or Liquid Chromatography coupled with tandem Mass Spectrometry (GC-MS/MS or LC-MS/MS). Coffee is considered a particularly difficult matrix to work with.[109] The main culprit is caffeine, whose broad chromatographic peak blocks analysis masks many pesticides with similar retention times.[110] Accurate results require specialised extraction techniques, such as QuEChERS with additional clean-up steps, specifically designed to remove caffeine interference before analysis can begin.[111]

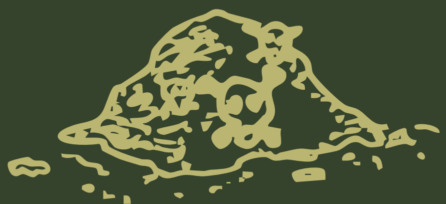
This matters enormously for how we read the historical record. Older studies, conducted with less sensitive detection methods, frequently reported no detectable residues even in green coffee beans. Those reassuring findings may say more about the limitations of the tools used than about what was actually in the coffee. As analytical methods have improved, residues that were once invisible have come into view and the picture that emerges is considerably less clean than regulators and industry have long assumed.

Photo by Preston250800 at Vecteezy.com

HIGH PESTICIDE RESIDUES IN COFFEE PULP – TOXIC COMPOST?

Coffee pulp and husks hold real potential as compost inputs and soil improvement within a circular economy model[112], but only if the source material is clean. Where pesticide use is intensive, recycling by-products back to the soil may inadvertently close a contamination loop rather than a nutrient one. The available evidence, though limited, is concerning.

A study from the Jimma Zone in Ethiopia detected much higher DDT, endosulfan, cypermethrin, and permethrin concentrations in coffee pulp, compared to green beans.[98] Systematic monitoring, however, remains almost entirely absent. Most circular economy initiatives promoting coffee waste composting do not require prior residue testing of the source material, a significant oversight given the contamination rates documented in green coffee.



To conclude: The honest answer to whether pesticides reach your cup is: we do not know enough. Historical monitoring relied on detection methods too crude to find what was there.

Regulatory frameworks focused on green coffee, not the roasted and brewed product most people consume. Industry research concentrated on glyphosate, a substance that behaves relatively well under heat and therefore offers the most reassuring results, while saying little about the organophosphates, neonicotinoids, and fungicides that behave very differently. Roasting itself is not a standardised process: temperature, duration, and bean variety all produce different outcomes, making sweeping claims about residue elimination scientifically untenable. What emerges is not reassurance, but a systematic absence of the rigorous, independent, multi-residue monitoring that would allow us to answer the question with confidence.

A DOUBLE STANDARD IN RESIDUE REGULATION

The double standards in global pesticide policy extend beyond what farmers are allowed to spray. Where you live also dictates how much pesticide residue regulators consider acceptable in your coffee. The result is a tiered system in which some consumers matter more than others.

Glyphosate illustrates the gap. Brazil permits 1.0 mg/kg of glyphosate in coffee[113]; the EU allows only 0.1 mg/kg. Recent Brazilian monitoring detected glyphosate at 0.18 mg/kg, within legal limits locally, but nearly double the EU threshold. With 164 registered glyphosate products approved for Brazilian coffee production, it remains the most common residue found. Diuron is another example: Banned in Europe and classified as a probable carcinogen, it remains on sale in 29 products for coffee production in Brazil, where the legal residue limit stands at 1.0 mg/kg, one hundred times higher than the EU default of 0.01 mg/kg that should apply to banned substances.[114] Recent Brazilian monitoring detected Diuron at 0.06 mg/kg: compliant at home, a clear violation in Europe.[115]

European consumers are not fully protected either. When the EU bans a pesticide, residue limits in imported food should fall to the default threshold of 0.01 mg/kg.[114] For coffee, that rule is not consistently applied. The EU maintains inexplicably higher limits for multiple banned substances, setting Diuron's coffee limit at 0.05 mg/kg, five times above the standard default. Diuron is not alone. Several other EU-banned pesticides retain similarly elevated residue thresholds for coffee imports, leaving a gap in the regulatory framework that consumers have no reason to suspect exists.

ENVIRONMENTAL IMPACTS

Pesticide use in coffee production does not only harm the people who grow it, it also impacts the environment those people depend on.

Scientists tell us that globally, seven of nine "planetary boundaries" have now been officially exceeded[116], meaning human activity has pushed Earth's critical natural systems beyond the safe operating space that has kept the planet stable and habitable for the last 12,000 years. This threatens not only the stability of global ecosystems but also long-term food security worldwide. Pesticides contribute significantly to breaching multiple planetary boundaries. And the energy-intensive production of pesticides itself contributes to climate change.[117] Despite accounting for roughly 2% of global synthetic chemical production, their footprint on Earth systems is disproportionately high.

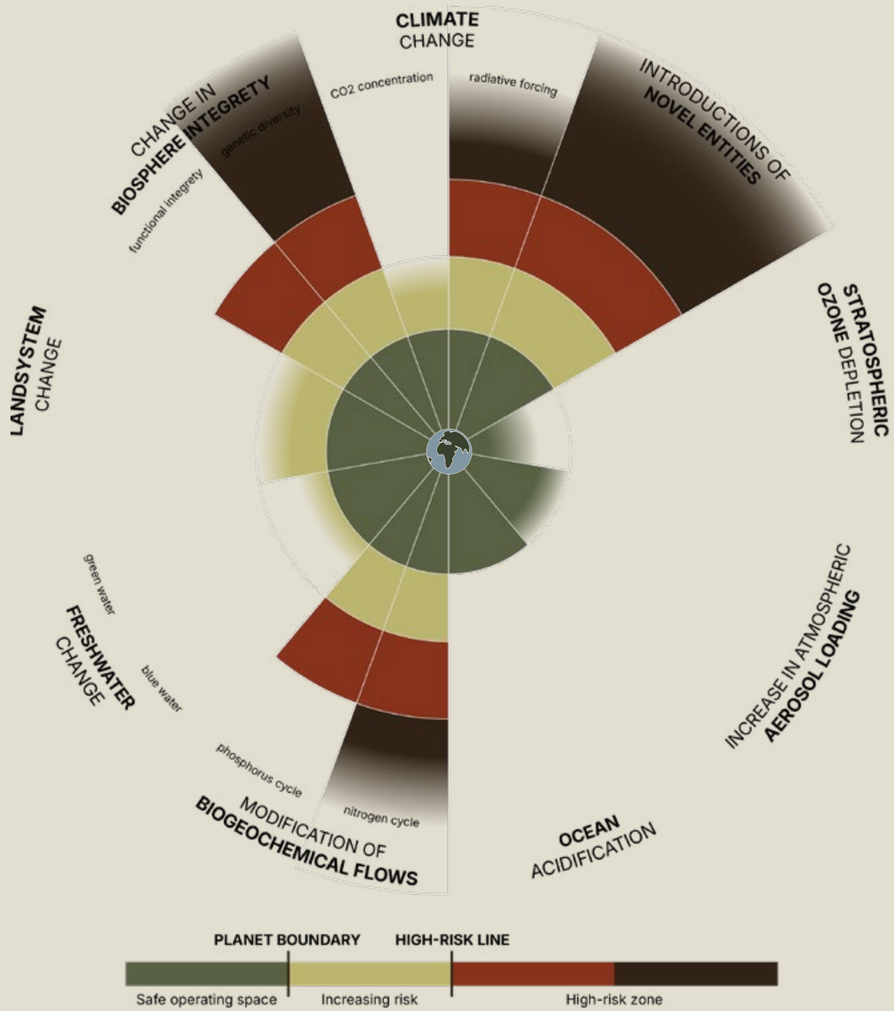


Figure 14: Planetary bounderies[116]

WATER

Pesticide use in coffee cultivation causes serious harm to both surface and groundwater systems that farming communities, aquatic life, and downstream populations all depend on. And of course, almost all rivers flow to the sea, meaning that pesticides applied to coffee end up in the marine environment, threatening ocean health.

SURFACE WATER CONTAMINATION

Pesticides used in coffee production can reach surface water through spray drift, soil erosion on steep tropical hillsides, and the disposal of pesticide containers and once in the water, many of these substances resist conventional treatment methods.[118] The evidence from major coffee-producing regions shows widespread pesticide contamination that threatens aquatic biodiversity and expose communities that are dependent on these water sources for drinking, cooking, and irrigation:

Pesticide runoff from coffee production is particularly concerning given mounting evidence of ecological collapse in freshwater systems—for example, a recent UN report on collapsing freshwater fish migrations (2026) found that global freshwater fish populations have declined by roughly 81% since 1970, with pollution identified as a key driver of this crisis.[119]

Brazilian public authorities have documented cases where entire municipal water supplies were declared polluted by pesticides.[120]

In Colombia, pesticide residues were detected in 81.3% of surface water samples taken from coffee-growing regions, including already-prohibited substances such as DDT and endosulfan alongside currently used pesticides like chlorpyrifos.[121] Uganda's coffee areas show chlorpyrifos contamination at levels that pose measurable risk to aquatic biodiversity, while other pesticides (like 2,4-D and carbendazim) exceed safe thresholds in surface waters.[122] In Vietnam's Mekong Delta, residues of multiple pesticides have been found in water and sediments at concentrations well above safe limits.[123]

A high share currently used/ registered pesticides for coffee production are very toxic to fish:

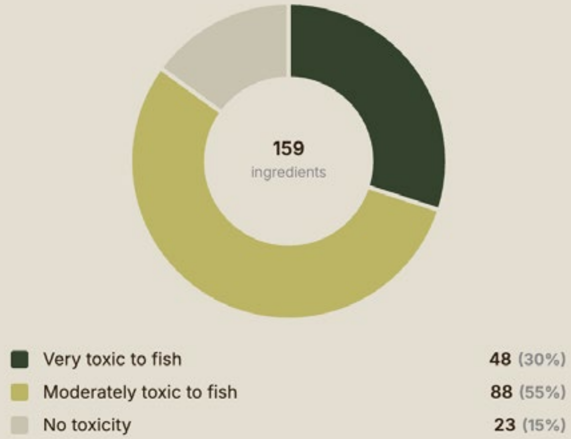


Figure 15: Pesticides used in coffee production - toxicity towards fish[26]

GROUNDWATER CONTAMINATION

Some pesticide compounds move through soil and leach into groundwater, a serious concern where these sources supply drinking water. How far they travel depends on soil type: sandy soils with low organic matter offer little resistance, while loam and clay bind pesticides more effectively.[124] In Brazil's Mantiqueira Range, studies found a 23.7% probability of groundwater contamination,[125] with atrazine residues detected across the country.[120] Sulfentrazone and thiamethoxam have similarly demonstrated the capacity to reach groundwater supplies.[125]

WASTEWATER AS CONTAMINATION PATHWAY

Pesticides also reach water systems through the washing of sprayers and tanks, and the discharge from coffee processing facilities themselves. Pulping, fermentation, and washing operations all generate effluent that can carry significant pesticide concentrations into surrounding waterways.

Research in Ethiopia's Oromia Region, the country's primary Arabica production area, detected persistent organochlorines including aldrin, DDT, and endosulfan in streams receiving processing wastewater, originating from both farm applications and facility discharge.[126]

A critical review found that even after treatment, coffee wastewater retains pesticide residues at concentrations sufficient to threaten aquatic life. Studies have confirmed both phytotoxic and cytogenotoxic effects, and removal attempts since 2013 have produced unsatisfactory results, pointing to the need for fundamentally different processing technologies.[127]

What these findings share is that the cost of pesticide-dependent coffee production does not stay on the farm. It moves through watersheds, enters drinking water, and threatens the aquatic biodiversity and communities that depend on these sources.

SOIL

IMPACT OF PESTICIDE USE ON SOIL HEALTH IN COFFEE PLANTATIONS

When pesticides are applied, they do not simply vanish after application. Many pesticides accumulate in soils over years and harm soil biodiversity that keeps farmland alive and productive.

The scale of this is only beginning to be understood. A landmark study across 373 sites in 26 European countries found pesticide residues in 70% of soils tested, identifying them as the second strongest driver of soil biodiversity loss after soil properties themselves.[128] In coffee-growing regions, the impacts can be very concerning. Beneficial organisms, earthworms, fungi, nitrogen-fixing bacteria, that drive nutrient cycling, maintain soil structure, and sequester carbon, can particularly be impacted. Nitrogen-fixing bacteria matter because coffee trees are nitrogen-hungry crops, and when pesticide exposure cuts bacterial populations by 30–60%, farmers lose a free, natural source of fertility.[129] Synthetic fertilisers fill the gap, but at a cost. They acidify soils, suppress further microbial life, and pull farmers deeper into a cycle of chemical dependency that grows harder to break each season. Ammonia-oxidising microbes, critical to soil fertility, show consistent declines of 20–40% under herbicide and fungicide exposure.[130] Earthworms face mortality rates of 40–80% from carbamates and pyrethroids common in coffee production, gutting the burrowing activity that aerates soil and breaks down organic matter.[131]

Herbicides carry particular risks. Research comparing weed management methods in coffee found that post-emergence herbicides caused greater damage to soil microbial communities than manual or mechanical alternatives.[33] Prolonged use reduces organic matter, acidifies soil, and lowers microbial biomass.[32] One study found that herbicide residues had a stronger influence on the diversity of soil fungi than the soil's natural characteristics. Herbicides explained about 33% of the differences in fungal diversity, compared to 18% explained by soil properties.[31]

Only 27% of the currently used pesticides have a low toxicity towards earthworms:

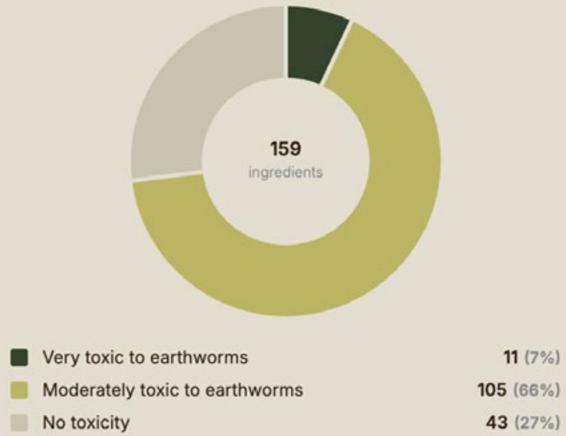
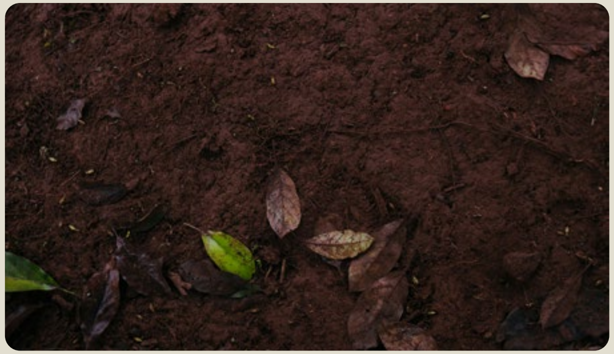
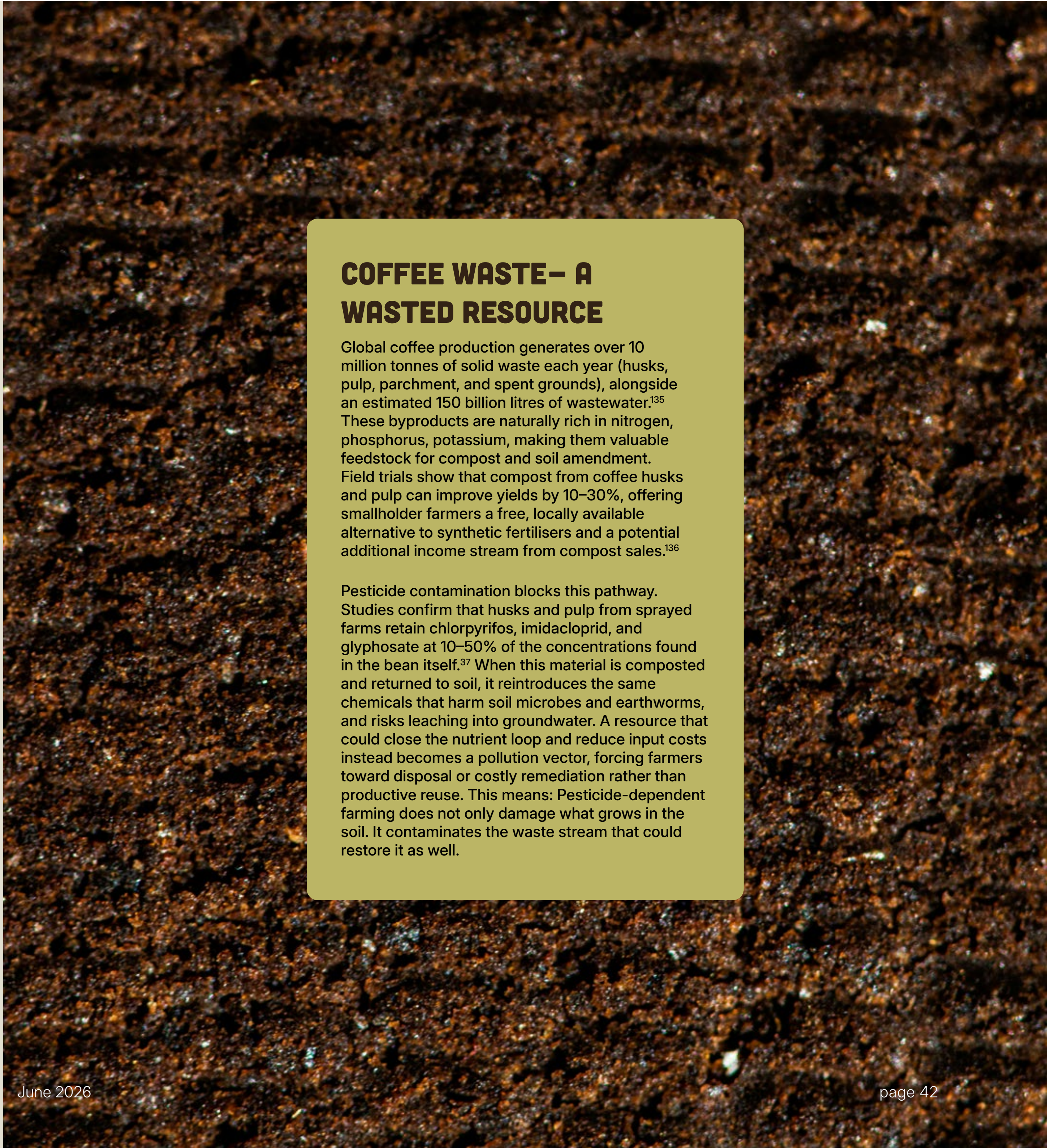


Figure 16: Pesticides used in coffee production - toxicity towards earthworms[26]



Field data from producing regions confirm what laboratory studies predict. In Vietnam's Lam Ha district, soil samples from coffee plantations revealed organophosphorus and carbamate residues at concentrations sufficient to harm soil life, with chlorpyrifos reaching 391 µg/kg (profenofos at 63 µg/kg, carbosulfan at 41 µg/kg).[132] In Mexico, shaded coffee farms with 22 years of glyphosate application showed earthworm densities roughly half those of untreated soils.[133] Across four continents, unpublished CIRAD research has found glyphosate and its breakdown product AMPA in coffee-growing soils[95] at concentrations above EU benchmark levels for perennial crops[134]. In Nicaragua and Brazil, three fungicides, epoxiconazole, cyproconazole, and azoxystrobin, were detected at concentrations sufficient to harm soil organisms.

Every teaspoon of healthy soil holds more living organisms than there are people on Earth, but decades of pesticide exposure are systematically dismantling that diversity, leaving behind dead, compacted, acidified ground that struggles to hold water, cycle nutrients, or resist disease, undermining the very conditions that make coffee farming sustainable and productive in the first place.



COFFEE WASTE– A WASTED RESOURCE

Global coffee production generates over 10 million tonnes of solid waste each year (husks, pulp, parchment, and spent grounds), alongside an estimated 150 billion litres of wastewater.[135] These byproducts are naturally rich in nitrogen, phosphorus, potassium, making them valuable feedstock for compost and soil amendment. Field trials show that compost from coffee husks and pulp can improve yields by 10–30%, offering smallholder farmers a free, locally available alternative to synthetic fertilisers and a potential additional income stream from compost sales.[136]

Pesticide contamination blocks this pathway. Studies confirm that husks and pulp from sprayed farms retain chlorpyrifos, imidacloprid, and glyphosate at 10–50% of the concentrations found in the bean itself.[37] When this material is composted and returned to soil, it reintroduces the same chemicals that harm soil microbes and earthworms, and risks leaching into groundwater. A resource that could close the nutrient loop and reduce input costs instead becomes a pollution vector, forcing farmers toward disposal or costly remediation rather than productive reuse. This means: Pesticide-dependent farming does not only damage what grows in the soil. It contaminates the waste stream that could restore it as well.

POLLINATORS/ BIODIVERSITY

IMPORTANCE OF INSECT BIODIVERSITY IN COFFEE PRODUCTION

Biodiversity above the ground matters as much as what lives beneath it — both are essential to productive and resilient coffee farming. Two ecological services are foundational: pollination and biological pest control. Study after study demonstrates the massive impact pollinators have not only on increased fruit weight and yields but also on flavor.

Arabica coffee is capable of self-pollination, but studies consistently show that bees and other pollinators substantially increase productivity by improving fruit set, fruit size, and overall yield. Research at Mount Kilimanjaro documented a 7.4% increase in fruit weight attributable to pollinator activity, a gain that translates directly into income for smallholder farmers already operating on narrow margins.[137] Field experiments in Costa Rica found that forest-based pollinators raised yields approximately 21% above what self- or wind-pollination alone produced.[138] A recent field study in Brazilian coffee farms introduced stingless bee colonies and found that they boosted coffee yields by about 67% near hives[139]. In experimental plots in Ethiopia, coffee plants pollinated by honey bees produced up to 70% more seeds than those without insect pollination.[140] For farmers who depend on each harvest to cover costs and feed families, these are not marginal differences.

Pollinator activity also shapes the aroma and quality of the roasted bean itself — factors that determine price in specialty coffee markets. Recent research confirms that bee pollination measurably improves roasted bean quality, meaning that the loss of pollinators threatens how much the coffee is worth.[141]

Natural enemies of coffee pests provide equally critical services. Parasitic wasps, predatory beetles, and spiders suppress populations of the coffee berry borer and other economically damaging species.[142] Studies show that pollinators and natural predators together boost coffee productivity far more than either service delivers alone.[143]

Birds too play a measurable role in coffee productivity. Pest-controlling birds and pollinating bees work synergistically to amplify fruit weight and fruit set. Research quantifying this relationship found that excluding both birds and bees from coffee plants reduced yields by an average of 24.7%, equivalent to a loss of over US$1,000 per hectare.[143]

IMPACT OF PESTICIDE ON INSECT BIODIVERSITY

Insect biodiversity has plummeted worldwide. This has been especially well studied in Europe, where insects declined by up to 75% over recent decades, with pesticide use identified as one of the primary drivers of loss.[144] On coffee farms, the consequences of that global dynamic play out in ways that cut directly into yields, farmers' incomes, and the long-term viability of the crop itself.

When insecticides kill natural pest predators alongside their target species, secondary outbreaks follow. Farmers respond with further applications. The biological infrastructure that once kept pest pressure in check collapses, and chemical dependency fills the gap. The scale of pollinator exposure in coffee is significant. Of the pesticides currently used in coffee production, 64% are either very toxic or moderately toxic to bees: 29% are classified as very toxic, 35% as moderately toxic, and only 36% show low or no toxicity.

These chemicals reach pollinators through direct contact and through contaminated nectar and pollen, with coffee flowering seasons creating particularly acute risk windows when spraying overlaps with peak bee activity.

The documented effects are serious. Neonicotinoids such as imidacloprid and thiamethoxam, alongside organophosphates like chlorpyrifos, produce both lethal and sublethal effects: impaired navigation, reduced pollen collection, weakened immune systems, and queen failure at field-realistic concentrations.[145]

Soil-applied imidacloprid translocates into nectar and pollen at concentrations sufficient to kill or severely harm beneficial insects.[146] Combined exposure to insecticides and fungicides such as pyraclostrobin damages bees' fat bodies and compromises detoxification capacity, a particular concern where coffee receives multiple pesticide applications in a single season.[147] A recent field study on Brazilian coffee farms confirmed chronic exposure of bee colonies to thiamethoxam and clothianidin residues in leaves, nectar, and pollen.[139] Research in coffee home gardens found that agrochemical use significantly reduced both flower visitation time and the number of pollinator species present.[148]

All in all 64% of currently used pesticides in coffee production are either very toxic or moderately toxic to pollinators:

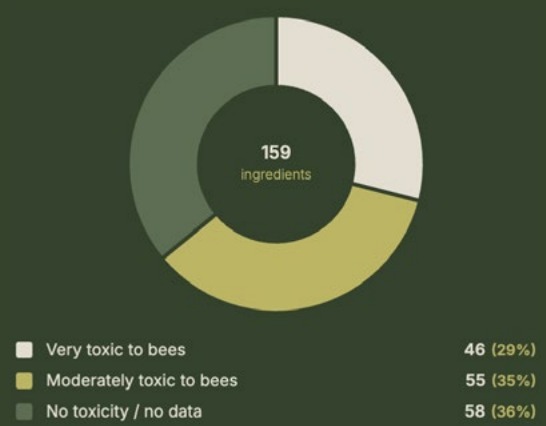


Figure 17: Pesticides toxicity towards bees[26]

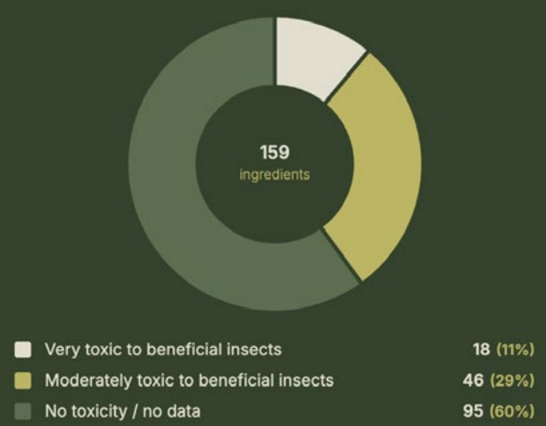


Figure 18: Pesticides toxicity towards beneficial insects[26]

FOOD SECURITY IMPLICATIONS

The consequences of pollinator loss do not stop at the edge of the coffee field. Most of the world's coffee is grown by smallholder farmers, many of whom grow home gardens alongside their coffee plots for food, medicine and income. When pesticide use drives pollinator decline across the farm landscape, it threatens the productivity of those food systems too, crops that feed families, not markets.

Figures make this concrete: Pollinators support approximately 75% of flowering plant species and 35% of global food crops, with an estimated economic value of $235–577 billion annually.[149] In El Salvador and Nicaragua, coffee agroforestry systems supplied roughly half of household firewood and contained 119 commonly used medicinal plant species, a critical resource for families with limited access to health services.[150] In Chiapas (Mexico), farmers who kept bees alongside coffee reported substantially higher income sufficiency than those who did not, while fruits and vegetables from the same systems fed seasonal workers and supported household nutrition through barter.[151]

Pollinators loss due to pesticide exposure reduces the yield, quality, and income that the next harvest can deliver. For farmers already navigating income insecurity, depleted harvests, and climate variability, the loss of biodiversity is not an environmental footnote, it is one more pressure on households that have very little room left to absorb it.[152]

Photo by Maria Gabriela Bertolini at Vecteezy.com

ECONOMIC IMPACT

LOSS THROUGH REJECTED EXPORTS

Several documented cases illustrate the economic risks linked to pesticide residues in coffee trade. In 2022, Japan rejected multiple Kenyan coffee shipments after detecting chlorpyrifos at 0.06 mg/kg, just above Japan's limit of 0.05 mg/kg.[49] The financial consequences were far from minor: Kenya faced potential annual market losses estimated at USD 10–15 million and inspection rates on Kenyan shipments rose to 30%.[153] This contributed to a ban of chlorpyrifos in Kenya.[154] In Taiwan, a shipment of Brazilian green coffee was blocked in 2020 after residues exceeded permitted levels.[155] Brazilian coffee faces ongoing scrutiny in the EU, where field studies have measured glyphosate residues at 0.14–0.21 mg/kg under common application practices, above the EU limit of 0.1 mg/kg, even though Brazil's own limit sits at 1.0 mg/kg.[156]

What makes this situation particularly unjust is the chain of responsibility behind it. Agrochemical companies headquartered in Europe and the United States profit from selling substances to producing countries that are banned at home, while farmers who apply these chemicals often lack full information about residue limits in destination markets. Consuming countries should protect their citizens. But a system in which banned substances are legally exported, commercially promoted, and then used as grounds for rejecting a shipment distributes risk and profit in a deeply unequal way. The farmer carries the exposure, the liability, and the financial loss. The chemical companies carry none of them.

A SYSTEM THAT FAILS FARMERS AND CONSUMERS

The case of Kenya shows how the system fails at multiple levels. Japan repeatedly rejects Kenyan green coffee imports due to elevated chlorpyrifos levels.

As agronomist John Ngeno from the University of Eldoret notes: "Farmers often apply pesticides too close to harvest rather than earlier in the season".[49]

But responsibility cannot rest on farmers alone.

Most receive little or no training, limited agronomic advice, and weak extension support. They deliver coffee to processing factories with little bargaining power — sometimes without even immediate payment — locked into a system that depends on pesticides but offers few tools to use them safely or to understand the market consequences of residue violations.

CALCULATION FOR A COFFEE FARM

If a coffee farm typically produces 1,000 kg of coffee beans per hectare without pollinators, the yield could increase by 20% with the presence of pollinators.[138] This would result in an increase of 200 kg per hectare.

Assuming an average market price of $2.50 per kg of Arabica coffee (prices can vary widely depending on the market and region), the increased yield from pollination could generate an additional $500 per hectare.

