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Pesticide Resistance: Hidden Battle in our Fields

Anirban Barik, Dipsikha Mondal, Pringal Upadhyay, Aditi Kundu and *Supradip Saha
Division of Agricultural Chemicals, ICAR-Indian Agricultural Research Institute, New Delhi- 110012, India
*Corresponding Author's email: official.supradip@gmail.com

In protecting crops, pesticides have played a vital role. It not only protect crops from insects, diseases and weeds, but also help farmers to secure food production. However, non-judicious and indiscriminate use has created the problem of pesticide resistance. Like antibiotics in human losing their efficacy against resistant microorganisms, pesticides slowly become less effective as pests and pathogens adapt to them. In a heterogeneous population, few surviving individuals can eventually develop into a resistant population, which is difficult to control. This hidden battle is called pesticide resistance and it threatens crop productivity and increases pesticide use. Thus, enhancement of crop production costs, and negative impact on environmental and food-safety occurs. Pesticide resistance is mainly attributed to repeated application of the same pesticide or mode of action, overdose of a pesticide, poor application practices and inadequate resistance-management strategies. The problem can be managed by practicing integrated pest management, rotation of pesticides with different modes of action, use of biological and cultural control measures. This article describes the science behind pesticide resistance, its causes and consequences. It also deals with problems and practical approaches that farmers, scientists and policymakers can adopt to win this hidden battle in our fields.

Keywords: Pesticide resistance; pesticide resistance management; integrated pest management; mode of action; resistance development

Introduction:

As a plant protection measure, farmers spray pesticides to protect their crops from insects, diseases, and weeds. Most of the time, these pesticides work well when applied at recommended dose but after using the same product again and again, something unexpected can happen, the pests stop responding. The same pesticide that once gave excellent control no longer works as it used to. This is not because the pesticide has become weak, it is because the pests have changed.

Pesticide resistance develops slowly over time. In every pest population, a few individuals naturally possess traits that help them survive a pesticide spray. These survivors reproduce and pass those traits to the next generation. As this process continues, the resistant individuals become more common, making the pesticide less effective. What begins as a small problem in one field can eventually spread across entire farming regions.

Today, pesticide resistance is becoming a serious challenge for agriculture worldwide. The Food and Agriculture Organization (FAO) estimates that pests and plant diseases destroy 20–40% of global crop production each year, causing economic losses of more than USD 220 billion (FAO, 2021). At the same time, more weed, insect, and fungal species are developing resistance to pesticides, while the discovery of new pesticides with different modes of action has slowed down. The impact goes far beyond reduced crop yields. Farmers may need to spray more often or use higher doses, increasing production costs and putting extra pressure on the environment. Beneficial insects, soil health, and water quality can also be affected. If resistance is not managed wisely, it could threaten both food security and sustainable agriculture.

The good news is that resistance can be slowed. By using pesticides responsibly, rotating different modes of action, adopting Integrated Pest Management (IPM), and combining chemical control with biological and cultural practices, farmers can protect the effectiveness of existing pesticides for many years to come. Understanding how resistance develops is the first step towards managing it successfully.

Development of resistance

Pesticide resistance is a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species.

Diagram: Resistance development in a pest population, step by step.

Within any pest population, a small proportion of individuals possess heritable genetic variations that confer reduced susceptibility to a specific pesticide. Upon application of pesticides, susceptible individuals are eliminated, while those with resistance-associated traits survive. These survivors reproduce and transmit the resistance alleles to their offspring. Through successive generations and continued selection pressure, the frequency of resistance increases, ultimately leading to a population predominantly composed of resistant individuals and a consequent decline in pesticide efficacy.

There are different ways pests fight back, scientists usually sort the tricks pests use into three groups.

Type of resistance	What happens	Simple explanation
Target-site resistance	The part of the pest's body the pesticide attacks changes shape.	Like changing the lock so the key no longer fits.
Metabolic resistance	The pest produces enzymes that break the pesticide down before it can do harm.	Like having a powerful stomach that digests poison safely.
Behavioral resistance	The pest changes its behavior to avoid contact with the chemical.	Like learning to walk around a trap instead of stepping into it.

Why this matters beyond the farm

Pesticide resistance is often framed as a farmer's problem, but its consequences ripple far past the field edge. When a chemical loses its punch, the first response is almost always more of it: higher doses, shorter spray intervals, and tank mixes that combine several active ingredients at once. Each of these adjustments raises production costs, and those costs eventually surface in the price of food. The environmental bill grows in parallel. Heavier and more frequent applications mean greater pesticide loading in soil, surface water, and groundwater, along with increased drift into hedgerows, wetlands, and neighboring habitats. Pollinators, soil microbes, and the natural enemies that keep secondary pests in check are also affected, weakening the very ecological services that agriculture depends on. Once these communities collapse, pest outbreaks tend to become more frequent, not less, locking farmers into an even tighter chemical dependency. There is a public health dimension as well. Farm workers handling concentrated formulations face higher exposure, and rural communities living near intensively sprayed land carry a measurable share of that burden. When older, more hazardous chemistries are pulled back into use because newer ones have failed, these risks rise sharply. Resistance, in other words, is not simply an agronomic inconvenience; it is an economic, ecological, and social cost that is paid well beyond the boundary of any single farm.

