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Natural Products for Crop Protection in the Indian Agricultural System

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Abstract

India's food and nutritional security depends on intensifying agricultural productivity while reducing externalities of synthetic pesticides. Natural products—botanical extracts, microbial biopesticides, mineral- and plant-derived oils, pheromones and other semiochemicals—offer eco-friendly options that complement Integrated Pest Management (IPM). This review synthesizes the current landscape of natural-product crop protection in India, covering modes of action, key use-cases in major crops (rice, cotton, pulses, horticulture), formulation advances, regulatory considerations, on-farm adoption constraints, and future directions. Evidence from field deployments shows that neem-based products, nucleopolyhedroviruses (NPVs), Bacillus thuringiensis (Bt) formulations, Trichoderma-based biofungicides, and pheromone-based mass trapping can reduce pest pressure and pesticide residues, stabilize yields, and support beneficial arthropods when integrated with cultural and mechanical controls. Remaining challenges include variability in active-ingredient content, short field persistence, quality assurance, scale-up of production, and context-specific efficacy under climate variability. A pathway forward is proposed around standardization, robust bioefficacy data, encapsulation technologies, digital IPM decision support, and last-mile extension to mainstream natural products in Indian agriculture.

Keywords: biopesticides, neem (Azadirachtin), nucleopolyhedrovirus (NPV), Trichoderma, pheromone traps, essential oils, IPM, residue reduction, India

1. Introduction

Indian agriculture supports over half of the population and spans diverse agroecologies from irrigated Indo-Gangetic plains to rainfed Deccan and arid western zones. Pest and disease pressure remains a key constraint to productivity in staple cereals (rice, wheat, maize), commercial crops (cotton, sugarcane), pulses and oilseeds, and high-value horticulture. While synthetic pesticides have delivered short-term control, their overuse has contributed to resistance development, resurgence, natural enemy disruption, and residue concerns affecting food safety and export compliance.

Natural-product crop protection agents—derived from plants, microbes, naturally occurring minerals, and semiochemicals—present a complementary toolbox for sustainable intensification. They typically feature narrower spectra, novel or multi-site modes of action, shorter pre-harvest intervals, and compatibility with biological control. India has a unique advantage: a long tradition of using plant-based protectants (e.g., neem) and strong public-sector research capacity in biocontrol and pheromone ecology. This paper reviews the science, practice, and policy of natural products in the Indian context and outlines practical integration into IPM.

2. Definitions and Classification

Natural products for crop protection include:

1. **Botanical pesticides:** Extracts or purified actives from plants (e.g., azadirachtin from *Azadirachta indica*; karanjin from *Pongamia pinnata*; capsaicinoids from chili; allicin-related compounds from garlic; curcuminoids from turmeric; rotenone and pyrethrins from specific sources where permitted).
2. **Microbial biopesticides:** Living organisms or their metabolites, such as **Bt** (for lepidopterans), **NPVs** (e.g., *Helicoverpa armigera* NPV, *Spodoptera litura* NPV), entomopathogenic fungi (**Beauveria, Metarhizium**), biofungi (**Trichoderma spp.**), and beneficial bacteria (**Pseudomonas, Bacillus** spp.).
3. **Semiochemicals:** Species-specific chemical signals—especially **sex pheromones**—used for monitoring, mass trapping, lure-and-kill, and mating disruption.
4. **Natural-origin fungicides and bactericides:** Antagonistic microbes, plant oils (tea tree, thyme, eucalyptus, clove), chitosan, and certain allowable mineral salts (e.g., bicarbonates) in organic systems.
5. **Oils and soaps:** Horticultural/mineral oils and potassium salts of fatty acids for soft-bodied pests and mites.
6. **Bioherbicides and allelopathy:** Living agents or phytotoxins from plants/microbes for weed suppression; non-selective natural acids (e.g., pelargonic/acetic acid) in non-crop areas.

3. Botanical Pesticides: India's Comparative Advantage

Neem (Azadirachtin)

Neem-based formulations are the flagship Indian botanical pesticide.

Modes of action include antifeedancy, growth regulation, oviposition deterrence, and sterilization in insects, with relatively low non-target toxicity.

Use-cases: Rice stem borers/leaf folders (as part of IPM), cotton bollworms and sucking pests, vegetables (whiteflies, aphids), and stored grain protection.

Strengths: Multi-site action delays resistance; short PHIs; compatibility with parasitoids and predators.

Limitations: Photolability and variability in azadirachtin content demand quality-assured formulations and proper timing (evening sprays, adjuvants, repeat applications).

Karanj (Pongamia) and Other Plants

Karanjin exhibits insecticidal and antifeedant effects; often used in blends with neem to broaden activity. Garlic, chili, turmeric, annona seed, lantana **and** lemongrass/citronella oil**s** show repellency, oviposition deterrence, or antifungal effects. Standardization, solvent choice, surfactants, and encapsulation strongly influence field performance.

4. Microbial Biopesticides

 # *Bacillus thuringiensis* (Bt)

Bt produces Cry proteins that perforate the midgut of susceptible lepidopteran larvae. **Applications in India:** Vegetables (cabbage/cauliflower DBM), pulses (pod borers), and fruit crops under IPM.

Best practices: Early larval stages, thorough coverage, evening sprays, and resistance management (rotation with non-Bt modes).