CALCULATION FOR AN ANNUAL LOSS AT COUNTRY LEVEL (E.G. ETHIOPIA)

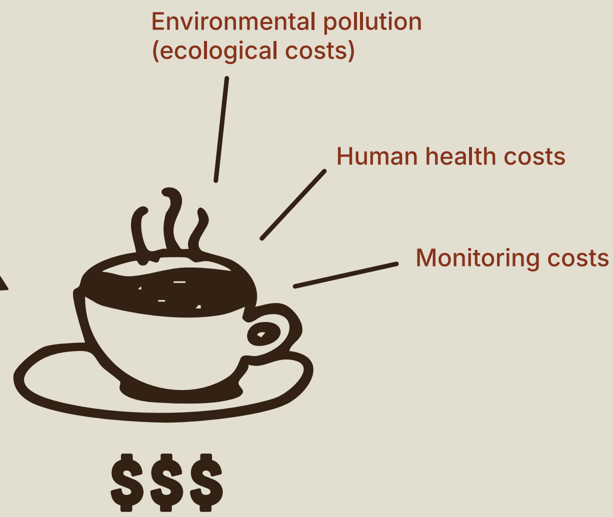
If pollinator populations decline, leading to a 20% reduction in yield, farmers could lose $500 per hectare annually.

If there are 790,000 hectares of coffee land in Ethiopia[160] the total economic loss due to pollinator decline could be $395 million annual loss.

EXTERNAL COSTS– THE TRUE PRICE OF COFFEE

The price on a bag of coffee reflects what the market charges. It does not reflect what production actually costs. Health treatment for pesticide-poisoned farmworkers, water remediation, residue monitoring, soil degradation, biodiversity loss, and greenhouse gas emissions from chemical-intensive farming are real losses, carried by ecosystems, communities, and public budgets — none of which appear on a corporate balance sheet.[157]

Ecological costs generated along agricultural value chains never appear in product prices. These are real losses, carried by ecosystems and communities, that corporate balance sheets do not capture, consumers do not see, but that farmers, soils, and watersheds absorb every season.[158]



Research in Uganda and Honduras found an average additional ecological cost of production of around 7.22 USD/kg.

The ecological costs are mostly driven by the terrestrial and aquatic ecotoxicity, which indicates the importance of pesticide impacts.[159]

THE HIDDEN COSTS OF MONITORING FOR GLOBAL SOUTH COUNTRIES

Monitoring and remediation add further burdens that consistently fall on the wrong shoulders. Testing food products for residues, analysing surface water and groundwater contamination, monitoring soil and pollinator health, and treating drinking water affected by agricultural runoff all generate substantial costs. These are largely borne by national food safety authorities, environmental agencies, and water utilities, institutions that are frequently underfunded in producing countries, while the agrochemical companies whose products generate the need for this infrastructure carry none of it. In a world where public budgets for food safety are shrinking, the case for less chemical-intensive coffee production is not only ecological, it is fiscal.

HUMAN RIGHTS IMPACT

The ecological and health impacts described above are human rights violations. Pesticide contamination of water, soil, and air and the loss of biodiversity affect a range of internationally recognised human rights, including the right to the highest attainable standard of health, the right to safe and healthy working conditions, children's rights, and the human right to safe drinking water.

In coffee-producing regions, exposure to hazardous pesticides often occurs in contexts marked by poverty, weak labour protections, limited access to healthcare, and inadequate regulatory oversight. Under the UN Guiding Principles on Business and Human Rights, governments and companies have a responsibility to prevent foreseeable harm linked to hazardous chemicals in supply chains and to protect affected communities from exposure.[161]

The UN Special Rapporteur on hazardous substances has confirmed that states carry a duty to prevent exposure to toxic chemicals and to protect the rights to health, clean water, a healthy environment, and safe working conditions.[162] Pesticide contamination of surface water and groundwater in coffee-growing regions strikes directly at the right to safe drinking water, recognised under the International Covenant on Economic, Social and Cultural Rights and affirmed by the UN General Assembly in 2010.[163] When farmers and farmworkers handle toxic substances without adequate training, protective equipment, or access to medical care, their right to safe and healthy working conditions is violated in practice, season after season.[164]

The UN has further recognised that biodiversity loss directly threatens the human right to a clean, healthy, and sustainable environment.[165] The Kunming-Montreal Global Biodiversity Framework reinforces this, calling on states to protect species and ecosystems and to minimise the impacts of resource use on biodiversity, including phasing-out HHPs in agriculture by 2035.[166] Monoculture coffee production, dependent on pesticide inputs that degrade soil life, contaminate water, and eliminate pollinators, is contrasting to these obligations.

In several producing regions, children work on coffee farms and are directly exposed to pesticides, at precisely the stage of life when bodies are most vulnerable to chemical harm. States that have ratified the Convention on the Rights of the Child are legally obligated to protect children from such exposure.[167] That is not a technicality. It is a basic condition of a dignified childhood

SOLUTIONS

The costs of pesticide dependency in coffee are well-documented — from residues in soils and water to farmworker health risks, pollinator decline, import rejections, and the paradox of pest resistance that makes chemicals less effective over time. The pressure for change is building from multiple directions. Regulatory phase-outs of HHPs are accelerating across many countries. In addition, rising costs of fossil-based inputs are eroding the economic case for chemical-intensive management. And climate change is simultaneously deepening the problem: coffee berry borer and coffee leaf rust are expanding their geographic range, accelerating their reproductive cycles, and colonising areas previously outside their reach.

These dynamics expose a structural vulnerability that simply switching one chemical for another - or increasing volumes - cannot resolve. The root cause is the production system itself. Intensive monocultures that are low in biodiversity, high in inputs, stripped of shade create the very conditions in which pests proliferate and natural control mechanisms collapse. Broad-spectrum pesticides accelerate this process by eliminating the predators and parasitoids that would otherwise regulate pest populations. The result is a system that generates the outbreaks it was designed to prevent, and that grows more dependent on chemical inputs with each cycle.

The good news is that coffee production does not need to remain locked into this pattern. Across coffee-growing regions, proven alternatives already demonstrate that pesticide dependence can be reduced while protecting yields, farm incomes, and ecosystem health. The most effective approaches do not simply swap one pesticide for another — they rebuild the farm as a healthier system, where pests and diseases are less likely to spread in the first place.

The following section outlines what these approaches look like in practice, and what it would take to make them the norm.

INTEGRATED PEST MANAGEMENT

Reducing pesticide reliance in coffee requires systemic transformation, not input substitution. A farm that is low in biodiversity, stripped of shade, and with degraded soils will continue generating outbreaks regardless of what is sprayed to control pests, whether its synthetic or biological pesticides. The system is structurally weak, and no chemical can compensate for that weakness indefinitely.

Integrated Pest Management (IPM) provides the right framework — but only when prevention genuinely comes first. In practice, many coffee systems operating under the IPM label remain skewed toward routine chemical application, with preventive strategies receiving far less attention than they deserve. Prevention is the foundation on which everything else depends, and the IPM triangle makes this hierarchy visible.

Prevention forms the broad base — farm redesign, biodiversity, healthy soils, and structural complexity that makes the system inherently less hospitable to pests. Monitoring sits above it, tracking infestation levels to determine whether intervention is actually warranted. When thresholds are reached, the response moves upward: cultural controls such as sanitary harvesting, then biological control through natural enemies, and finally biopesticides as a targeted last resort. The triangle narrows toward the top for a reason — each layer should be needed less frequently than the one below it. And critically, the layers reinforce each other: agroforestry creates the habitat that makes biological control effective; healthy soils support biopesticide performance; cultural controls reduce the pest pressure that biological agents then suppress. Integration across all layers, not sequential escalation, is what makes IPM work.

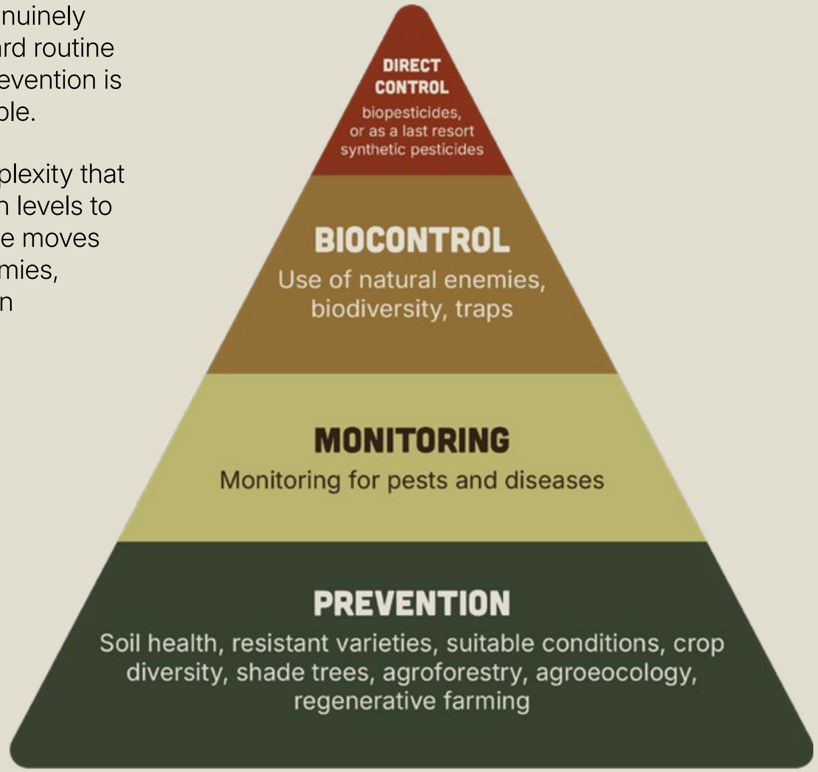


Figure 19: Integrated Pest Management triangle

PREVENTION: REDESIGNING THE FARM

Reducing pesticide reliance in coffee requires transforming the farming system itself, through approaches such as agroforestry, agroecology, regenerative agriculture, and organic farming. These approaches differ in scope and complexity, often overlap in practice, and are not competing paradigms; they are mutually reinforcing pathways toward the same outcome. What unites them is a shared logic: production systems designed to resist and recover from pest and disease pressure at source, rather than systems that simply treat symptoms with chemicals.

REGENERATIVE FARMING: A STARTING POINT, NOT A DESTINATION

Regenerative farming focuses on restoring soil health[168] and rebuilding the farm's biological function through compost, cover crops, mulching, reduced soil disturbance, and practices fostering healthier root systems. By improving nutrient cycling, microbial diversity, and water retention, these gains boost plant vigour and resilience — directly reducing vulnerability to pests and diseases.[169] After the 2012–2014 Central American leaf rust crisis, farmers using organic fertilisation and mulching recovered faster with significantly less fungicide use[170], and studies across Guatemala, Honduras, and Mexico show that nutrient-rich soils can slow rust progression by 30–50%[171]. Beneficial soil microorganisms such as Bacillus subtilis and Trichoderma have been shown to suppress coffee leaf rust by inhibiting spore germination by up to 66%.[172] In practice, farmers boosting soil biology via organic inputs (compost, manure, bioinoculants) see rust pressure decline over time: microbial diversity enhances nutrient uptake and plant immunity, reducing disease severity by 40-90% without fungicides.[173] Another example from Vietnam: A regenerative coffee farm documented by Rainforest Alliance reduced pesticide and fertilizer use by planting shade trees, adding ground cover, and applying organic manure and bioinoculants. The result was fewer pest and disease outbreaks and better soil health, showing how farm redesign can lower chemical dependence over time.[174]

However, regenerative farming is also the approach most frequently criticised for doing too little. Standards vary widely in ambition, and a particular concern is the 'no-till' model: while protecting soils from physical disturbance is a genuine step forward, some no-till approaches are linked to significantly increased herbicide use. With that the approach trades one form of soil harm for another. More broadly, regenerative practices are often applied to existing monoculture layouts without shifting toward diversified polycultures or agroforestry, prioritising measurable soil metrics over the deeper systemic change that genuinely reduces pest and disease pressure at source.[175] This makes it the most attractive entry point for large coffee companies: it fits existing supply chain structures, and requires the least disruption to farm layout or production systems. The risk is that it becomes a ceiling rather than a starting point — capturing the language of regeneration while leaving the structural vulnerability of monoculture intact.

This tension is visible in the carbon credit market, where regenerative practices in coffee are increasingly linked to sustainability premiums and carbon finance.[176] In theory, soil building and emissions reductions generate financial rewards for farmers. In practice, measurement, verification, and certification costs tend to favour larger farms and organised supply chains[177], frequently excluding the smallholder farmers who make up the backbone of global coffee production[178]. This means that while carbon finance can support regenerative transitions in some settings, it should not be treated as the main solution for coffee. For most smallholders, the more relevant value of regenerative farming is its direct agronomic benefit: healthier soils, lower input costs, greater resilience, and less dependence on pesticides and external fertilisers.

Regenerative farming, at its best, is a meaningful first step towards reducing pesticide dependence. But without progressing toward greater structural diversity — through agroforestry, intercropping, or agroecological design — it risks trading mechanical disturbance of the soil for potentially more harmful reliance on hazardous chemicals.

Reducing pesticide and synthetic fertiliser can have a direct impact on the carbon accounting for the coffee sector. Coffee production is widely characterized by use of fertilizers and agrochemicals to sustain high and qualitatively reliable yields. This in turn has a direct negative impact affecting surrounding natural ecosystems and biodiversity, freshwater quality and health of coffee producers and local communities.

Moreover, research clearly shows that pesticides contribute significantly to greenhouse gas emissions: 99% of all synthetic chemicals, including pesticides, are derived from fossil fuels and their manufacturing, packaging, transport, application, and even breakdown after application immensely contribute to carbon emissions.

The production of one kilogram of pesticide requires about 10 times more energy than one kilogram of nitrogen fertilizer.[142] At the same time, the coffee industry has been concerned for decades by its vulnerability to the impacts of climate change: As coffee plants have shown to be extremely sensitive to altitude, temperature and water availability, areas suitable for coffee production could shrink by 50% by 2050 or earlier[179, 180, 181].

Even the International Trade Center calls upon the coffee industry to not only focus on climate adaptation but also on mitigation by reducing its own contribution to greenhouse gas emissions.[182] Thus, coffee producers and retailers have increasingly been committed to reducing carbon emissions at the different stages of coffee production, transport, processing and consumption[179], but fully integrated and standardized approaches for the sector seem to be missing.

Here, the coffee sector could be the front runner and early mover for the agricultural sector and make a virtue of necessity.[183] Considering (1) proven evidence from sustainable coffee systems showing meaningful reductions in synthetic fertilizers and agrochemicals, the shift from non-shaded monoculture to agroforestry systems, crop diversification, and integrated pest management enhances natural pest control, improves soil health, and thus simultaneously reduces the need for both fertilizers and pesticides; and (2) the use of agrochemicals as a major source of carbon emissions, which is not yet common practice. Up to now, the reduction of synthetic pesticide use has been omitted from climate change solutions, and synthetic pesticide use is even presented as a climate change mitigation strategy by industrial agriculture interests.

By Svane Bender, Deutsche Umwelthilfe e.V./ Environmental Action Germany

AGROFORESTRY: NATURE'S SHIELD

Of all the preventive approaches, agroforestry brings the most fundamental change to how a coffee farm functions. Growing coffee under a diverse canopy of locally native trees shifts the farm from a structurally simple, pest-prone monoculture into a layered, self-regulating ecosystem, and for Coffea arabica, this is closer to its natural state than the sun-exposed plantations that dominate industrial production. Its genetic origins lie in the understorey forests of Ethiopia and South Sudan, and that heritage shows: Arabica is inherently shade-tolerant, a trait that intensive cultivation has suppressed rather than eliminated.[184]

The ecological benefits are wide-ranging and well-documented.

