E-ISSN: 2582-9467
Popular Article
Raj et al. (2026)

Pesticide Residues in Indian Fruits and Vegetables: Status, Health Risks and the Way Forward

Rishabh Raj[1], Krishna[1], Jitesh Singh Bisht[2]*, Ashutosh[2] and Manoj Joshi[2]

[1]Department of Horticulture, College of Agriculture, GBPUA&T, Pantnagar, Uttarakhand-263145
[2]Department of Entomology, College of Agriculture, GBPUA&T, Pantnagar, Uttarakhand-263145

Corresponding Author
Jitesh Singh Bisht
Email: jiteshento@gmail.com

OPEN ACCESS

Keywords

Pesticide residues, MRL, FSSAI, Food safety, Horticulture, IPM, BharatGAP, Export, PHI, India.

How to cite this article:

Raj, R., Krishna., Bisht, J. S., Ashutosh., and Joshi, M. 2026. Pesticide Residues in Indian Fruits and Vegetables: Status, Health Risks and the Way Forward. *Vigyan Varta* 7 (09): 121-129.

ABSTRACT

India is among the world's largest producers and consumers of fruits and vegetables, yet pesticide residue contamination in these commodities remains a significant and under addressed challenge to food safety, public health and export competitiveness. This article examines the current status of pesticide residues in Indian horticultural produce, drawing on national food safety surveillance data, export rejection records and published residue monitoring studies. High-risk commodities including okra, brinjal, chilli, tomato, grapes and leafy vegetables consistently show maximum residue limit (MRL) violations in monitoring surveys, with organophosphates, pyrethroids and carbamates among the most frequently detected classes above permissible levels. The article discusses the human health implications of acute and chronic pesticide exposure, with particular concern for children, farm workers and populations in high-intensity pesticide-use regions. It evaluates the regulatory framework governing pesticide use and residue standards in India, encompassing the roles of the Food Safety and Standards Authority of India (FSSAI), the Central Insecticides Board and Registration Committee (CIB & RC) and the Agricultural and Processed Food Products Export Development Authority (APEDA). Key drivers of persistent MRL violations, including pre-harvest interval (PHI) non-compliance, pesticide overdosing, extension failures and market incentives for cosmetically perfect produce are analysed. The article further outlines evidence-based solutions including integrated pest management (IPM), Good Horticulture Practices (GHP), Bharat GAP certification, residue testing at packhouse level and targeted farmer education. The article concludes that reducing pesticide residues in Indian produce demands a coordinated response from farmers, regulators, markets and consumers, and that the tools to achieve safe, residue-compliant horticulture are already available what is needed is the institutional will and financial commitment to deploy them at scale.

INTRODUCTION:

India is the second-largest producer of fruits and vegetables in the world, contributing over 342 million tonnes of horticultural produce annually from approximately 28.7 million hectares (NHB, 2023). This immense productive capacity supplies not only the domestic population of 1.4 billion people but also generates horticultural exports valued at over USD 4.5 billion per annum to markets in Europe, the Gulf, Southeast Asia and beyond. Yet running alongside this scale of production is a challenge that receives far less public attention than it deserves: the contamination of fruits and vegetables with pesticide residues that exceed the limits considered safe for human consumption.

India uses approximately 60,000 to 70,000 metric tonnes of pesticides annually, a figure that places it among the highest consumers of pesticides in Asia (Khandare *et al*., 2022). Horticultural crops including fruits, vegetables, spices and plantation crops account for a disproportionately large share of this usage relative to their cultivated area, owing to the high commercial value of produce, intense pest and disease pressures and the cosmetic quality standards demanded by organised retail and export markets. The result is a food system in which pesticide residues above maximum residue limits (MRLs) i.e., the legal upper limits for pesticide concentrations in food are detected with troubling regularity in monitoring surveys across the country.

