

Botanical Pesticides: Traditional Knowledge to Modern Sustainable Pest Management in India

Dr. Anand Kumar

Prof. Veena P. Swami

Dr. Barrister Kumar Gupta

Department of Zoology, B.S.N.V.P.G. College (Lucknow University), Lucknow - 226001 (U.P.), India

Email: anadkumar051976@gmail.com

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Abstract

Botanical pesticides, derived from plants and their secondary metabolites, offer an eco-friendly and sustainable alternative to synthetic chemical pesticides. This chapter provides a comprehensive overview of botanical pesticides, covering their historical use in India, classification, traditional formulations, preparation methods, and applications in modern agriculture. The history traces their use from ancient Vedic practices to contemporary Integrated Pest Management (IPM) and organic farming programs, highlighting key plant species such as neem (*Azadirachta indica*), karanj (*Pongamia pinnata*), tulsi (*Ocimum sanctum*), and pyrethrum (*Chrysanthemum cinerariifolium*). Classification is discussed based on source plant, chemical nature, and mode of action, emphasizing their multifaceted insecticidal, repellent, antifeedant, growth-regulating, and ovicidal properties. Preparation methods—including aqueous extraction, oil extraction, solvent extraction, decoction, fermentation, and powdered formulations—are detailed, with reference to traditional and ICAR-recommended practices. The chapter also presents a comparative evaluation of botanical versus chemical pesticides, highlighting the advantages of botanical pesticides in terms of biodegradability, safety for non-target organisms, resistance management, and suitability for sustainable and organic farming. Limitations, such as slower action, short residual activity, and variable efficacy, are discussed alongside their significance in promoting environmentally safe and cost-effective pest management strategies. Overall, this chapter underscores the potential of botanical pesticides to support sustainable agriculture, reduce chemical pesticide dependency, and enhance food security in India and beyond.

Keywords: Botanical Pesticides, Indigenous Knowledge, Classification, Preparation Methods, Botanical Pesticides vs Chemical Pesticides, Significance and Limitations

Introduction

Botanical pesticides are naturally derived pest control agents obtained from plants or plant-based products, including leaves, seeds, roots, bark, flowers, and essential oils. These substances have been used in traditional agricultural practices for centuries, long before the advent of synthetic chemical pesticides. In recent decades, interest in botanical pesticides has increased significantly due to growing concerns over the adverse environmental and health effects associated with conventional agrochemicals, such as pesticide resistance, bioaccumulation, non-target toxicity, and environmental pollution (Isman, 2006; Regnault-Roger et al., 2012).

Plants synthesize a wide range of secondary metabolites—such as alkaloids, terpenoids, phenolics, flavonoids, and glycosides—that play a defensive role against herbivores, pathogens, and insects. Many of these compounds exhibit insecticidal, antifeedant, repellent, growth-regulating, or oviposition-detering properties, making them valuable tools in pest management (Koul et al., 2008). Well-known examples of botanical pesticides include neem (*Azadirachta indica*), pyrethrum (*Chrysanthemum cinerariifolium*), rotenone (*Derris spp.*), nicotine (*Nicotiana tabacum*), and essential oils from plants such as eucalyptus, clove, and citronella (Isman, 2000).

Botanical pesticides are generally biodegradable, exhibit low persistence in the environment, and are often less toxic to non-target organisms, including humans, livestock, and beneficial insects, when compared to synthetic pesticides. These characteristics make them particularly suitable for sustainable agriculture, organic farming systems, and integrated pest management (IPM) programs (Copping & Duke, 2007; Pavela, 2016). Moreover, the complex mixture of bioactive compounds present in plant extracts reduces the likelihood of rapid pest resistance development, a major challenge in modern pest control (Regnault-Roger et al., 2012).

In developing countries such as India, botanical pesticides hold special significance due to their local availability, cost-effectiveness, and compatibility with traditional farming knowledge. Plants like neem, karanj (*Pongamia pinnata*), tulsi (*Ocimum sanctum*), and lantana (*Lantana camara*) have been extensively studied and utilized for managing a wide range of agricultural pests (Singh & Pandey, 2018). With increasing emphasis on eco-friendly pest management and stricter regulations on synthetic pesticides, botanical pesticides are emerging as promising alternatives that support agricultural sustainability, environmental safety, and food security.

History of Botanical Pesticides Used in India

Botanical pesticides have been used in India since ancient times and are deeply rooted in traditional agricultural practices and indigenous knowledge systems. Ancient texts such as the Vedas, Arthashastra, Charaka Samhita, and Sushruta Samhita describe the use of plant extracts, oils, ashes, and fumigation methods for protecting crops and stored grains from pests (Prakash & Rao, 1997; Saxena, 2000).