Microclimate Regulation

Shade trees can reduce temperatures around coffee berries by up to 4°C that directly reduce the rate of increase in Coffee Berry Borer (CBB) populations by 34%.[185] Higher temperatures accelerate its reproductive cycle and expand its geographic range; shade cover works against both.[186] Climate change makes this dynamic increasingly urgent: CBB has already been found at higher elevations as a result of rising temperatures, and damage is projected to worsen over time as both the number of pest generations per year and the number of eggs laid per female increase.[187]

Habitat for Natural Enemies

Agroforestry sustains the farm's free pest control workforce. The diversity of trees and other plants provide extrafloral nectaries, shelter, and nesting sites for the natural enemies like birds, bats, ants, parasitoid wasps, and predatory insects all year-round[188]: In Cameroonian shaded cacao farms, these birds and bats delivered pest-control value worth $478 per hectare per year — but only on farms with substantial shade cover above 50%. Below that threshold, the ecosystem service effectively disappeared.[189] A recent global meta study confirmed that coffee farms with high shade (>30 %) harbour the highest species diversity compared to low shade or even sun monoculture.[190]

Additional benefits are the increase in pollinators

A global meta-analysis found that animal pollination increases Arabica coffee fruit set by around 18% on average, driven by the richer pollinator communities that tree diversity and forest proximity support through the availability of flowers and nectar.[191]

INTERCROPPING: MORE THAN A SOIL TOOL

Intercropping is widely used across regenerative, agroforestry, and organic systems — most commonly for its soil benefits. Leguminous cover crops fix nitrogen, reduce erosion, and feed soil microbial communities, and this alone justifies their use. But intercropping's potential as a pest management tool is equally significant and far less recognised.

The choice of which plants to grow between coffee rows matters enormously. Plants like e.g. sunn hemp and buckwheat as nitrogen fixer do more than improve soil — they provide pollen and nectar that sustain predatory insects throughout the year, including during the long periods when coffee itself offers nothing.[188] Green lacewings (Chrysoperla externa), parasitoid wasps, and other natural enemies need plant-based food to survive and reproduce, not just prey. Without it, they disappear from the farm during low-pest periods and are absent precisely when the next outbreak begins. Sunn hemp provides pollen that supports lacewing adults and larvae, which in turn prey on coffee leaf miner, coffee berry borer, mites, and scales. Pairing it with buckwheat — a prolific nectar producer — increases predator survival further still.[192] Field experiments have shown that intercropping these two species with coffee significantly increases both predation and parasitism rates on coffee leaf miner compared to monoculture plots where no plant food was available.[193]

The distinction that matters here is one of intention. Planting sunn hemp for nitrogen fixation and planting it to feed natural enemies are not the same decision, even if the crop looks identical. Regenerative frameworks tend to prioritise the soil dimension; agroecological thinking asks what role each plant plays in the farm's food web. In practice, a well-designed intercropping system can deliver both — but only if species are chosen with pest management explicitly in mind, not just soil metrics.

The distinction that matters here is one of intention. Planting sunn hemp for nitrogen fixation and planting it to feed natural enemies are not the same decision, even if the crop looks identical. Regenerative frameworks tend to prioritise the soil dimension; agroecological thinking asks what role each plant plays in the farm's food web. In practice, a well-designed intercropping system can deliver both — but only if species are chosen with pest management explicitly in mind, not just soil metrics.

Landscape Connectivity

A single well-managed farm surrounded by monocultures will always be fighting uphill against the biological pressure its landscape generates. Farms embedded within or adjacent to forested landscapes experience consistently lower pest pressure because the surrounding environment acts as a biological buffer — continuously replenishing populations of natural enemies and maintaining the ecological complexity that pest regulation depends on.[194]

Soil and Fungal Communities

The stable microclimate and undisturbed soils of agroforestry systems also support insect-pathogenic fungi such as Beauveria bassiana, which naturally infects and kills CBB and other pests.[188] Full-sun monocultures actively suppress these fungi through soil exposure, high temperatures, and physical disturbance — removing a layer of biological control that agroforestry maintains at no cost.

ONGOING DEBATE ABOUT AGROFORESTRY

The persistent concern that shade reduces yields deserves scrutiny. Much of that evidence comes from studies using artificial shade nets, which mimic almost none of the ecological dynamics of a real agroforestry system.[195] More recent research tells a different story: some Arabica cultivars actually yield better under shade than in full sun, and what matters most is not simply how much shade is provided, but which trees provide it.[196]

Agroforestry is not a generic solution, tree selection and shade management require genuine care. Trees chosen purely for nitrogen fixation or timber value may contribute little to biological pest control. The most effective agroforestry systems deliberately include species that provide year-round nectar and pollen for natural enemies, harbour extrafloral nectaries, and avoid inadvertently feeding the herbivores they are meant to suppress. Get the design right, and agroforestry becomes one of the most powerful and cost-effective tools available for reducing pesticide dependence, while simultaneously building climate resilience, biodiversity, and long-term farm productivity. Get it wrong, and it is just trees in a field.

AGROFORESTRY AND THE FERTILISER COST CRISIS

Chemical fertiliser use in coffee is widespread and, in major producing countries, near-universal. Excessive nitrogen inputs cause a cascade of environmental harm: nitrous oxide emissions (273 times more potent than CO_2), waterway pollution and algal blooms, air pollution through ammonia volatilisation, and progressive soil acidification that degrades microbial life and long-term productivity.[197] In monoculture systems, nitrogen and pesticide use are strongly linked with each other, creating a cycle that doubles the environmental and financial burden. A 10-year study of 798 farms in Vietnam found farmers routinely applying four types of chemical fertiliser annually, often above recommended rates.[198]

The economics compound the problem. Conventional sun-grown coffee requires 150–300 kg of nitrogen per hectare per year across a perennial crop that takes 5–6 years to reach full production.[199] Between 1980 and 2022, the fertiliser price index rose 3.6 times faster than arabica prices and 9.2 times faster than robusta.[200] Geopolitical disruptions have pushed costs even further.[201]

Agroforestry, regenerative, and organic systems offer a proven way out of this dependency. Nitrogen-fixing trees such as Inga species and cover crops like sunn hemp capture atmospheric nitrogen and build soil organic matter, progressively reducing the need for synthetic inputs. In Vietnam, a regenerative farm documented by Rainforest Alliance cut both pesticide and fertiliser use simultaneously through shade trees, ground cover, and organic inputs. For smallholder farmers, breaking synthetic fertiliser dependency is not just an environmental choice, as prices rise and supply chains remain volatile, it is an economic necessity

AGROECOLOGY: SYSTEMS, NOT SYMPTOMS

Agroecology is frequently conflated with agroforestry[202], but it asks a different set of questions. While agroforestry redesigns the farm, agroecology goes further and asks why the farm needs redesigning in the first place and who gets to decide how.

At its core, agroecology applies ecological principles[203] to entire food systems, treating the farm not as an isolated production unit but as part of a wider landscape shaped by ecology, farmer knowledge, local markets, labour conditions, and community resilience. This landscape-level perspective matters: a single well-managed farm surrounded by monocultures will always be fighting against the biological pressure its surroundings generate. Agroecology advocates for coordinated, community-level transitions that make individual farm investments more durable. It also helps explain why farmers adopt or resist changes like agroforestry, decisions shaped not just by agronomy but by social relations, historical memory, and institutional context.[204]

Unlike regenerative agriculture or agroforestry, agroecology is explicitly a social and political movement. It centres farmer knowledge over external expertise, champions smallholder autonomy, and challenges the power structures -seed systems, input markets, price-setting mechanisms - that keep farmers locked into chemical dependency. For coffee, this means the transition away from pesticides is inseparable from questions of who controls seeds, who sets prices, and who bears the cost when things go wrong. Pesticide reduction, in an agroecological frame, is not a technical fix, it is a political act.

ORGANIC FARMING

Because synthetic pesticides are not used, organic coffee systems depend more heavily on prevention, sanitation, resistant varieties, biocontrol agents, and biopesticides. In practice, this often means using beneficial fungi, bacteria, traps, and habitat for natural enemies instead of routine spraying. Organic production does not solve every problem on its own, but it proves that coffee can be grown with far less chemical dependence while also protecting soil, water, and farmworker health. The global organic coffee area has expanded five-fold since 2004. More than 890,000 hectares of coffee were grown organically in 2017, led by Brazil, Indonesia and Côte d'Ivoire.[205] Among certification schemes in voluntary sustainability standard-certified coffee areas, organic expanded the most (33%) in 2013–2017.[206]

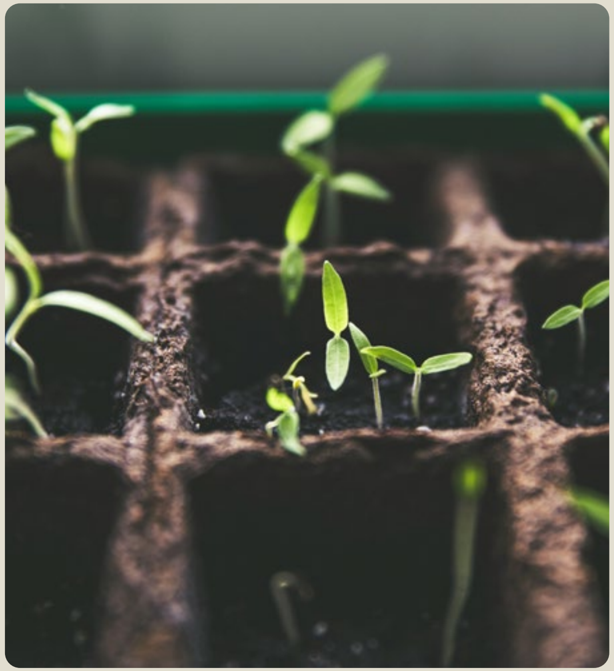
RESISTANT VARIETIES AND DISEASE CONTROL

For diseases like coffee leaf rust or root-knot nematodes, resistant varieties are one of the most important proven solutions. They reduce the need for fungicide spraying by making the plant itself less vulnerable. But resistance works best when combined with healthy soils, shade, and good farm management, because plants under less stress are better able to withstand disease pressure. In other words, resistance is not a stand-alone fix; it is part of a broader system that reduces chemical dependence.

RESISTANT VARIETIES: EFFECTIVE BUT NOT ENOUGH ALONE

For diseases like coffee leaf rust and root-knot nematodes, resistant varieties tackle the problem at the source, making the plant itself less vulnerable rather than repeatedly treating the symptoms with fungicides.

The challenge is adoption. Coffee is a perennial crop that takes 5–6 years to reach full production and can remain productive for up to 40 years[207], which makes farmers understandably reluctant to replace established plants with untested cultivars. When renovation is considered, traditional varieties are typically favoured over newly developed hybrids, driven by cultural preference, family tradition, the influence of neighbours, and the simple fact that certified seedlings are often too expensive for smallholders to access.[208] Plant breeding for pest and disease resistance in perennial systems is also slow by nature, with timelines that rarely match the urgency of emerging disease pressure. The result is a significant gap between what resistant varieties can offer in principle and how widely they are actually planted in the field.



MONITORING AND CULTURAL MEASURES: KNOWING WHEN AND HOW TO ACT

In conventional systems, calendar spraying (applying chemicals on a fixed schedule regardless of actual pest pressure) is standard practice, and one of the most costly and wasteful. Monitoring by assessing infestation levels changes that logic: interventions happen only when pest populations genuinely reach an economic threshold. Alcohol-based traps and systematic field scouting are simple, well-established tools that make this possible.[188]

Cultural practices are the natural complement — and consistently underestimated. Harvesting dry and overripe fruit from trees and collecting fallen berries from the ground is among the most effective CBB control measures available, outperforming many chemical interventions when done promptly and have been widely adopted by smallholder farmers in Brazil.[209]

BIOLOGICAL CONTROL: LIVING SOLUTIONS

Nature already provides coffee farmers with an army of allies. Beneficial fungi, bacteria, parasitoid wasps, ants, birds, bats, and spiders all prey on or suppress the pests and diseases that damage coffee crops, including Coffee Berry Borer, Coffee Leaf Miner, and scale insects.[208] Biological control means working with these organisms rather than against them, keeping pest and disease pressure in check before outbreaks take hold. The logic is straightforward: when farmers stop spraying broad-spectrum pesticides, the natural enemies that were being killed alongside the pests come back and biological control gets stronger over time.

Agroforestry makes biological control work even better. Shade maintains the humidity and temperature that Beauveria bassiana needs to perform well, while diverse vegetation provides habitat and food sources for natural enemies. Well-managed shade systems and targeted biological control genuinely reinforce each other.[208]

That said, biological control is not a simple swap for pesticides. These living organisms are sensitive to timing and local conditions in ways that chemicals are not, and Beauveria bassiana remains expensive and variable in performance, a real barrier for smallholder farmers. Predator-based approaches are still underdeveloped.[188] Getting biological control into wider use requires better access to affordable products, more farm-level research, and extension support that translates science into practice.

DIRECT CONTROL: THE LAST RESORT, NOT THE FIRST RESPONSE

When prevention and biological control are not sufficient to keep pest and disease pressure below acceptable thresholds, direct intervention becomes necessary. Even then, the principle holds: reach for the least harmful option first.

Biopesticides are the first port of call. The most widely available are neem-derived products, neem oil and leaf extracts from Azadirachta indica, effective against a range of coffee pests including Coffee Leaf Miner and spider mites, without the broad toxicity of synthetic insecticides.[188] However, the range of commercially available biopesticides for coffee remains limited, and this is a significant gap that needs addressing.

Where chemical pesticides cannot be avoided, product selection matters. Any HHPs and any active ingredients identified for phase-out under the Global Coffee Platform framework should be strictly avoided. The goal is not to find a legal substitute for a banned product, but to use the least hazardous effective option available, at the right dose and the right time, while continuing to build the agroecosystem conditions that reduce the need for chemical intervention over time.

Photo by Oleh Bilovus at Vecteezy.com

PESTS, DISEASES AND WEEDS

Coffee production is affected by a range of economically significant pests and diseases. Climate change, farming system choices, and tree health all determine how severe these pressures become and how much pesticide farmers use in response.

EXAMPLES OF PESTS

Coffee Berry Borer (Hypothenemus hampei)

The Coffee Berry Borer (CBB) is the most economically damaging insect pest in coffee worldwide. These small black beetles bore directly into the cherry, construct galleries inside, and lay their eggs within the fruit. The result is reduced bean weight, degraded cup quality, and direct financial losses, infested beans carry bitter or fermented flavours that can disqualify entire lots from specialty markets.[210] Rising temperatures are making the problem worse, accelerating the borer's reproductive cycle and pushing its range into higher altitudes previously too cool for significant populations.[211]

Pesticide use: Because the beetle lives protected inside the cherry[212], insecticides have limited reach, field data show they reduce infestations by only around 30%, compared to 80–90% achieved through integrated management[213]. Commonly used insecticides include chlorpyrifos, imidacloprid, thiamethoxam, cypermethrin, acetamiprid, beta-cyfluthrin, bifenthrin – all carry significant human health and environmental risks.

Alternative control: Farmers who manage CBB successfully combine multiple approaches: sanitary harvesting to remove fallen and overripe cherries, alcohol-based trapping, intercropping with repellent species such as the shrub lantana (Lantana camara), and agroforestry to buffer microclimate temperatures and fragment coffee plots — physically hindering beetle movement across and between farms while supporting natural predator communities.[208]

The fungus Beauveria bassiana is the most promising biocontrol agent, achieving 50–70% effectiveness against CBB and already available in commercial formulations.[209] Agroforestry conditions with moderate temperatures and high humidity actively support its performance, creating a direct functional link between shade management and biocontrol efficacy. Its key limitation is that it cannot reverse damage when infestation is already high at the start of the season, reinforcing the importance of early monitoring and preventive action.[209] Parasitoid wasps have proven largely ineffective due to life cycle mismatches with CBB[214], while entomopathogenic nematodes show variable results ranging from 5% to 45%[213] — useful in some contexts but not yet reliable as a standalone tool.