A maximum residue limit is defined as the highest concentration of a pesticide residue, expressed in milligrams per kilogram (mg/kg), that is legally permitted in or on a food commodity when the pesticide is applied correctly in accordance with good agricultural practice (Codex Alimentarius, 2023). MRLs are set by regulatory bodies including the Codex Alimentarius Commission internationally, and by FSSAI in India, based on toxicological studies and dietary exposure assessments. The pre-harvest interval (PHI) — the minimum number of days that must elapse between the last pesticide application and harvest — is a critical management tool for ensuring residues fall within MRL at the time of consumption. Non-compliance with PHI is among the most common causes of MRL violations in Indian horticulture (Sharma *et al*., 2022).

The consequences of this residue problem are threefold. At the level of public health, chronic dietary exposure to sub-lethal concentrations of pesticides has been linked to a range of adverse outcomes including endocrine disruption, neurodevelopmental effects in children, carcinogenicity and immunotoxicity. At the level of trade, pesticide residue violations are the leading cause of rejection of Indian horticultural exports by the European Union under the EU Rapid Alert System for Food and Feed (RASFF), causing significant economic losses to farmers and exporters (Singh *et al*., 2023). And at the level of domestic food safety governance, the fragmented, under-resourced and inconsistently enforced regulatory framework means that the vast majority of produce consumed within India is never tested for residues at all. This article examines the current residue situation in Indian horticulture, analyses its causes and consequences, reviews the regulatory and institutional responses and proposes practical, evidence-based solutions for producers, policymakers and consumers alike.

Pesticide Use in Indian Horticulture: Context and Scale

To understand the residue problem, it is first necessary to understand why pesticides are used so intensively in Indian horticulture. Horticultural crops are inherently high-value and high-risk. A single incursion of fruit fly in a mango orchard, or a late blight outbreak in a potato field, can destroy an entire season's income. In this context, pesticide use is not irrational — it is a rational response to genuine production risk in a system that offers farmers few alternative tools and even fewer safety nets (Khandare *et al*., 2022).

The pesticide classes most commonly used in Indian horticulture include organophosphates (chlorpyrifos, profenophos, dimethoate), synthetic pyrethroids (cypermethrin, lambda-cyhalothrin), carbamates (carbendazim, mancozeb), neonicotinoids (imidacloprid, thiamethoxam) and triazole fungicides (propiconazole, tebuconazole). Many of these molecules are broad-spectrum, contact or systemic in action and have varying persistence in plant tissues and on fruit surfaces. Their residue behaviour — how quickly they degrade, how deeply they penetrate the fruit tissue and how much washing reduces their concentration — differs significantly across compounds and commodities (Sharma *et al*., 2022).

Several factors drive overuse. Pesticide retailers, who often serve as the primary source of crop protection advice for smallholder farmers in the absence of functional extension services, have a commercial incentive to recommend higher doses and more frequent applications than labels prescribe. The cosmetic standards of modern supply chains — supermarkets, export packhouses and urban wholesale markets — demand blemish-free produce that incentivises prophylactic spraying irrespective of actual pest pressure. Calendar-based spraying, in which farmers apply pesticides on fixed schedules rather than in response to monitored pest thresholds, is widespread and results in both economically unnecessary applications and elevated residue risk at harvest (Patel *et al*., 2023). Furthermore, the proliferation of counterfeit and substandard pesticides — estimated to account for 20 to 30 per cent of the domestic market — means that farmers may unknowingly use products with unknown or incorrect active ingredient concentrations, further complicating residue prediction and management.

Current Residue Status: What Monitoring Data Reveals

National-level food safety surveillance conducted by FSSAI and commodity-specific monitoring by APEDA provide a sobering picture of pesticide residue status in Indian horticultural produce. FSSAI's annual surveillance data consistently shows that between 20 and 30 per cent of vegetable samples and 10 to 20 per cent of fruit samples carry detectable pesticide residues, with MRL violations recorded in two to five per cent of samples across commodity groups — a figure that, when scaled to the volume of produce consumed nationally, represents a very large number of non-compliant transactions (FSSAI, 2023).