Neem (*Azadirachta indica*) emerged as the most important botanical pesticide during the medieval period, widely used in the form of leaf extracts, seed kernel powders, and oils. Other plants such as karanj, tobacco, garlic, chilli, and tulsi were also commonly employed in traditional pest control practices (Schmutterer, 1990).

The use of botanical pesticides declined during the colonial period with the introduction of synthetic chemicals but regained importance after independence due to concerns over pesticide resistance, environmental pollution, and health hazards. Systematic research by ICAR led to the development of neem-based formulations such as NSKE and azadirachtin, which are now integral components of Integrated Pest Management and organic farming systems in India (Schmutterer & Singh, 1995; Prakash et al., 2008).

Historical Timeline of Botanical Pesticides in India

Period	Key Developments
Pre-Vedic period (before 1500 BCE)	Use of plant extracts, oils, and ash for pest control (Saxena, 2000)
Vedic period (1500–500 BCE)	References to botanical pest control in Vedas
Mauryan period (~300 BCE)	<i>Arthashastra</i> describes plant-based fumigation and sprays (Prakash & Rao, 1997)
Medieval India	Extensive use of neem, tobacco, <i>calotropis</i>
Colonial era (1800–1940)	Decline of botanicals due to chemical pesticides
Post-independence (1950–1970)	ICAR initiates systematic research
1980s–1990s	Neem-based IPM promoted nationwide (Schmutterer & Singh, 1995)
2000s onwards	Organic farming and biopesticide commercialization
Present	Policy support for eco-friendly pest management

Classification of Indian Botanical Pesticides

Indian botanical pesticides are traditionally classified based on source plant, chemical nature, and mode of action. Such classifications are widely adopted in Indian agricultural research and ICAR-recommended literature (Prakash & Rao, 1997; Koul et al., 2008).

Classification Based on Source Plant

Botanical Source	Plant Species	Major Active Constituents	Target Pests / Use
Neem	<i>Azadirachta indica</i>	Azadirachtin, salannin, nimbin	Chewing and sucking insect pests
Karanj	<i>Pongamia pinnata</i>	Karanjin, pongamol	Lepidopteran larvae, aphids
Tobacco	<i>Nicotiana tabacum</i>	Nicotine	Aphids, mites, thrips
Pyrethrum	<i>Chrysanthemum cinerariifolium</i>	Pyrethrins	Mosquitoes, flies, beetles
Custard apple	<i>Annona squamosa</i>	Acetogenins	Stored grain pests
Garlic	<i>Allium sativum</i>	Allicin, sulphur compounds	Repellent and antifungal
Chilli	<i>Capsicum annuum</i>	Capsaicin	Repellent and antifeedant
Tulsi	<i>Ocimum sanctum</i>	Eugenol	Repellent and antimicrobial

Neem (*Azadirachta indica*) is considered the most important botanical pesticide in India due to its broad-spectrum activity, biodegradability, and compatibility with Integrated Pest Management (IPM) systems (Schmutterer & Singh, 1995).

Classification Based on Chemical Nature

Botanical pesticides contain diverse groups of bioactive compounds that affect insect physiology and behavior (Isman, 2006).

Chemical Group	Examples	Indian Plant Sources
Alkaloids	Nicotine	<i>Nicotiana tabacum</i>
Terpenoids	Azadirachtin, pyrethrins	Neem, chrysanthemum
Phenolics	Eugenol	Tulsi, clove
Sulphur compounds	Allicin	Garlic
Flavonoids	Karanjin	Karanj

These compounds act either individually or synergistically, reducing the chances of resistance development in insect populations (Regnault-Roger et al., 2012).

Classification Based on Mode of Action

Botanical pesticides exhibit multiple modes of action, making them suitable for sustainable pest management programs (Pavela, 2016).

Mode of Action	Botanical Example	Effect on Insects
Antifeedant	Neem (azadirachtin)	Inhibits feeding behavior
Repellent	Chilli, garlic	Avoidance and deterrence
Growth regulator	Neem	Disrupts molting and metamorphosis
Ovicidal	Neem oil	Egg mortality
Contact poison	Pyrethrum	Nervous system paralysis

Traditional Botanical Formulations Used in India

Traditional botanical formulations are cost-effective, eco-friendly, and widely promoted under ICAR-led IPM and organic farming programs (ICAR, 2018). Neem Seed Kernel Extract (NSKE) is one of the most extensively recommended traditional botanical pesticides in India for controlling a wide range of insect pests (Prakash et al., 2008).