Coffee Leaf Miner (Leucoptera coffeella)

The Coffee Leaf Miner (Leucoptera coffeella in Latin America, Leucoptera caffeina in Africa) attacks coffee foliage worldwide. Tiny moths lay eggs on leaves, and hatching larvae burrow into leaf tissue, creating the characteristic brown mines that reduce photosynthesis and — in severe cases — cause up to 50% yield loss through premature leaf drop.[215] Populations peak during dry months and are strongly shaped by temperature and humidity, often more than by natural enemies or farming practices alone.[216]

Pesticide use: Chemical control is becoming less reliable. Commonly used insecticides, like thiamethoxam, chlorantraniliprole, fipronil, abamectin, lufenuron, profenofos, fipronil, phenylpyrazole are facing documented resistance in Brazil, reducing their efficacy precisely where pest pressure is highest.[217] Several carry significant health and environmental risks.

Alternative control: The good news is that alternative management options for CLM are relatively diverse and, importantly, affordable. Shade-grown agroforestry generally reduces larval densities, though the relationship is not straightforward — what matters most is the surrounding landscape.[218] Research in Puerto Rico and Brazil shows that forest cover beyond the farm boundary is the single most important factor in maintaining the social wasps, lizards, ants, and other natural predators that keep CLM in check. Twig-nesting ants in shaded farms prey directly on eggs, larvae, and pupae; intercropping with rubber trees creates microclimates that slow larval development.[219]

Biopesticides offer a credible direct control option. Neem-based products suppress Leaf Miner populations without harming predatory mites.[220] Formulations combining neem with citronella and D-limonene inhibit larval development, and geraniol and orange-citronella products reduce larval and pupal survival.217 Some plant-based extracts, including castor bean221 and Momordica charantia[222] — can even be prepared directly by farmers, making CLM one of the more practical entry points for farmer-led biological control developed with support from extension services and coffee institutes.

Other common pests include Stem borer (Monochamus leuconotus), Green scale (Coccus spp.), Antestia bugs (Antestiopsis spp.) and Mealybug (Planococcus kenyae).

EXAMPLES OF DISEASES

Coffee Leaf Rust (Hemileia vastatrix)

Coffee Leaf Rust (CLR) is one of the most serious threats to Arabica coffee globally.[223] Wind and rain spread coffee leaf rust spores, which thrive at around 21°C. So the disease is most prevalent in Arabica grown in the warm, humid conditions of low altitudes.[224] Infected leaves develop characteristic yellow-orange dusty spots on their undersides, leading to defoliation, uneven berry ripening, and significant yield losses. Severely affected plants produce light, astringent beans and in bad outbreaks, dead beans that turn brown after processing with sour, off-flavours that destroy cup quality.[225] Climate change is expanding the conditions under which it spreads, and no coffee-growing region is exempt.

Pesticide use: Without an integrated management approach, pesticide use is not efficient to control the fungus. Nevertheless, farmers often rely on fungicides programs using fungicides like epoxiconazole, cyproconazole, tebuconazole, azoxystrobin and chlorothalonil either via soil drench or via foliar application.[226]

Alternative control: No single management approach is sufficient, effective and durable control requires combining multiple integrated strategies: agroforestry design, biological control and resistant varieties.[227] Shade trees can block spore dispersal and reduce disease incidence, but some canopy configurations create conditions that favour the fungus, and heavily cropping trees are consistently more vulnerable regardless of shade. Shade tree species choice, canopy openness, and regular pruning are the critical management levers.

Biological control adds a powerful complementary layer. Several Bacillus species have shown field-level effectiveness, with preventive application consistently producing the strongest results. The fungus Calonectria hemileiae is particularly promising, reducing CLR severity by 70–90% in plant trials and in some cases matching fungicide performance.[228] The fungus Lecanicillium lecanii, embedded in a natural web of ants, scale insects, and spore predators, can suppress rust epidemics at landscape scale, an excellent example of how functional biodiversity delivers disease control as a natural service.[229]

Together, carefully managed agroforestry and targeted biological control represent the most promising pathway to durable CLR management — reducing fungicide dependence while building the ecological resilience that long-term disease management demands.

Coffee berry disease, CBD (Colletotrichum sp.)

Coffee Berry Disease (CBD), caused by Colletotrichum kahawae, is confined to the African continent but highly destructive within its range, with severe outbreaks causing up to 90% yield losses.[230] Different variants appear throughout the countries where coffee is cultivated. This fungus might appear in the stems, the leaves, and the coffee varieties when they are not ripe (green berries). In advanced stages, the coffee berries dry out and acquire a dark color. It is believed that plantations with low levels of fertilization and low soil moisture are more susceptible to this disease.

Pesticide use: Farmers often rely on fungicides programs using fungicide like epoxiconazole, cyproconazole, tebuconazole, azoxystrobin and chlorothalonil either via soil drench or via foliar application.

Alternative control: As with other major coffee diseases, no single management approach is sufficient, combining agroforestry management and biological control offers the most promising pathway. The role of shade trees in agroforestry in CBD management is again context-dependent and not straightforward (see above).[231] Biological control shows clear promise. Streptomyces spp. have demonstrated inhibitory effects on C. kahawae in plant trials[232], and Beauveria bassiana, already established against Coffee Berry Borer, has also been shown to significantly reduce CBD fruit rot, pointing to its value as a multi-target biocontrol agent[233]. Critically, research comparing fungicide-treated and untreated plants found lower CBD severity on unsprayed leaves, attributed to a richer leaf microflora on untreated plants.[234] Routine fungicide application may therefore actively suppress the plant's natural defence against C. kahawae — a compelling argument for restraint in chemical use and for supporting the plant's own biological defence system as a core management strategy.

WEEDS

Weeds also play a critical role in coffee systems. While competition from weeds can reduce yields, especially during the early stages of plant establishment, evidence suggests that mature coffee plants can tolerate, and in some cases benefit from, moderate weed cover. Nevertheless, herbicides are frequently applied preventively, without consideration of actual weed pressure or economic thresholds.

Pesticide use: Glyphosate, glufosinate-ammonium, paraquat, 2,4-D.

Alternative control: Vietnam offers a relevant example. In June 2021, the country introduced a complete ban on the import and use of glyphosate, previously among the most widely used herbicides in its coffee sector. The Global Coffee Platform's Collective Action Initiative responded by developing an integrated weed management manual for farmers, and glyphosate residues in green coffee subsequently decreased across all five Central Highlands provinces.[235] Alternatives include manual weeding, integrated pest management, and biological control, approaches that require more labour but reduce long-term chemical dependency. The transition was not without difficulty, and substitute herbicides are now themselves under regulatory scrutiny, underlining that replacing one chemical with another is not a solution. What Vietnam's experience does demonstrate is that residue levels can respond meaningfully when policy action is paired with practical farmer support.

RECOMMENDATIONS

1. REGULAR MONITORING OF PESTICIDE RESIDUES IN GREEN AND ROASTED BEANS

Coffee is one of the least-tested imported commodities despite high pesticide contamination rates (23% show pesticides banned in EU in green beans, 72% showed AMPA in roasted coffee in the US). Most coffee-consuming nations do not systematically test green or roasted coffee for pesticide residues. That must change, consumers have a right to know what is in their cup.

Recommendations:

- Require routine, testing of all imported coffee, green and roasted
- Require disclosure of all detected residues, including multi-residue "cocktail effects."

2. CLOSE THE DOUBLE STANDARD ON PESTICIDE EXPORTS

59% of pesticides used in coffee are already banned in the European Union, yet are still exported to producing countries. The EU is not alone, either. This paradigm is unacceptable.

Recommendations:

- Ban all export of pesticides that are prohibited domestically.
- Require agrochemical companies to disclose export volumes of HHPs to producing countries.
- Align import rules with export rules: if a pesticide is banned for use, it should not be tolerated as a residue.

3. PHASE OUT HIGHLY HAZARDOUS PESTICIDES (HHPS) IN COFFEE PRODUCTION

60–77% of pesticides used in coffee production are classified as HHPs. This presents an urgent crisis for coffee and health.

Recommendations:

- Governments, standards and companies should phase out all HHPs in coffee by 2030, in line with global commitments[236, 237] (50% reduction of Hazardous Chemicals stated by Kunming-Montreal Global Biodiversity Framework, Target 7)[166]
- Eliminate 'GCP prohibited' pesticides by 2026
- Eliminate GCP 'phaseout pesticides' by 2030
- Support farmers to adopt sustainable agricultural practices, including agroecology in line with global commitments

4. REFORM CERTIFICATION SCHEMES

Half of coffee is certified. Most certifications do either a bad job, or a mediocre job, at curbing pesticides in coffee. Coffee certification bodies must all urgently transition to chemical-free standards. No more half measures, marketing speak, and waffling.

Recommendations:

- Require certification schemes to monitor and publish pesticide use data and phase out HHPs
- Introduce mandatory residue testing for certified coffee.
- Provision of/ supporting access to high quality tools for carrying out farm maintenance to support cultural control
- Reward agroecological performance, not just compliance checklists.
- Systematic field-level impact monitoring for prioritising targeted intervention

5. INVEST IN AGROECOLOGICAL AND AGROFORESTRY SYSTEMS, BIOLOGICAL CONTROLS, AND CIRCULAR SYSTEMS

Monocultures strip away the shade canopies and biodiversity that once naturally controlled pests, creating chemical dependency. A transition to agroforestry and agroecology can facilitate an end to the coffee industry's chemical addiction and ensure future soil fertility and pollinators essential for coffee production

Recommendations:

- Redirect subsidies from chemical inputs to agroecological transition support at a landscape level - ensuring small holder farmers build strong connected systems.
- Scale up national programs for agroforestry, shade restoration, and diversified cropping.
- Require buyers to adopt procurement standards that reward low-input and agroecological production.
- Introduce price premiums tied to pesticide reduction and biodiversity outcomes.
- Fund farmer training in integrated pest management, including natural predator and pollinator management.
- Support local production of biopesticides and botanical extracts.
- Require testing of coffee pulp and husks before composting.
- Support pesticide-free waste-to-compost programs.
- Promote circular nutrient systems to reduce chemical fertilizer dependency.

6. STRENGTHEN WORKER PROTECTION AND OCCUPATIONAL HEALTH SYSTEMS

Most coffee farmers and farmworkers do not have adequate PPE, many are poisoned by pesticides, and even chronic poisoning is widespread.The most efficient way to protect farmers' health is to phase out the use of any HHPs.

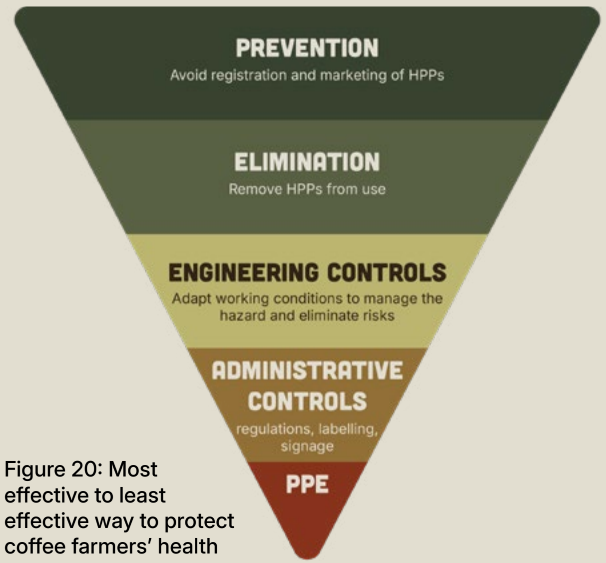


Figure 20: Most effective to least effective way to protect coffee farmers' health

Recommendations:

- Phase out HHPs
- Provide adequate PPE assistance and training to farmers and farmworkers.
- Ensure farmers receive clear guidance on MRLs and pre-harvest intervals.
- Enforce compliance through inspections, establish easy to access complaint mechanisms.
- Introduce biological monitoring (e.g. cholinesterase testing) for workers handling organophosphates.
- Require medical surveillance programs in major producing regions with an accessible reporting and recording system in place (e.g. by collecting health impacts by anonymous questionnaires and reporting to a local poisoning centre).

7. SUPPORT PRODUCER-LED RESEARCH AND DECISION-MAKING

Impoverished coffee farmers bear the health risks and economic losses while having little influence over pesticide policy.

Recommendations:

- Fund producer-led trials of agroecological methods and biocontrols.
- Establish farmer advisory councils to inform national pesticide policy.
- Ensure producers participate in global coffee sustainability platforms.

8. PROTECT WOMEN AND CHILDREN

Women and children face disproportionate exposure to pesticides that can cause miscarriages, birth defects, and more.

Recommendations:

- Prohibit pesticide application by minors and enforce buffer zones around homes, schools, and water sources.
- Integrate maternal and child health monitoring into agricultural extension services.
- Provide targeted training for women farmers and workers.

9. PROTECT WATER, SOIL, AND BIODIVERSITY

Common coffee pesticides are contributing to the mass extinction crisis that we are in, harming biodiversity and water quality. Pesticide residues are widespread in water bodies and soil.

Recommendations:

- Require watershed-level and soil monitoring of pesticide contamination in coffee-producing countries.
- Incentivize soil-restoring practices (mulching, composting, cover crops).
- Ban pesticides classified as "very toxic to bees" and require pollinator-safe management plans.

10. INCREASE TRANSPARENCY AND ACCOUNTABILITY ACROSS THE SUPPLY CHAIN

Reliable data on pesticide use is hard to come by, and much of the needed monitoring is sporadic at best.

Recommendations:

- Require companies to publish pesticide use data, residue testing results, and farm-level risk assessments.
- Create a global public database of pesticide residues in coffee.
- Require traceability to farm level for all certified, "sustainable" or "high risk" coffee.

11. ADDRESS THE CLIMATE-PESTICIDE FEEDBACK LOOP

Climate change is increasing pest pressure, driving more pesticide use. At the same time, synthetic pesticides and fertilisers are contributing to climate change, land degradation and undermining climate resilience.

Recommendations:

- Integrate climate adaptation into pest management strategies.
- Support breeding programs for pest-resistant, climate-resilient varieties.
- Promote landscape-level biodiversity corridors to stabilize ecosystems.
- Reduce fossil based inputs, like pesticides and synthetic nitrogen fertilizer.