High-risk vegetables in national monitoring surveys include okra (bhindi), brinjal, chilli, tomato, cabbage, cauliflower, spinach and bitter gourd. These commodities are frequently sprayed close to harvest due to their short cropping cycles, rapid market turnover and severe pest pressure from insects such as thrips, whitefly, fruit borers and aphids. Among fruits, grapes, mango, papaya and banana have been flagged in multiple residue surveys. The pesticides most commonly detected above MRL include chlorpyrifos (an organophosphate), profenophos, cypermethrin, monocrotophos (banned in India since 2018 for use on certain crops, yet still detected), carbendazim and dimethoate (Singh *et al*., 2023).

The export dimension of the residue problem is particularly stark. The EU's RASFF database, which records food safety alerts from member states, consistently ranks India among the top five countries generating notifications for pesticide residue violations in fresh fruits and vegetables. Commodities most frequently flagged include curry leaves, okra, bitter gourd, green chillies, grapes and fresh herbs. In a single year, India may generate 50 to 100 RASFF notifications for pesticide residues, each representing a consignment rejection with direct economic consequences for the exporter and indirect reputational consequences for the Indian horticultural sector as a whole (Khandare *et al*., 2022). State-level variation is also significant: studies from Punjab and Haryana vegetable growing districts show systematically higher residue prevalence compared to Himalayan hill states where pesticide use intensity is lower and organic farming more prevalent (Patel *et al*., 2023).

Table 1: Residue Status of Key Horticultural Commodities in India — Monitoring Summary

Commodity	Risk category	Frequently detected molecules above MRL	Primary concern
Okra (bhindi)	Very high	Profenophos, cypermethrin, acephate	Short PHI, multiple sprays near harvest
Brinjal	Very high	Chlorpyrifos, imidacloprid, carbendazim	Shoot & fruit borer control overuse
Chilli (fresh)	High	Monocrotophos*, profenophos, dimethoate	Banned molecules still in use
Tomato	High	Chlorpyrifos, lambda-cyhalothrin, thiamethoxam	PHI non-compliance, rapid turnover
Grapes	High	Profenophos, cypermethrin, mancozeb	EU RASFF rejections, export loss
Cabbage/ Cauliflower	Moderate-High	Chlorpyrifos, quinalphos, deltamethrin	Foliar residue persistence
Mango	Moderate	Carbendazim, dimethoate, thiamethoxam	Post-harvest treatment residues
Curry leaves	Very high	Multiple organophosphates	Highest EU RASFF notifications

**Monocrotophos use on vegetables banned in India since 2018; still detected in surveillance samples.*

Health Implications of Pesticide Residue Exposure

The health risks associated with dietary pesticide residue exposure operate across two distinct time scales and exposure scenarios. Acute toxicity, resulting from a single high-dose exposure, is most relevant to farm workers and family members who may consume produce immediately after spraying or who handle pesticide concentrate without adequate protection. Symptoms of acute organophosphate poisoning — including nausea, excessive salivation, miosis, muscle tremors and in severe cases respiratory failure — are well documented in Indian agricultural communities and represent a significant occupational health burden (Kumar *et al*., 2023).

For consumers, chronic low-level dietary exposure is the primary concern. Organophosphate and carbamate pesticides inhibit acetylcholinesterase, the enzyme essential for normal neurological function. Chronic low-level exposure has been associated with neurodevelopmental deficits in children, including reduced IQ, attention deficits and motor impairment — findings consistent across epidemiological studies from multiple countries (Bhatt *et al*., 2022). Neonicotinoids, widely used in Indian vegetable production, have been implicated in endocrine disruption and immunotoxicity. Organochlorine pesticides, many of which are now banned but persist as environmental contaminants in soils and sediments, bioaccumulate in fatty tissue and have been associated with increased cancer risk, particularly breast and prostate cancers, in chronically exposed populations.

Children are disproportionately vulnerable to pesticide residue exposure because their body weight-adjusted intake of fruits and vegetables is higher than adults, their detoxification enzyme systems are immature and their rapidly developing nervous and endocrine systems are more sensitive to chemical disruption (Bhatt *et al*., 2022). Similarly, pregnant women face specific risks, as organophosphate exposure during gestation has been linked to reduced birth weight and adverse neurodevelopmental outcomes in offspring. Farm worker families in high-pesticide-use districts represent the most acutely exposed population, combining occupational exposure with dietary exposure from home-grown produce and environmental contamination of water and soil.