 # Nucleopolyhedroviruses (NPVs)

NPVs specific to *Helicoverpa armigera* (HNPV) and *Spodoptera litura* (SNPV) are widely used. **Advantages:** High host specificity, safety to beneficials, zero residues. **Operational notes:** Viral occlusion bodies degrade under UV; tank-mix with UV protectants, apply at dusk, repeat at economic threshold levels (ETLs).

 # Entomopathogenic Fungi

Beauveria bassiana and **Metarhizium anisopliae** infect via cuticle penetration and are effective against whiteflies, aphids, thrips, and some borers. **Environmental fit:** Perform well under moderate humidity; in arid zones, microclimate management (drip/mulch), evening applications, and compatible wetting agents improve success.

 # Biofungicides and PGPR

Trichoderma harzianum/viride suppress soilborne pathogens (*Rhizoctonia*, *Sclerotium*, *Fusarium*, *Pythium*) via mycoparasitism, antibiosis, and induced systemic resistance. **Pseudomonas fluorescens** and Bacillus subtilis strains provide foliar and rhizosphere protection. **Deployment:** Seed treatment, nursery root dips, soil/compost incorporation, and drip application; compatibility with organic manures and compost teas.

5. Semiochemicals: Pheromones and Beyond

 # Monitoring and Decision Support

Pheromone lure traps enable early detection**,** ETL-based spraying**,** and resistance management. Cotton (pink bollworm), rice (yellow stem borer), and fruit/vegetable pests are common targets.

 # Mass Trapping and Mating Disruption

High-density trap deployment or mating disruption dispensers reduce mating success and pest population growth. In cotton and pomegranate, pheromone-based strategies reduce synthetic insecticide rounds when integrated with sanitation and crop-stage timing.

6. Natural Fungicides, Oils, Soaps, and Bioherbicides

Plant essential oils (tea tree, thyme, clove, eucalyptus) and chitosan exhibit antifungal and induced-resistance effects on powdery mildews and post-harvest rots. Horticultural/mineral oils smother scales, mealybugs, mites, and eggs, while potassium soaps desiccate soft-bodied pests.

Bioherbicides and allelopathic mulches (e.g., residues from sorghum/mustard) can suppress certain weeds; non-selective natural acids help in orchard basins and non-crop strips. Selectivity and crop safety must be verified locally.

7. Formulation Science and Application Technology

- **Standardization:** Active content (e.g., azadirachtin ppm) and viable counts (e.g., CFU for *Trichoderma*, IU for Bt, occlusion bodies for NPV) are critical QC parameters.
- **Encapsulation & UV protection:** Microencapsulation, nanoemulsions, lignin or starch-based carriers, and UV absorbers extend field life of botanicals and viruses.
- **Adjuvants & pH:** Many natural actives are pH-sensitive; buffering spray solutions (pH ~6–7), adding sticker-spreaders, and avoiding hard water improve deposition and efficacy.
- **Precision delivery:** Drip chemigation for biofungicides, electrostatic sprayers for canopy coverage, and slow-release pheromone dispensers enhance performance while reducing labor.

8. Efficacy in Major Indian Crops

Rice

- **Targets:** Stem borer, leaf folder, brown planthopper (BPH), sheath blight.
- **Tools:** Neem-based sprays for early lepidopterans; pheromone monitoring for stem borer; Trichoderma for nursery/soil disease suppression.
- **Integration:** Resistant varieties, synchronized planting, balanced N, and ecological engineering (flowering strips for natural enemies).

Cotton

- **Targets:** Pink bollworm, *Spodoptera* spp., whiteflies, jassids, mealybugs.
- **Tools:** Pink bollworm pheromone traps/mating disruption; Neem/Karanj for sucking pests; HNPV/SNPV rotations; Beauveria for whiteflies; oils/soaps for mealybugs (with precise coverage).
- **Outcomes:** Reduced late-season insecticide sprays, better predator conservation.

Pulses and Oilseeds

- **Targets:** *Helicoverpa*, aphids, pod borers, fungal wilts.
- **Tools:** HNPV at ETL, Bt for early instars, neem sprays, Trichoderma seed treatment and soil application.

 # Horticulture (Vegetables and Fruits)

- **Targets:** DBM in cole crops, thrips/mites in chilies, fruit borers in tomato, mealybugs and fruit flies.
- **Tools:** Bt for DBM; Metarhizium/Beauveria for thrips/mites; methyl eugenol/pheromone lures for fruit flies; essential-oil fungicides against powdery mildew; horticultural oils for scales/mealybugs.
- **Postharvest:** Edible coatings and chitosan reduce spoilage and fungicide reliance.

9. Safety, Environmental Footprint, and Resistance Management

Natural products generally exhibit lower mammalian toxicity and shorter residues. Their selectivity preserves parasitoids and predators, strengthening biological control. However, resistance is still possible (e.g., with single-molecule botanicals or repeated Bt use). Best practice is rotation of modes of action, adherence to ETLs, and refuge strategies where relevant. For microbial agents, respecting viability (storage cold chain, shelf-life) is key to consistent results.

Conclusions

Natural products are not a silver bullet but a **powerful backbone** of sustainable IPM in India when deployed with agronomic and ecological intelligence. Their strengths—selectivity, safety, and compatibility with biological control—fit India's need to reduce residues, meet export standards, and restore agro-ecosystem services. Success depends on quality-assured inputs, precise timing, farmer-centric extension, and supportive policy. With continued R&D in formulation and decision support, and stronger supply chains, natural products can move from niche to norm across Indian farming systems.

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