REFERENCES

1 University of Hertfordshire, n.d. Pesticide Properties Database. https://sitem.herts.ac.uk/aeru/ppdb/en/ (accessed Oct 2025)

2 International Coffee Organization, 2026. Coffee Market Report. https://www.ico.org/

3 Enveritas, n.d. Enveritas. https://www.enveritas.org/

4 International Trade Centre, 2021. The Coffee Guide (4th edition). https://www.intracen.org/file/itccoffee4threport20210930webpagespdf

5 Maneje Bem - Fitocon, n.d. The economic importance of coffee cultivation in family farming and how to reduce economic risks. https://www.manejebem.com.br/publicacao/novidades/a-importancia-economica-do-cultivo-de-cafe-na-agricultura-familiar-e-como-diminuir-os-riscos-economicos

6 International Coffee Council, 2012. Trends in coffee consumption in selected importing countries. https://www.ico.org/documents/icc-109-8e-trends-consumption.pdf

7 International Comunicaffe, 2026. Europe's green coffee imports recovering, but still below pre pandemic levels, shows new statistical report from the ECF. https://www.comunicaffe.com/europes-green-coffee-imports-recovering-but-still-below-pre-pandemic-levels-shows-new-report-from-the-ecf/

8 Public Eye, 2024. Banned pesticides notified for export from the EU. https://www.publiceye.ch/en/topics/pesticides/weltkarte/

9 World Coffee Research, 2018. Annual Report. https://worldcoffeeresearch.org/download/b0f3daa9-4fa7-43ca-8b79-6c49902c070d

10 Daly, J. et al., 2018. Jamaica in the Arabica Coffee Global Value Chain. https://doi.org/10.13140/RG.2.2.35977.95849

11 World Coffee Research, 2022. Core Collection—Quality Evaluation. https://worldcoffeeresearch.org/es/programs/coffea-arabica-genetic-diversity

12 Senjani Agro, 2023. Arabica vs Robusta: The Difference From A to Z you Should Know. https://www.singleestatecoffee.nl/en/arabica-vs-robusta-whats-the-difference/

13 Góngora, C.E. et al., 2023. A Novel Caffeine Oleate Formulation as an Insecticide to Control Coffee Berry Borer, Hypothenemus hampei, and Other Coffee Pests. https://doi.org/10.3390/agronomy13061554

14 Martínez, G., 2017. Chlorogenic acid is a fungicide active against phytopathogenic fungi. https://doi.org/10.1016/j.pestbp.2017.05.012

15 Lima Júnior, J., 2014. A "chuva" de agrotóxicos em Rio Verde-GO: exemplo de prática ofensiva aos direitos humanos que demanda análise interdisciplinar. http://www.publicadireito.com.br/artigos/?cod=c947c73def1af5e6

16 AGNews, 2018. Top 20 Brazilian agrochem companies in 2017: Mergers will increase market concentration in the future. https://www.agribusinessglobal.com/markets/americas/mergers-and-acquisitions-the-prominence-of-brazil/

17 Pignati, W.A. et al., 2017. Spatial distribution of pesticide use in Brazil: a strategy for Health Surveillance. https://doi.org/10.1590/1413-812320172210.17742017.

18 Revista Pesquisa Fapesp, 2022. Pesticides can affect the health of agricultural workers. https://revistapesquisa.fapesp.br/en/pesticides-can-affect-the-health-of-agricultural-workers/

19 World Bank Group, 2017. An Overview of Agricultural Pollution in Vietnam: Summary Report. https://openknowledge.worldbank.org/server/api/core/bitstreams/af2e8eac-4752-5fef-9873-7dd3177a5127/content

20 Heinrich Böll Foundation Nairobi, 2023. Toxic Business, Highly Hazardous Pesticides in Kenya. https://ke.boell.org/sites/default/files/2023-09/data-and-facts_highly-hazardous-pesticides-in-kenya-1.pdf

21 Pesticide Action Network (PAN), 2024. PAN International List of Highly Hazardous Pesticides. https://pan-international.org/wp-content/uploads/PAN_HHP_List.pdf

22 European Commission, n.d. Active substances, safeners and synergists. https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/start/screen/active-substances (accessed Oct 2025)

23 Stockholm Convention, n.d. Stockholm Convention on Persistent Organic Pollutants. https://pops.int/

24 Rotterdam Convention, n.d. Rotterdam Convention. https://pic.int/

25 FAO/WHO, 2016. Guidelines on Highly Hazardous Pesticide. http://www.fao.org/3/i5566e/i5566e.pdf

26 University of Hertfordshire, n.d. Pesticide Properties Database. https://sitem.herts.ac.uk/aeru/ppdb/en/ (accessed Oct 2025)

27 International Agency for Research on Cancer (IARC), 2015. IARC Monographs Volume 112: evaluation of five organophosphate insecticides and herbicides. https://www.iarc.who.int/wp-content/uploads/2018/07/MonographVolume112-1.pdf

28 Reuters, 2024. Bayer must pay $78 million in latest Roundup cancer trial, jury finds. https://www.reuters.com/legal/bayer-must-pay-78-mln-latest-roundup-cancer-trial-jury-finds-2024-10-10

29 Brazil, Ministério da Agricultura, Pecuária e Abastecimento. List of registered pesticide for coffee production (recieved upon request).

30 Clean Label Project, 2026. Coffee Study. Coffee Study - Clean Label Project. https://cleanlabelproject.org/coffeestudy/

31 Wen, X. et al., 2025. Impact of long-term use of multiple herbicides on soil microbial communities and nutrient cycling across different agricultural land-use types. https://doi.org/10.1016/j.agee.2025.109879.

32 Bayata, A. et al., 2025. Prolonged Glyphosate Application Effects on Soil Microbial Biomass Carbon in Coffee Cultivation Systems: Preliminary Observation. https://doi.org/10.11648/j.innov.20250602.12

33 Meena, R.S. et al., 2020. Impact of Agrochemicals on Soil Microbiota and Management: A Review. https://doi.org/10.3390/land9020034

34 Gaines TA, et al., 2020. Mechanisms of evolved herbicide resistance. https://doi.org/10.1074/jbc.REV120.013572

35 Nong nghiep moi truong, 2021. Banning Glyphosate herbicide from June 30. https://van.nongnghiepmoitruong.vn/banning-glyphosate-herbicide-from-30-june-d291273.html

36 Vietnam Business Insider, 2025. Vietnam's Coffee Sector Reaps Rewards from Collective Action Toward Sustainable Development. https://vietnambusinessinsider.vn/vietnams-coffee-sector-reaps-rewards-from-collective-action-toward-sustainable-development-a45470.html

37 Merhi, A., et al. 2022. A review on the pesticides in coffee: Usage, health effects, detection, and mitigation. https://doi.org/10.3389/fpubh.2022.1004570

38 Global Coffee Platform, 2023. Coffee Sustainability Reference Code. Annex: Pesticide Lists. https://www.globalcoffeeplatform.org/wp-content/uploads/2023/08/CSRC21_ANNEX-PESTICIDES-LIST_2023.pdf

39 Environmental Protection Agency (EPA), 1999. Chlorothalonil. https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-081901_1-Apr-99.pdf

40 Marciano, L.P.A. et al., 2024. A novel approach to triazole fungicides risk characterization: Bridging human biomonitoring and computational toxicology. https://doi.org/10.1016/j.scitotenv.2024.176003.

41 Environmental Protection Agency (EPA), 2024. Diuron: Report of the Cancer Assessment Review Committee. https://downloads.regulations.gov/EPA-HQ-OPP-2015-0077-0191/content.pdf

42 European Chemicals Agency (ECHA), n.d. Substance Infocard, Diuron. https://www.echa.europa.eu/substance-information/-/substanceinfo/100.005.778 (accessed October 2025)

43 Saunders, M., et al., 2012. Chlorpyrifos and neurodevelopmental effects: a literature review and expert elicitation on research and policy. https://doi.org/10.1186/1476-069X-11-S1-S5.

44 Rauh, V., et al. 2011. Seven-year neurodevelopmental scores and prenatal exposure to chlorpyrifos, a common agricultural pesticide. https://europepmc.org/article/MED/21507777

45 European Commission, 2013. Neonicotinoids. https://food.ec.europa.eu/plants/pesticides/approval-active-substances-safeners-and-synergists/renewal-approval/neonicotinoids_en

46 ScienceDirect, n.d. Imidacloprid. https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/imidacloprid

47 Wang, P.-W., et al., 2024. Prenatal and childhood neonicotinoid exposure and neurodevelopment: A study in a young Taiwanese cohort. https://doi.org/10.1016/j.scitotenv.2024.174232

48 Groenen, D., 2018. The Effects of Climate Change on the Pests and Diseases of Coffee Crops in Mesoamerica. https://doi.org/10.4172/2332-2594.1000239

49 Nation Africa, 2022. Kenya's coffee risks ban in Japan over higher pesticide residue. https://nation.africa/kenya/business/seeds-of-gold/kenya-s-coffee-risks-ban-in-japan-over-higher-pesticide-residue-3904456

50 Moreira, K.S., et al., 2025. Pesticide residues in the coffee industry - an occupational concern? https://doi.org/10.1590/0103-8478cr20250037

51 Ryberg, M.W.,et al., 2018. Addressing bystander exposure to agricultural pesticides in life cycle impact assessment. https://doi.org/10.1016/j.chemosphere.2018.01.088

52 Danwatch, 2016. Brazilian coffee is sprayed with deadly pesticides. https://danwatch.dk/en/brazilian-coffee-is-sprayed-with-deadly-pesticides/

53 Mulugeta T., et al., 2025. Drivers of the unintended use of emptied chemical containers by smallholder farmers. https://doi.org/10.1186/s12889-025-23848-0.

54 Mayorga Coffee, 2022. Conventional Coffee Farming Is Poisoning Local Communities. https://mayorgacoffee.com/blogs/news/conventional-coffee-farming

55 Hutter H.P., et al., 2018. Cytotoxic and Genotoxic Effects of Pesticide Exposure in Male Coffee Farmworkers of the Jarabacoa Region, Dominican Republic. https://doi.org/10.3390/ijerph15081641.

56 Balen, A.J.S. & Chaitra, H., 2023. Impact of pesticide on health of coffee plantation workers. https://www.ijnrd.org/papers/IJNRD2306196.pdf

57 Danwatch, 2016. Brazilian coffee is sprayed with deadly pesticides. https://old.danwatch.dk/en/undersogelseskapitel/brazilian-coffee-is-sprayed/

58 Guia Trabalhista, n.d. Norma Regulamentadora 31 - NR 31. https://www.guiatrabalhista.com.br/legislacao/nr/nr31.htm#31.8_Agrot%C3%B3xicos,_Adjuvantes_e_Produtos_Afins__

59 Garrigou, A., et al., 2020. Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. https://doi.org/10.1016/j.ssci.2019.104527

60 Nassar, P.P.M. & Ribeiro, M.G., 2020. Considerations for cholinesterase biomonitoring in flower and ornamental plant greenhouse workers. https://doi.org/10.1016/j.scitotenv.2019.135228

61 Ujunwa, E.I., et al., 2021. Health Implications of Production and Consumption of Coffee. https://www.researchgate.net/profile/Raymond-Ekemube/publication/358137686_Health_Implications_of_Production_and_Consumption_of_Coffee/links/61f21d7d5779d35951d88d5e/Health-Implications-of-Production-and-Consumption-of-Coffee.pdf

62 Ngowi A.V., et al., 2001. Acute health effects of organophosphorus pesticides on Tanzanian small-scale coffee growers. https://doi.org/10.1038/sj.jea.7500172.

63 Buralli R.J., et al., 2020. Occupational exposure to pesticides and health symptoms among family farmers in Brazil. https://doi.org/10.11606/s1518-8787.2020054002263.

64 Prado J.B., et al., 2017. Acute Pesticide-Related Illness Among Farmworkers: Barriers to Reporting to Public Health Authorities. https://doi.org/10.1080/1059924X.2017.1353936.

65 Dasgupta, S., et al., 2007. Pesticide poisoning of farm workers–implications of blood test results from Vietnam. https://doi.org/10.1016/j.ijheh.2006.08.006.

66 Wesseling, C., et al., 2005. Acute pesticide poisoning and pesticide registration in Central America. https://doi.org/10.1016/j.taap.2005.03.033.

67 Hutter, H.-P., et al., 2018. Subjective Symptoms of Male Workers Linked to Occupational Pesticide Exposure on Coffee Plantations in the Jarabacoa Region, Dominican Republic. https://doi.org/10.3390/ijerph15102099

68 Human Rights Watch, 2018. You Don't Want to Breathe Poison Anymore. https://www.hrw.org/report/2018/07/20/you-dont-want-breathe-poison-anymore/failing-response-pesticide-drift-brazils

69 Zhang L., et al., 2019. Exposure to Glyphosate-Based Herbicides and Risk for Non-Hodgkin Lymphoma: A Meta- Analysis and Supporting Evidence. https://doi.org/10.1016/j.mrrev.2019.02.001

70 FUNVERDE, 2010. The relationship between cancers and pesticides.

71 Kuzovenkova D., et al., 2025. Coffee consumption is associated with later age-at-onset of Parkinson's disease. https://doi.org/10.1101/2025.02.07.25321819.

72 ARD, 2025. Berufskrankheit Parkinson durch Pestizide. https://www.ardmediathek.de/video/unser-land/berufskrankheit-parkinson-durch-pestizide/br/Y3JpZDovL2JyLmRlL2Jyb2FkY2FzdC9GM jAyNFdPMDEyOTcyQTAvc2VjdGlvbi82MGEyZDI3MC0wZjIzLTQ0YjItOWNjMy03MjI0MzMyMmE1NTA

73 UCLA Health, 2026. Widely used pesticide linked to more than doubled Parkinson's risk. https://www.uclahealth.org/news/release/widely-used-pesticide-linked-more-doubled-parkinsons-risk

74 Santos, J.R. et al., 2025. Pesticide exposure and the development of Parkinson disease: a systematic review of Brazilian studies. https://doi.org/10.1590/0102-311XEN011424

75 Farnham, A., et al., 2021. Long-Term Neurological and Psychological Distress Symptoms among Smallholder Farmers in Costa Rica with a History of Acute Pesticide Poisoning. https://doi.org/10.3390/ijerph18179021

76 Moshammer, H., et al., 2020. More pesticides — less children? https://doi.org/10.1007/s00508-019-01566-z

77 Mamane A., et al., 2015. Occupational exposure to pesticides and respiratory health. https://doi.org/10.1183/16000617.00006014.

78 Mejía, R., et al., 2014. Pesticide-Handling Practices in Agriculture in El Salvador: An Example from 42 Patient Farmers with Chronic Kidney Disease in the Bajo Lempa Region. https://doi.org/10.4236/odem.2014.23007

79 Lebov J.F., et al., 2016. Pesticide use and risk of end-stage renal disease among licensed pesticide applicators in the Agricultural Health Study. https://doi.org/10.1136/oemed-2014-102615.

80 Conti, C.L., et al., 2018. Pesticide exposure, tobacco use, poor self-perceived health and presence of chronic disease are determinants of depressive symptoms among coffee growers from Southeast Brazil. https://doi.org/10.1016/j.psychres.2017.11.063

81 Global Coffee Report, 2026. Number of women in leadership in the coffee industry increases, ICO reports. https://www.gcrmag.com/number-of-women-in-leadership-in-the-coffee-industry-increases-ico-reports/

82 Mello, C.M. & Silva, L.F., 2011. Factors associated with pesticide poisoning: cross-sectional study among coffee plantation workers in southern Minas Gerais. http://scielo.iec.gov.br/scielo.php?script=sci_abstract&pid=S1679-49742013000400007&lng=en&nrm=is

83 Lekei, E., et al., 2020. Acute pesticide poisoning amongst adolescent girls and women in northern Tanzania. https://doi.org/10.1186/s12889-020-8374-9

84 Beyond Pesticides, 2025. Literature Review of Over 200 Studies Highlights Pesticide Threats to Women's Reproductive Health. https://beyondpesticides.org/dailynewsblog/2025/04/literature-review-of-over-200-studies-highlightspesticide-threats-to-womens-reproductive-health/

85 Rauh, V.A., et al., 2006. Impact of prenatal chlorpyrifos exposure on neurodevelopment in the first 3 years of life among inner-city children. https://doi.org/10.1542/peds.2006-0338.