A real example: Bt cotton in India

One of the clearest cautionary tales comes from India's cotton fields. In the early 2000s, farmers began planting Bt cotton, a genetically modified variety that produces its own insecticide against the pink bollworm. For about a decade it worked beautifully and farmers enjoyed the benefit. Then, by the mid-2010s, pink bollworms in several Indian states started shrugging off Bt cotton. The reason was simple, and it was predicted years. Many farmers planted Bt cotton year after year on the same land, often without the recommended "refuge" plots of non-Bt cotton that allow some sensitive insects to survive and dilute the resistant ones. Even the cleverest tool fails if you use it the same way every time.

What actually works

The single most important idea in resistance management is this: stop hitting pests with the same chemical, the same way, over and over. Almost everything else flows from that. This is the core of Integrated Pest Management (IPM), which combines chemical, biological, and cultural methods so that no single tool has to carry the whole burden.

Table: Common resistant management strategies

Strategy	What it means	Why it helps
Rotate pesticides	Use chemical with different modes of action in turn.	Pests can't adapt a moving target.
Use biological controls	Bring in natural enemies like ladybugs, parasitic wasps, or fungi.	Cuts dependence on chemicals.
Rotate crops	Change what you plant each season.	Breaks pest life cycle.
Use the right dose	Avoid both under- and over-spraying.	Lower doses speed up resistance; higher ones waste money and harm the environment.
Monitor pest populations	Scout fields and track which pests are present and at what density.	Let farmers act early and only when needed.
Plant resistant varieties	Grow crop varieties bred to withstand pests or diseases.	Reduce overall pesticide need.

Distributing responsibility across the system

Effective resistance management involves multi-stakeholder, requiring coordinated action across operational, scientific, and regulatory levels. At the operational level, growers shape selection pressure in the field through rotation of active ingredients across distinct modes of action, structured refugia, threshold-based spraying, and adherence to label-recommended doses. Because resistance evolves locally, on-farm decisions exert the strongest influence on its trajectory.

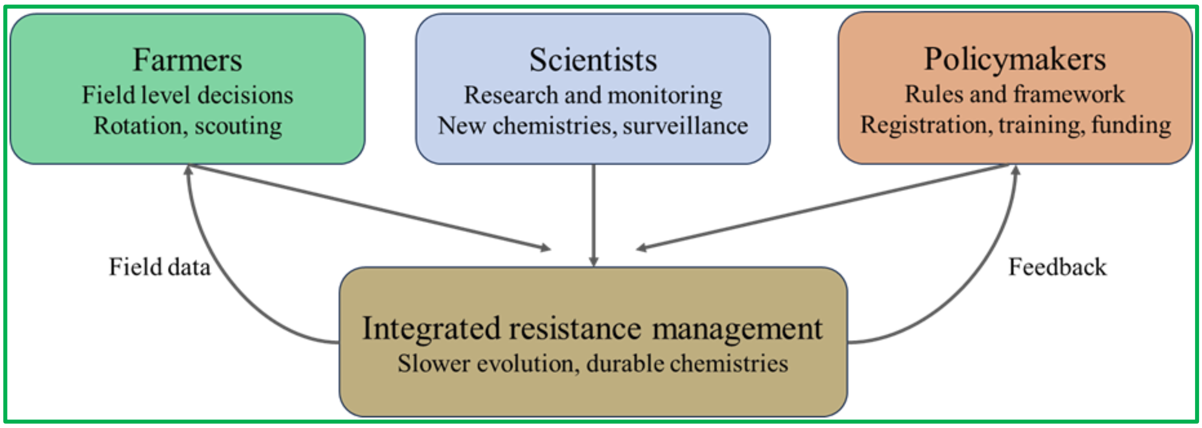

Diagram: Stakeholders in integrated resistance management.

The research community underpins these decisions by characterizing resistance mechanisms, developing novel chemistries and resistant crop traits, and maintaining surveillance networks that track resistance alleles. Bioassays and population-genetic monitoring provide the early-warning signals that make field interventions anticipatory rather than reactive. Regulatory institutions set the framework through product registration, label restrictions, mandatory management plans for high-risk actives, applicator certification, and extension services that translate research into practice. Australia's coordinated programs for cotton and cereals are widely cited as a successful model, having demonstrably delayed resistance through enforceable, science-based protocols. Resistance management therefore works best when the field, the laboratory, and the regulatory framework operate as an integrated feedback system rather than as independent actors.

Future perspectives

Resistance won't disappear. As long as we use pesticides, pests will keep evolving around them. That is just how biology works. But "won't disappear" is not the same as "can't be managed." The next decade will bring more precision tools: drones that find pest hotspots before damage is visible, AI systems that match treatments to local conditions in near real time, and gene-based approaches that can target one species without harming others. Combined with the older wisdom of crop rotation and natural enemies, these give farmers more options than they have ever had. Resistance management is not glamorous work. It is mostly small, careful decisions made one field at a time. But those decisions decide whether the chemicals we depend on today will still be useful in next twenty years, and whether the soil and water around our farms will still be in decent shape when we get there.

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