A commonly asked consumer question is whether washing and peeling adequately remove pesticide residues. The evidence suggests partial but incomplete protection. Water washing typically removes 10 to 75 per cent of surface residues depending on the pesticide's water solubility, the crop surface characteristics and the duration and vigour of washing. Systemic pesticides, which are translocated within plant tissues, are substantially less amenable to surface removal. Peeling of fruits such as apple, mango and citrus removes most surface and sub-surface residues but also removes the nutrient-dense peel. Blanching and cooking reduce thermolabile pesticide residues by 20 to 90 per cent depending on the molecule (Sharma *et al*., 2022). In aggregate, standard consumer practices provide meaningful but not complete mitigation of residue exposure, underscoring the importance of reducing residues at the farm level rather than relying on post-harvest mitigation by consumers.

Table 2: Key Drivers of Pesticide MRL Violations in Indian Horticulture and Their Implications

S. No.	Driver	Description	Implication
1.	**PHI non-compliance**	Pressure from market price volatility and perishability drives early harvesting before residues have degraded to safe levels. Most smallholders do not know the PHI of pesticides they apply.	Direct cause of MRL violations at harvest
2.	**Pesticide overdosing**	"More is better" mindset, poor label literacy and retailer-driven advice result in application at doses 2-5 times higher than recommended.	Elevated initial residue load; longer time to safe level
3.	**Pesticide cocktailing**	Mixing multiple molecules to cover a broader	Synergistic residue effects;

		pest spectrum without understanding combined residue effects or label restrictions.	unpredictable MRL outcomes
4.	**Counterfeit pesticides**	20-30% of market estimated to contain spurious products with unknown active ingredient concentrations.	Uncontrolled residue deposition; farmer deception
5.	**Calendar spraying**	Fixed-schedule applications irrespective of actual pest thresholds result in unnecessary sprays close to harvest.	Avoidable residue loads; increased input cost
6.	**Weak extension services**	Farmer reliance on pesticide retailers for advice; KVKs and state departments lack IPM-trained horticulture staff.	No access to PHI guidance or IPM alternatives
7.	**No farm-gate testing**	Absence of rapid residue screening at mandi or collection point means non-compliant produce reaches consumers without detection.	Zero market consequence for residue violation

Regulatory Framework: Strengths, Gaps and Recent Reforms

India's pesticide regulatory architecture involves multiple agencies with distinct but overlapping mandates, a structure that has historically contributed to fragmented enforcement and inconsistent outcomes. The Central Insecticides Board and Registration Committee (CIB&RC), operating under the Insecticides Act 1968, is responsible for the registration, approval and prohibition of pesticide products. It evaluates toxicological and efficacy data submitted by manufacturers and sets label claims including crop-pesticide combinations and PHI. However, the Act — now over five decades old — is widely acknowledged to be in need of comprehensive revision to reflect contemporary toxicological understanding, the proliferation of new pesticide classes and the requirements of international trade (Patel *et al*., 2023).

The Food Safety and Standards Authority of India (FSSAI), established under the Food Safety and Standards Act 2006, holds jurisdiction over MRL setting for pesticides in food commodities and conducts national food safety surveillance through its network of state food laboratories. FSSAI has made progressive strides in recent years, including the expansion of its MRL schedule, the harmonisation of several MRLs with Codex Alimentarius standards and the issuance of a 2021 advisory directing state governments to train farmers on GAP and GHP compliance, appropriate pesticide use and PHI adherence (FSSAI, 2021; Raj *et al*., 2025). Nevertheless, a significant gap remains: for many pesticide-crop combinations, India either lacks a specific domestic MRL or has set limits that are not aligned with importing country standards, creating automatic non-compliance in export markets even when Indian-registered products are used correctly (Singh *et al*., 2023).