86 Columbia University, 2011. Prenatal Exposure to Common Insecticide Linked to Decreases in Cognitive Functioning At Age Seven. https://www.publichealth.columbia.edu/news/prenatal-exposure-common-insecticide-linked-decreasescognitive-functioning-age-seven

87 Zhang, H., et al., 2022. Neonicotinoid Insecticides and Their Metabolites Can Pass through the Human Placenta Unimpeded. https://doi.org/10.1021/acs.est.2c06091

88 Daily Coffee News, 2024. ILO Leading $10.8 Million Child Labor in Coffee Project. https://dailycoffeenews.com/2024/07/09/ilo-leading-10-8-million-child-labor-in-coffee-project/

89 Terre de Hommes, 2023. Child Labour in the Coffee Industry in Eastern Uganda Report. https://int.terredeshommes.nl/news/child-labour-in-the-coffee-industry-in-eastern-uganda-report

90 Council On Environmental Health, 2012. Pesticide exposure in children. https://doi.org/10.1542/peds.2012-2757.

91 Rousseau K.L., et al., 2026. Postnatal pesticide exposure and executive function in children and adolescents: Findings from South Africa. https://doi.org/10.1016/j.envres.2025.123310.

92 European Commission, n.d. RASFF Window. https://webgate.ec.europa.eu/rasff-window/screen/search?event=searchResultList&searchQueries= (accessed Oct 2025)

93 Guadalupe, G.A., et al., 2024. Comprehensive Bibliometric Study in the Context of Chemical Hazards in Coffee. https://doi.org/10.3390/toxics12070526

94 Pesticide Action Network, 2024. Double standard, Double risk. Banned pesticides in Europe's food supply. https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/Report_Double%20standards%2C%20double%20risk.pdf

95 Villain, L., 2025. Large-scale assessment of pesticide residues in coffee and soil of contrasted Coffea arabica and C. canephora cropping systems in four countries [Conference Presentation]. ASIC 2025 Conference, Lisbon, Portugal. https://youtu.be/hiyfCrCkNMA?si=0OLnGl4ipjDn5Ukl

96 Son, J.-H:, et al., 2021. A safety survey on pesticide residues in green coffee beans. https://doi.org/10.11002/kjfp.2021.28.5.598

97 Agência Nacional de Vigilância Sanitária (ANVISA), n.d. Programa de Análise de Resíduos de Agrotóxicos em Alimentos. https://www.gov.br/anvisa/pt-br/assuntos/agrotoxicos/programa-de-analise-de-residuos-em-alimentos/ (accessed Oct 2025)

98 Mekonen, S., et al., 2014. Pesticide residue evaluation in major staple food items of Ethiopia using the QuEChERS method: A case study from the Jimma Zone: Pesticide residues in food items. https://doi.org/10.1002/etc.2554.

99 Daba, M., et al., 2021. Organochlorinated Pesticides Concentration Levels in Green Coffee Bean from Oromia, Ethiopia. https://www.researchpublish.com/upload/book/Organochlorinated%20Pesticides-6330.pdf

100 Harmoko, H., et al., 2015. QuEChERS Method for the Determination of Pesticide Residues in Indonesian Green Coffee Beans using Liquid Chromatography Tandem Mass Spectrometry. https://doi.org/10.5614/j.math.fund.sci.2015.47.3.7

101 Mathrubhumi, 2022. Coffee Board warns of pesticide residue in coffee. https://english.mathrubhumi.com/features/agriculture/coffee-board-warns-to-reduce-pesticide-content-in-coffee-powder-export-to-europe-2a991df6

102 Chen, Z., et al., 2019. Determinations of dinotefuran and metabolite levels before and after household coffee processing in coffee beans using solid-phase extraction coupled with liquid chromatography-tandem mass spectrometry. https://doi.org/10.1002/jsfa.9300

103 Mekonen, S., et al., 2015. Effect of Household Coffee Processing on Pesticide Residues as a Means of Ensuring Consumers' Safety. https://doi.org/10.1021/acs.jafc.5b03327

104 Harmoko, H., et al., 2024. Application of the QuEChERS method combined with UHPLC-QqQ-MS/MS for the determination of isoprocarb and carbaryl pesticides in Indonesian coffee. https://doi.org/10.1039/D4AY00243A

105 Gamal, A., et al., 2025. Pesticide residues in green, roasted, and capsule coffee from the Egyptian market: Occurrence, processing effects, and health risk assessment. https://doi.org/10.1016/j.foodchem.2025.144671.

106 Bytof, G., et al., 2025. Glyphosate losses through various stages of coffee production and consequences for human exposure. https://doi.org/10.1080/19440049.2024.2427667https://doi.org/10.1080/19440049.2024.2427667

107 Clean Label Project, 2025. Coffee Study. https://cleanlabelproject.org/coffee-study/

108 Radulović, J., et al., 2024. GC-MS/MS and LC-MS/MS analysis followed by risk ranking of mepiquat and pyrethroids in coffee. https://doi.org/10.1016/j.jfca.2024.106100.

109 Dias C.M., et al., 2013. Multi-residue method for the analysis of pesticides in Arabica coffee using liquid chromatography/tandem mass spectrometry. https://doi.org/10.1080/19440049.2013.801088.

110 Bresin, B., et al., 2015. Analysis of organo-chlorine pesticides residue in raw coffee with a modified "quick easy cheap effective rugged and safe" extraction/clean up procedure for reducing the impact of caffeine on the gas chromatography–mass spectrometry measurement, Journal of Chromatography A. https://doi.org/10.1016/j.chroma.2014.12.016.

111 Gamal, A., et al., 2024. Optimization and validation of high throughput methods for the determination of 132 organic contaminants in green and roasted coffee using GC-QqQ-MS/MS and LC-QqQ-MS/MS. https://doi.org/10.1016/j.foodchem.2024.139223. Epub 2024 Apr 4. PMID:38604032.

112 Krishnaveni, A., et al., 2022. Coffee pulp compost A viable organic source of nutrients for Soil and Crops. https://doi.org/10.5281/zenodo.6463637

113 Foloni, L.L., 2024. Glyphosate residues in coffee beans: Impact of application methods and compliance with MRLs. https://awsjournal.org/article/glyphosate-residues-in-coffee-bean-impact-of-application-methods-and-compliance-with-mrls/

114European Commission, n.d. EU legislation on MRLs. https://food.ec.europa.eu/plants/pesticides/maximum-residue-levels/eu-legislation-mrls_en (accessed Oct 2025)

115 Ministério da Agricultura, Pecuária e Abastecimento, 2022. Monitoramento e Avaliações de Produtos Pesticidas Registrados para o Café Resíduos de Pesticidas em café - PNCRC-Vegetal. https://cncafe.com.br/wp-content/uploads/1-Residuos-de-Pesticidas-em-cafe-PNCRC-Vegetal.pdf

116 Potsdam Institute for Climate Impact Research, 2025. Seven of nine planetary boundaries now breached – ocean acidification joins the danger zone. https://www.pik-potsdam.de/en/news/latest-news/seven-of-nine-planetary-boundaries-now-breached-2013-ocean-acidification-joins-the-danger-zone

117 Pesticide Action Network UK, Pesticide Action Network (PAN) North America & The Pesticide Collaboration, 2023. Pesticides and the Climate Crisis: A Vicious Cycle. https://www.panna.org/wp-content/uploads/2023/02/202301ClimateChangeEngFINAL.pdf

118 O Cossu, L., et al., 2024. Review on Pesticide Contamination and Drinking Water Treatment in Brazil: The Need for Improved Treatment Methods. https://doi.org/10.1021/acsestwater.4c00063

119 Carrington, D., 2026. Epic river migrations of fish rapidly collapsing, UN report finds. https://www.theguardian.com/environment/2026/mar/24/epic-river-migrations-of-fish-rapidly-collapsing-un-report-finds

120 Machado, K.C., et al., 2016. A preliminary nationwide survey of the presence of emerging contaminants in drinking and source waters in Brazil. https://doi.org/10.1016/j.scitotenv.2016.07.210.

121 García R.A, et al., 2020. Determination of organochlorine and organophosphorus residues in surface waters from the coffee zone in Quindío, Colombia. https://doi.org/10.1080/03601234.2020.1802185

122 Oltramare, C., et al., 2023. Pesticides monitoring in surface water of a subsistence agricultural catchment in Uganda using passive samplers. https://doi.org/10.1007/s11356-022-22717-2

123 Toan, P.V., et al., 2013. Pesticide management and their residues in sediments and surface and drinking water in the Mekong Delta, Vietnam. https://doi.org/10.1016/j.scitotenv.2013.02.026.

124 de Queiroz, V.T. et al., 2018. Environmental risk assessment for sustainable pesticide use in coffee production. https://doi.org/10.1016/j.jconhyd.2018.08.008.

125 dos Santos, G.M.A.D.A., et al., 2022. Potential Risk of Agrochemical Leaching in Areas of Edaphoclimatic Suitability for Coffee Cultivation. https://doi.org/10.3390/w14091515

126 Negatu B., et al., 2021. Environmental and Health Risks of Pesticide Use in Ethiopia. https://doi.org/10.5696/2156-9614-11.30.210601.

127 Aguiar, J., et al., 2016. Microencapsulation of natural antioxidants for food application – The specific case of coffee antioxidants – A review. https://doi.org/10.1016/j.tifs.2016.10.012

128 Köninger, J., et al., 2026. Pesticide residues alter taxonomic and functional biodiversity in soils. https://doi.org/10.1038/s41586-025-09991-z

129 Alengebawy, A., et al., 2021. Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. https://doi.org/10.3390/toxics9030042

130 Swaine, M., et al., 2025. Impact of pesticides on soil health: identification of key soil microbial indicators for ecotoxicological assessment strategies through meta-analysis. https://doi.org/10.1093/femsec/fiaf052

131 Gunstone T., et al., 2021. Pesticides and Soil Invertebrates: A Hazard Assessment. https://doi.org/10.3389/fenvs.2021.643847

132 Nguyet, N.T.M., et al., 2023. Occurrence and distribution of pesticide residues in coffee-growing soil at Lam Ha district, Lam Dong province. https://www.semanticscholar.org/paper/Occurrence-and-distribution-of-pesticide-residues-Dang-Vu/a37fbc2f973e6db0de3e9df3ea752da159acf0c2

133 García-Pérez, J.A., et al., 2014. Earthworm communities and soil properties in shaded coffee plantations with and without application of glyphosate. https://doi.org/10.1016/j.apsoil.2013.09.006.

134 Silva V. et al., 2018. Pesticide residues in European agricultural soils – A hidden reality unfolded. https://doi.org/10.1016/j.scitotenv.2018.10.441

135 Yusufoğlu, B., et al., 2024. Bio-recycling of spent coffee grounds: Recent advances and potential applications. https://doi.org/10.1016/j.cofs.2023.101111

136 Circular Innovation Hub, 2023. The Circular Economy in Coffee Culture. https://www.circularinnovationlab.com/post/the-circular-economy-in-coffee-culture

137 Classen, A., et al., 2014. Complementary ecosystem services provided by pest predators and pollinators increase quantity and quality of coffee yields. https://doi.org/10.1098/rspb.2013.3148

138 Ricketts, T.H., et al., 2004. Economic value of tropical forest to coffee production. https://doi.org/10.1073/pnas.0405147101.

139 Ramos J.D., et al., 2026. Stingless bees in coffee: yield gains and assessing neonicotinoid impact. https://doi.org/10.3389/frbee.2025.1644205

140 Jilo, R., et al., 2025. Honeybee pollination and its role in fruit set, seed yield, and quality of Coffea arabica. https://doi.org/10.1007/s42690-025-01637-x

141 Aristizábal, N., et al., 2025. Bee pollination affects coffee quality, yield, and trade-offs within them. https://doi.org/10.1016/j.agee.2024.109258

142 Escobar-Ramírez, S., et al., 2019. Biological control of the coffee berry borer: Main natural enemies, control success, and landscape influence. https://doi.org/10.1016/j.biocontrol.2019.05.011

143 Martínez-Salinas, A., et al., 2022. Interacting pest control and pollination services in coffee systems. https://doi.org/10.1073/pnas.2119959119

144 Hallmann, C.A., 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. https://doi.org/10.1371/journal.pone.0185809

145 Blacquière T., et al., 2012. Neonicotinoids in bees: a review on concentrations, side-effects and risk assessment. https://doi.org/10.1007/s10646-012-0863-x

146 Krischik, V., et al., 2015. Soil-Applied Imidacloprid Translocates to Ornamental Flowers and Reduces Survival of Adult Coleomegilla maculata, Harmonia axyridis, and Hippodamia convergens Lady Beetles, and Larval Danaus plexippus and Vanessa cardui Butterflies. https://doi.org/10.1371/journal.pone.0119133

147 Conceição de Assis, J., et al., 2022. Sublethal doses of imidacloprid and pyraclostrobin impair fat body of solitary bee Tetrapedia diversipes (Klug, 1810). https://doi.org/10.1016/j.envpol.2022.119140.

148 Manson, S., et al., 2022. Flower Visitation Time and Number of Visitor Species Are Reduced by the Use of Agrochemicals in Coffee Home Gardens. https://doi.org/10.3390/agronomy12020509

149 Gallai, N., et al., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. https://doi.org/10.1016/j.ecolecon.2008.06.014

150 Méndez, V. E., et al., 2010. Agrobiodiversity and Shade Coffee Smallholder Livelihoods: A Review and Synthesis of Ten Years of Research in Central America. https://doi.org/10.1080/00330124.2010.483638

151 Anderzén, J., et al., 2020. Effects of on-farm diversification strategies on smallholder coffee farmer food security and income sufficiency in Chiapas, Mexico. https://doi.org/10.1016/j.jrurstud.2020.04.001.