Some other traditional formulations are commonly used in India by small and marginal farmers and are recommended in organic and low-input farming systems by ICAR and other agencies are given below in table -

Formulation	Ingredients	Target Pests
Neem oil spray (0.5–1%)	Neem oil + soap	Sucking pests
Chilli–garlic extract	Chilli + garlic + water	Repellent insects
Tobacco decoction	Tobacco leaves + water	Aphids, mites
Dashparni ark	Extracts of ten plant species	Broad-spectrum pests
Ash and neem leaf mixture	Wood ash + neem leaves	Stored grain pests

Botanical Pesticides Used in Agriculture in India

India has a long tradition of using plant-based pest control agents, supported by indigenous knowledge systems and, more recently, by ICAR and national organic farming programs. The most important botanical pesticides used in Indian agriculture are given below in the table-

Botanical Plant	Family	Major Bioactive Compounds	Pests Controlled / Use
Neem (<i>Azadirachta indica</i>)	Meliaceae	Azadirachtin, nimbin, salannin	Aphids, whiteflies, jassids, caterpillars, borers (Schmutterer, 1990; Isman, 2006)
Karanj (<i>Pongamia pinnata</i>)	Fabaceae	Karanjin, pongamol	Lepidopteran larvae, aphids, beetles (Prakash & Rao, 1997)
Tobacco (<i>Nicotiana tabacum</i>)	Solanaceae	Nicotine	Aphids, thrips, mites (Isman, 2006)
Pyrethrum (<i>Chrysanthemum cinerariifolium</i>)	Asteraceae	Pyrethrins	Mosquitoes, flies, beetles (Copping & Duke, 2007)
Custard apple (<i>Annona squamosa</i>)	Annonaceae	Acetogenins	Stored grain pests, caterpillars (Prakash et al., 2008)
Garlic (<i>Allium sativum</i>)	Amaryllidaceae	Allicin, diallyl sulphides	Repellent to sucking pests and mites (Koul et al., 2008)
Chilli (<i>Capsicum annuum</i>)	Solanaceae	Capsaicin	Repellent to caterpillars and sucking pests (Prakash & Rao, 1997)

Tulsi (<i>Ocimum sanctum</i>)	Lamiaceae	Eugenol, ursolic acid	Repellent and antimicrobial (Regnault-Roger et al., 2012)
Calotropis (<i>Calotropis procera</i>)	Apocynaceae	Cardiac glycosides	Caterpillars and beetles (Prakash et al., 2008)
Derris (<i>Derris elliptica</i>)	Fabaceae	Rotenone	Chewing insects, beetles (Copping & Duke, 2007)
Eucalyptus (<i>Eucalyptus globulus</i>)	Myrtaceae	Eucalyptol (cineole)	Repellent to insects (Koul et al., 2008)
Lantana (<i>Lantana camara</i>)	Verbenaceae	Lantadene A & B	Leaf-feeding insects (Prakash et al., 2008)
Sweet flag (<i>Acorus calamus</i>)	Acoraceae	β -asarone	Stored grain pests (Isman, 2006)
Clove (<i>Syzygium aromaticum</i>)	Myrtaceae	Eugenol	Insect repellent and fumigant (Regnault-Roger et al., 2012)
Vitex (<i>Vitex negundo</i>)	Lamiaceae	Flavonoids, terpenoids	Mosquitoes and leaf feeders (Prakash & Rao, 1997)

Methods of Preparation of Botanical Pesticides

Botanical pesticides are natural pest control agents derived from plants, often containing bioactive compounds such as alkaloids, terpenoids, flavonoids, or phenolics. Their preparation is critical to ensure efficacy, stability, and safety.

Various methods are employed depending on the plant part used, the targeted pest, and the formulation type (Isman, 2006; Khanuja et al., 2000).

Aqueous Extraction

This is the most commonly used and traditional method, especially in India.