APEDA plays a critical role in the export dimension, operating residue monitoring programmes for major export horticultural commodities including grapes, mangoes and fresh vegetables, and supporting the adoption of GLOBALG.A.P. and BharatGAP certification among export-oriented farmer clusters. At the state level, agriculture departments are nominally responsible for enforcement of pesticide use regulations, but practical enforcement capacity — in terms of trained inspectors, testing infrastructure and legal follow-through — remains severely limited across most states (Kumar *et al*., 2023). The 2022 draft Pesticides Management Bill, which has been under consideration for two decades, proposes stronger registration protocols, enhanced penalties for adulterants and a more integrated approach to MRL setting and enforcement. Its passage and implementation would represent a significant step forward for the regulatory architecture (Khandare *et al*., 2022).

Integrated Solutions: From Farm Practices to Market Mechanisms

Reducing pesticide residues in Indian horticultural produce is not a single-intervention challenge — it requires simultaneous action across farming practice, extension support, market incentives, consumer awareness and regulatory enforcement. The following evidence-based strategies, when implemented in combination, offer the most realistic pathway to systemic residue reduction.

Integrated Pest Management (IPM) as the Foundation

IPM remains the most robust and cost-effective framework for reducing pesticide dependence in horticulture. The IPM pyramid — biological control first, cultural and physical control second, selective chemical control only when economic thresholds are exceeded — directly addresses the calendar spraying and overdosing behaviours that drive MRL violations. Biological control agents including Trichoderma, Beauveria bassiana, Bacillus thuringiensis (Bt) and Chrysoperla have demonstrated effective pest suppression in vegetable and fruit systems in India when integrated with pheromone trap monitoring and resistant or tolerant varieties (Bhatt *et al*., 2022). Farmer Field Schools (FFS) on IPM, facilitated through KVKs and state horticulture departments, have consistently shown that trained farmers reduce pesticide applications by 30 to 50 per cent without yield penalty — a finding with direct implications for residue load at harvest.

PHI Compliance and Spray Record Keeping

PHI compliance is the single most impactful farm-level intervention for MRL reduction. Simple, crop-specific PHI calendars — listing each registered pesticide with its PHI expressed in days before harvest — have been developed by ICAR and state departments but remain poorly disseminated. Integrating PHI information into mobile advisory platforms such as Plantix, IFFCO Kisan and the Government's AgriStack initiative would place this information directly in farmers' hands at the point of spray decision. Mandatory spray record books — a requirement under BharatGAP and IndGAP certification — create accountability for PHI compliance and are increasingly being adopted in FPO-managed export supply chains (Raj *et al*., 2025).

Residue Testing at Packhouse and Mandi Level

The absence of residue consequence at the point of sale is a fundamental market failure driving persistent MRL violations. Rapid enzyme inhibition test kits, capable of detecting organophosphate and carbamate residues at approximate MRL thresholds within 30 minutes, are available at low cost and have been deployed with success in Maharashtra's grape export clusters and Himachal Pradesh's apple supply chain. Scaling rapid testing to major vegetable mandis — with transparent results displayed to buyers and sellers — would create an immediate market disincentive for residue-non-compliant produce. NABL-accredited pesticide residue laboratories, though expensive to establish, are essential for confirmatory multi-residue testing and should be co-located with APEDA-certified packhouses handling export produce (Singh *et al*., 2023).

BharatGAP and Certification-Linked Market Premiums

The 2024 launch of BharatGAP by the National Horticulture Board represents the most accessible certification pathway yet available for Indian horticultural farmers. BharatGAP's simplified documentation, group certification through FPOs and commodity-specific checklists directly address the barriers that limited uptake of the earlier IndGAP scheme (NHB, 2023). Critically, BharatGAP mandates spray record keeping and PHI compliance as core certification criteria, embedding residue management into the certification process rather than treating it as an optional add-on. For certification to deliver sustainable residue reduction, it must be linked to market premiums — whether through retail chains, e-commerce platforms or export buyers — that make compliance economically rewarding for farmers (Patel *et al*., 2023).