152 Lopez-Ridaura, S., et al., 2019. Food security and agriculture in the Western Highlands of Guatemala. https://doi.org/10.1007/s12571-019-00940-z

153 Business Focus, 2022. Kenya Risks Losing Shs48.8bn Japan Coffee Market Over Use Of Non-Recommended Pesticides. https://businessfocus.co.ug/kenya-risks-losing-shs48-8bn-japan-coffee-market-over-use-of-non-recommended-pesticides/

154 Route to Food, 2025. Pesticide Withdrawal is a step forward, but implementation gaps remain. https://routetofood.org/blog/pesticide_withdrawal_ban_kenya/

155 Taipei Times, 2020. Food items stopped at border for high pesticide levels. https://www.taipeitimes.com/News/taiwan/archives/2020/12/23/2003749232

156 CIRAD, n.d. CIRAD, agricultural research for the sustainable development of tropical and Mediterranean regions. https://www.cirad.fr/en

157 Ypak, 2025. The "hidden costs" of coffee production. https://www.ypak-packaging.com/news/the-hidden-costs-of-coffee-production/

158 Michalke, A., et al., 2025. True Cost Accounting: Assessing Environmental and Social Damages of Production (1st ed.). https://doi.org/10.4324/9781003345190

159 True Cost Alliance, 2025. Die ökologischen und sozialen Externalitäten von Kaffee am Beispiel von Uganda und Honduras. https://truecostalliance.eu/die-oekologischen-und-sozialen-externalitaetenvon-kaffee-am-beispiel-von-uganda-und-honduras

160 Ecofin Agency, 2025. Ethiopia Projects Record 694,000-Ton Coffee Harvest in 2025-26. https://www.ecofinagency.com/news-agriculture/0506-47158-ethiopia-projects-record-694-000-ton-coffee-harvest-in-2025-26

161 UN, 2011. Guiding Principles on Business and Human Rights. https://www.ohchr.org/sites/default/files/documents/publications/guidingprinciplesbusinesshr_en.pdf

162 Office of the United Nations High Commissioner for Human Rights (OHCHR), n.d. About toxics and human rights. https://www.ohchr.org/en/special-procedures/sr-toxics-and-human-rights/about-toxics-and-human-rights (accessed Nov 2025)

163 UN, 2010. The human right to water and sanitation. https://digitallibrary.un.org/record/687002?v=pdf

164 UN, 2019. Principles on human rights and the protection of workers from exposure to toxic substances. https://docs.un.org/en/A/HRC/42/41

165 UN, 2019. The human right to a clean, healthy and sustainable environment. https://digitallibrary.un.org/record/3945636?v=pdf

166 Convention on Biological Diversity, n.d. Target 7. Reduce Pollution to Levels That Are Not Harmful to Biodiversity. https://www.cbd.int/gbf/targets/7 (accessed Nov 2025)

167 UN, 1989. Convention on the Rights of the Child. https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-rights-child

168 Global Coffee Platform, n.d. GCP RegenCoffee Guidance. https://www.globalcoffeeplatform.org/our-work/tools/regencoffee/ (accessed Jan 2026)

169 Le Q.V., et al., 2021. A Study of Regenerative Farming Practices and Sustainable Coffee of Ethnic Minorities Farmers in the Central Highlands of Vietnam. https://doi.org/10.3389/fsufs.2021.712733

170 World Coffee Research, 2018. To fertilize, or to spray?: The link between nutrition and leaf rust. https://worldcoffeeresearch.org/news/2018/to-fertilize-or-to-spray-the-link-between-nutrition-and-leaf-rust

171 Polakiewicz, K., 2021. Integrated soil fertility management interactions with Hemileia vastatrix: combating the coffee leaf rust crisis. https://iad.ucdavis.edu/sites/g/files/dgvnsk4906/files/inline-files/Kate_Polakiewicz2017.pdf

172 World Coffee Research, 2018. Biological control of coffee leaf rust. https://worldcoffeeresearch.org/news/2018/biological-control-of-coffee-leaf-rust

173 Knowlton, S., 2026. Coffee Leaf Rust and the Limits of Genetic Resistance. https://samknowlton.substack.com/p/coffee-leaf-rust-and-the-limits-of

174 Rainforest Alliance, 2023. Regenerative Coffee: A Farmer's 40-year Journey in Vietnam. https://www.rainforest-alliance.org/in-the-field/regenerative-coffee-a-farmers-40-year-journey-in-vietnam/

175 Coffee Intelligence, 2025. Regenerative agriculture: Moving beyond talk to action. https://intelligence.coffee/2025/02/regenerative-agriculture-beyond-talk/

176 Solidaridad, 2026. Agroforestry and carbon: strengthening coffee farms and rural economies. https://www.solidaridadnetwork.org/news/agroforestry-and-carbon-strengthening-coffee-farms-and-rural-economies/

177 Nestlé, n.d. Regenerative Agriculture. https://www.nestle.com/sustainability/nature-environment/regenerative-agriculture (accessed Jan 2026)

178 Sustainability Directory, 2025. Scaling Carbon Markets for Smallholder Farmers. https://prism.sustainability-directory.com/scenario/scaling-carbon-markets-for-smallholder-farmers/

179 Valade, A., 2022. How the coffee industry is dealing with climate change. https://www.climate-chance.org/wp-content/uploads/2023/03/bs2022_en_utcatf_tendance_cafe.pdf

180 Moat, J., et al., 2017. Coffee Farming and Climate Change in Ethiopia. Impacts, Forecasts, Resilience and Opportunities. https://www.kew.org/sites/default/files/2019-01/Coffee%20Farming%20and%20Climate%20Change%20in%20Ethiopia.pdf

181 van Rikxoort, H., et al., 2014. Carbon footprints and carbon stocks reveal climate-friendly coffee production. https://doi.org/10.1007/s13593-014-0223-8

182 International Trade Centre, 2010. Climate Change and the Coffee Industry. https://www.intracen.org/file/climatecoffeech13msid322010ff1pdf

183 Tscharntke et al., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. https://doi.org/10.1016/j.biocon.2012.01.068

184 Duangsodsri, T., et al., 2019. A global approach to decipher molecular basis of coffee tree adaptation to shade. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20193464657

185 Jaramillo J. et al., 2009. Thermal Tolerance of the Coffee Berry Borer Hypothenemus hampei: Predictions of Climate Change Impact on a Tropical Insect Pest. https://doi.org/10.1371/journal.pone.0006487

186 Monge, O. et al., 2022. Unshaded coffee imposes a heavier load on thermoregulation than shaded coffee for birds in a tropical mountainous region. https://doi.org/10.1016/j.gecco.2022.e02117

187 Jaramillo, J., et al., 2011. Some Like It Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (Hypothenemus hampei) and Coffee Production in East Africa. https://doi.org/10.1371/journal.pone.0024528

188 Venzon, M., 2021. Agro-Ecological Management of Coffee Pests in Brazil. https://doi.org/10.3389/fsufs.2021.721117

189 Ferreira, D.F., et al., 2023. Not all farms are created equal: shady African cocoa farms promote a richer bat fauna. https://doi.org/10.1016/j.biocon.2023.110191

190 Manson, S. et al., 2024. Effect of shade on biodiversity within coffee farms: A meta-analysis. https://doi.org/10.1016/j.scitotenv.2024.169882

191 Moreaux, C., et al., 2022. The value of biotic pollination and dense forest for fruit set of Arabica coffee: A global assessment. https://doi.org/10.1016/j.agee.2021.107680

192 Venzon, M., et al., 2006. Suitability of leguminous cover crop pollens as food source for the green lacewing Chrysoperla externa (Hagen) (Neuroptera: Chrysopidae). https://pubmed.ncbi.nlm.nih.gov/18575698/

193 Rosado, M. C., et al., 2021. Cover crop intercropping increases biological control in coffee crops. https://doi.org/10.1016/j.biocontrol.2021.104675

194 Camila Hohlenwerger, et al., 2022. Forest cover and proximity to forest affect predation by natural enemies in pasture and coffee plantations differently. https://doi.org/10.1016/j.agee.2022.107958.

195 Koutouleas, A., et al., 2022. Shade effects on yield across different Coffea arabica cultivars - how much is too much? A meta-analysis. https://doi.org/10.1007/s13593-022-00788-2

196 Piato, K., et al., 2020. Effects of shade trees on robusta coffee growth, yield and quality. A meta analysis. https://doi.org/10.1007/s13593-020-00642-3

197 INKOTA, 2023. Green synthetic fertilisers: solutions for soil, climate, water and communities or dead end? https://www.inkota.de/sites/default/files/2024-12/greenfertilzer_discussionpaper_Final_%20ENG.pdf

198 Byrareddy, V., et al., 2019. Sustainable Production of Robusta Coffee under a Changing Climate: A 10-Year Monitoring of Fertilizer Management in Coffee Farms in Vietnam and Indonesia. https://doi.org/10.3390/agronomy9090499

199 Sadeghian-Khalajabadi, S. et al., 2022. Determinants of nitrogen use efficiency in coffee crops. A review. https://doi.org/10.22267/rcia.223902.183

200 Global Coffee Report, 2023. Experts examine rising fertiliser prices. https://www.gcrmag.com/experts-examine-rising-fertiliser-prices/

201 Pastorelli, S., et al., 2025. Sowing Fossil Dependence: How EU Farm Policy Turned Its Back on Sustainability. https://www.ciel.org/sowing-fossil-dependence-eu-agriculture/

202 Teixeira, H.M., et al., 2021. Impact of agroecological management on plant diversity and soil-based ecosystem services in pasture and coffee systems in the Atlantic forest of Brazil. https://doi.org/10.1016/j.agee.2020.107171

203 High Level Panel of Experts on Food Security and Nutrition (HLPE), 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. https://www.csm4cfs.org/summary-recommendations-hlpe-report-agroecology-innovations/

204 Wienhold, K & Goulao, L.F., 2023. The Embedded Agroecology of Coffee Agroforestry: A Contextualized Review of Smallholder Farmers' Adoption and Resistance. https://doi.org/10.3390/su15086827

205 FiBL-IFOAM, 2019. The World of Organic Agriculture. https://www.fibl.org/fileadmin/documents/shop/2020-organic-world-2019.pdf

206 'State of Sustainable Markets, 2019. Statistics and Emerging Trends. https://www.intracen.org/resources/publications/the-state-of-sustainable-markets-2019-statistics-and-emerging-trends

207 Daviron, B. & Ponte, S., 2005. The Coffee Paradox: Global markets, commodity trade and the elusive promise of development. https://doi.org/10.5040/9781350222984

208 Koutouleas, A. et al., 2022. Alternative plant protection strategies for tomorrow's coffee. https://doi.org/10.1111/ppa.13676

209 Johnson, M.A. et al., 2020. Coffee Berry Borer (Hypothenemus hampei), a Global Pest of Coffee: Perspectives from Historical and Recent Invasions, and Future Priorities. https://doi.org/10.3390/insects11120882

210 Lee D., et al., 2023. Economic Benefits from Managing Coffee Berry Borer (Hypothenemus hampei) in Hawaii. https://doi.org/10.3390/insects14040350.

211 Góngora, C.E., Gil, Z.N., Constantino, L.M. & Benavides, P., 2023. Sustainable Strategies for the Control of Pests in Coffee Crops. https://doi.org/10.3390/agronomy13122940

212 Perfect Daily Grind, 2019. A Guide to Common Coffee Pests & Diseases. https://perfectdailygrind.com/2019/01/a-guide-to-common-coffee-pests-diseases/

213 Aristizábal L.F., et al., 2016. Integrated Pest Management of Coffee Berry Borer: Strategies from Latin America that Could Be Useful for Coffee Farmers in Hawaii. https://doi.org/10.3390/insects7010006

214 Rodríguez, D., et al., 2017. A coffee agroecosystem model: III. Parasitoids of the coffee berry borer (Hypothenemus hampei). https://doi.org/10.1016/j.ecolmodel.2017.08.008

215 Dantas, J., et al., 2021. A Comprehensive Review of the Coffee Leaf Miner Leucoptera coffeella (Lepidoptera: Lyonetiidae)-A Major Pest for the Coffee Crop in Brazil and Others Neotropical Countries. https://doi.org/10.3390/insects12121130

216 Pereira, E.J.G., et al., 2021. Seasonal mortality factors of the coffee leafminer, Leucoptera coffeella. https://doi.org/10.1017/S0007485307005202

217 da Silva Bordinhon, W.B., et al., 2026. Botanical insecticides for the sustainable management of Leucoptera coffeella in coffee crops: Impacts on immature and adult stages under laboratory conditions. https://doi.org/10.1016/j.cropro.2025.107474

218 Righi, C.A., et al., 2013. Influence of rubber trees on leaf-miner damage to coffee plants in an agroforestry system. https://doi.org/10.1007/s10457-013-9642-9

219 Perfecto, I. & Vandermeer, J., 2020. The assembly and importance of a novel ecosystem: The ant community of coffee farms in Puerto Rico. https://doi.org/10.1002/ece3.6785. PMID: 33304482

220 Venzon, M., et al., 2005. The potential of NeemAzal or the control of coffee leaf pests. https://doi.org/10.1016/j.cropro.2004.07.008

221 Rossi, G.D., et al., 2010. Coffee leaf miner trypsin inhibition with castor bean leaf extracts mediated by a non-protein agent. https://www.researchgate.net/publication/262595571_Coffee_leaf_miner_trypsin_inhibition_with_castor_bean_leaf_extracts_mediated_by_a_non-protein_agent

222 Alves, D.S., et al., 2011. Coffea racemosa extract as an alternative for the control of coffee leafminer. https://www.researchgate.net/publication/295666358_Coffea_racemosa_extract_as_an_alternative_for_the_control_of_coffee_leaf_miner

223 World Coffee Research, 2025. Coffee leaf rust knows no borders—neither does coffee science. https://worldcoffeeresearch.org/es/news/2025/coffee-leaf-rust-knows-no-borders-neither-does-coffee-science

224 Mariño, Y.A., et al., 2026. Dynamics of coffee leaf rust (Hemileia vastatrix) in Puerto Rico: associations with season, cultivar, altitude, and hyperparasites. https://doi.org/10.3389/fpls.2026.1768440

225 Plant-Microbe-Insect Lab, n.d. Coffee Leaf Rust. https://www.plantmicrobeinsect.com/wp-content/uploads/2018/08/Coffee_Rust_English_final.pdf

226 Rainforest Alliance, 2025. Application of Triazoles for Control of Coffee Leaf Rust (Hemileia Vastatrix). https://knowledge.rainforest-alliance.org/docs/application-of-triazoles-for-control-of-coffee-leaf-rust-hemileia-vastatrix

227 Rodriguez-Gallo, Y., et al., 2024. Coffee leaf rust and berry borer management in agroforestry systems: A systematic literature review. https://doi.org/10.1016/j.atech.2024.100656.

228 Gómez-de la Cruz, I., et al., 2024. Biocontrol of Hemileia vastatrix, the Causal Agent of Coffee Leaf Rust, by Paenibacillus sp. NMA1017. https://doi.org/10.1094/PDIS-01-24-0015-RE

229 Das, D.K., et al., 2024. Efficacy of biological agent Lecanicillium lecanii for the management of coffee leaf rust in India. https://doi.org/10.1007/s42360-024-00763-9

230 Motisi, N., et al., 2019. Coffee tree architecture and its interactions with microclimates drive the dynamics of coffee berry disease in coffee trees. https://doi.org/10.1038/s41598-019-38775-5

231 Ayalew, B., et al., 2022. The impact of shade tree species identity on coffee pests and diseases. https://doi.org/10.1016/j.agee.2022.108152

232 Khan S., et al., 2023. Streptomyces as a promising biological control agents for plant pathogens. https://doi.org/10.3389/fmicb.2023.1285543

233 Bryan, G., et al., 2012. An evaluation of Beauveria bassiana as a natural control agent of the coffee berry borer, Hypothenemus hampei (Ferrari), in Jamaica. https://www.cabi.org/wp-content/uploads/Bryan-and-Robinson-2012-Beauveria-against-coffee-berry-borer.pdf

234 Waller, J.M. & Masaba, D.M., 2006. The microflora of coffee surfaces and relationships to coffee berry disease. https://doi.org/10.1080/09670870600568311

235 Global Coffee Platform, 2023. GCP Collective Action Initiative in Vietnam sees a significant reduction in the glyphosate residue levels in green coffee. https://www.globalcoffeeplatform.org/latest/2023/gcp-collective-action-initiative-in-vietnam-sees-a-significant-reduction-in-the-glyphosate-residue-levels-in-green-coffee/

236 FAO, n.d. Reducing the Global Risk from Highly Hazardous Pesticides. https://www.fao.org/pest-and-pesticide-management/pesticide-risk-reduction/reducing-global-risk-from-hhp/en/

237 United Nations Environment Assembly, 2024. Resolution adopted by the United Nations Environment Assembly on 1 March 2024: 6/11. Highly hazardous pesticides. https://documents.un.org/doc/undoc/gen/k24/008/43/pdf/k2400843.pdf