Bio-Pesticide Promotion and Input Substitution

India has a rich and underutilised portfolio of bio-pesticide options. Neem-based products (azadirachtin), botanical extracts, microbial biopesticides and semiochemicals (pheromones, repellents) offer pest control with minimal residue risk and are actively promoted under the Paramparagat Krishi Vikas Yojana (PKVY) and the National Project on Organic Farming (NPOF). The challenge is not availability but adoption: biopesticides are often perceived as slower-acting, more expensive per application and less familiar than synthetic molecules. Targeted subsidies, demonstration plots and farmer-to-farmer extension through FPOs can accelerate substitution, particularly for crops and pests where effective biopesticide options are established (Kumar *et al*., 2023).

CONCLUSION

Pesticide residues in Indian fruits and vegetables represent one of the most consequential and under-prioritised food safety challenges facing the country. The evidence is unambiguous: monitoring surveys document regular MRL violations in key vegetable and fruit commodities, export rejection data confirms the economic cost of residue non-compliance and toxicological research demonstrates the public health risks of chronic dietary pesticide exposure, particularly for children and farm communities. Yet this is emphatically not a problem without solutions. The tools — IPM, PHI calendars, BharatGAP certification, rapid residue testing, biopesticide promotion and FPO-mediated accountability — already exist and have demonstrated effectiveness in pilot contexts across India.

What is needed is a coordinated, funded and sustained commitment from all actors in the horticultural food system. Regulators must accelerate MRL harmonisation with Codex, pass the long-overdue Pesticides Management Bill and resource enforcement at state level. Extension systems must be rebuilt around crop-specific, IPM-focused, residue-aware advisory services. Markets must create and sustain price premiums that reward certified, residue-compliant produce. And consumers must exercise informed demand — asking questions, seeking certification labels and understanding that safe produce requires systemic investment, not just individual behaviour change. India's goal must not be a pesticide-free plate — an unachievable standard that serves no one — but a residue-safe plate, where what is eaten is demonstrably within limits that protect health. That goal is within reach, but only if every link in the horticultural food chain accepts its share of responsibility.

REFERENCES

Bhatt, D. L., Sharma, R. and Gupta, N. (2022). Neurodevelopmental effects of chronic organophosphate exposure in children of agricultural communities in North India: A cross-sectional study. Environmental Research, 204: 112048.

Codex Alimentarius Commission. (2023). Codex Alimentarius: Pesticide Residues in Food. Food and Agriculture Organization/World Health Organization, Rome.

Food Safety and Standards Authority of India (FSSAI). (2021). Advisory on Good Agricultural Practices (GAP) for fruits and vegetables. https://www.fssai.gov.in/

Food Safety and Standards Authority of India (FSSAI). (2023). Annual report on food safety surveillance: Pesticide residues in fruits and vegetables. FSSAI, New Delhi.

Khandare, A. L., Kumar, P. U. and Lakshmaiah, N. (2022). Pesticide use patterns, residue status and health risk assessment in Indian horticulture: A comprehensive review. Environmental Toxicology and Pharmacology, 91: 103832.

Kumar, S., Singh, A. and Yadav, R. K. (2023). Occupational pesticide exposure and health outcomes among horticultural farm workers in Uttarakhand: A field study. Journal of Occupational Health, 65(1): e12401.

National Horticulture Board (NHB). (2023). BharatGAP certification guidelines. Ministry of Agriculture and Farmers Welfare, Government of India. https://nhb.gov.in/

Patel, V., Chauhan, B. and Rawal, P. (2023). Drivers of pesticide overuse and MRL violations in smallholder vegetable systems in Gujarat and Maharashtra: An institutional analysis. Food Policy, 116: 102435.

Raj, R., Bora, K. H., Sharma, K. and Chaudhary, T. (2025). Good Agricultural Practices (GAP): Principles, Implementation and Impact on Sustainable Agriculture. Food and Scientific Reports, 6(6): 11-16.

Sharma, A., Kumar, V. and Shahzad, B. (2022). Pesticide residue behaviour in horticultural crops: Dissipation kinetics, pre-harvest interval compliance and the role of washing and cooking. Food Chemistry, 373: 131450.

Singh, B., Gupta, S. and Thind, S. K. (2023). Export rejections of Indian horticultural produce due to pesticide residue violations: Trends, commodities and regulatory implications. Food Control, 145: 109468.