Procedure

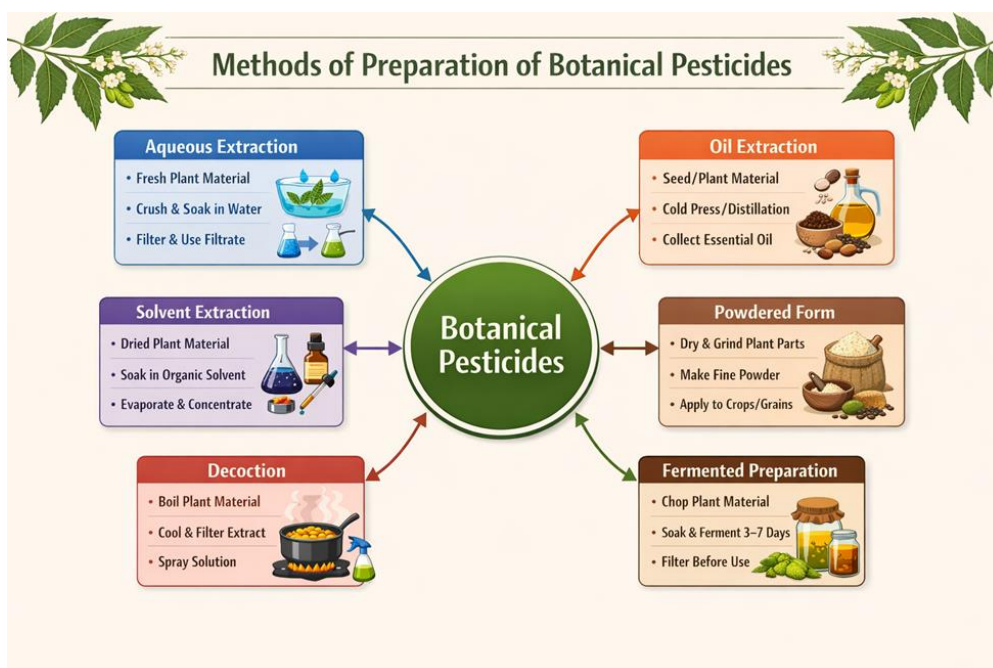
- Collect fresh plant material (leaves, seeds, roots, bark, or flowers).
- Wash thoroughly to remove dust and contaminants.
- Cut into small pieces and grind or crush.
- Soak in water (usually 1:10 to 1:20 w/v ratio) for a few hours to overnight.
- Filter to remove plant debris.
- Use the filtrate directly as a spray or dilute as required.

Examples:

- Neem leaf extract for controlling aphids, whiteflies (Koul et al., 2004).
- Tobacco leaf extract (contains nicotine) for sucking pests (Gupta et al., 2010).

Advantages: Simple, low-cost, environmentally safe.

Limitations: Short shelf-life; less concentrated compared to organic solvents.



Methods of preparation of botanical pesticides (adapted from Isman, 2006; Koul et al., 2004; Schmutterer, 1990; Gupta et al., 2010; Kumar et al., 2013).

Oil Extraction

Certain plants produce bioactive oils effective against pests, such as neem, eucalyptus, and citronella.

Procedure

- Collect seeds or plant parts rich in essential oils.
- Dry the material in shade to reduce moisture.
- Extract oil using cold-pressing or steam distillation.
- Blend with an emulsifier (soap solution) for foliar spray.

Examples

- Neem oil (*Azadirachta indica*) used against lepidopteran pests (Schmutterer, 1990).
- Eucalyptus oil for repelling insects.

Advantages: Concentrated and long-lasting effect; can be formulated as emulsifiable concentrates.

Limitations: Requires specialized equipment; slightly higher cost.

Solvent Extraction

Organic solvents (ethanol, methanol, acetone, or hexane) can extract specific active compounds not water-soluble (Koul et al., 2004).

Procedure

- Dry plant material is powdered.
- Soak in organic solvent (1:5 to 1:10 w/v ratio) for 24–72 hours.
- Filter and evaporate the solvent to concentrate the extract.
- Dilute with water before application or formulate as emulsifiable concentrate.

Examples

- Azadirachtin from neem seeds.
- Pyrethrins from Chrysanthemum flowers.

Advantages: Higher yield and potency; effective against a wide range of pests.

Limitations: Use of flammable/toxic solvents; not feasible for small-scale farmers.

Powdered Form

Dried plant material can be used as powder for direct application.

Procedure

- Harvest plant parts (leaves, seeds, bark).
- Dry in shade and grind into fine powder.

- Apply directly to soil, stored grains, or crop surfaces (Kumar et al., 2013).

Examples

- Chili powder for deterring caterpillars.
- Neem seed powder for stored grain pests.

Advantages: Simple, cost-effective, long shelf-life; slow-release action.

Limitations: Less effective for foliar pests unless mixed with water or oil.

Fermented Preparation

Fermentation enhances extraction of bioactive compounds and sometimes produces additional insecticidal metabolites (Isman, 2006).

Procedure

- Chop plant material finely.
- Soak in water and allow to ferment for 3–7 days.
- Filter the extract before spraying.

Examples: Fermented neem leaves for insect repellent; fermented garlic or onion extracts.

Advantages: Enhances efficacy and bioavailability; uses locally available resources.

Limitations: Requires careful handling; odour may be strong.

Decoction

Decoction involves boiling plant material to extract heat-stable compounds.

Procedure

- Take plant parts and boil in water for 30–60 minutes.
- Cool and filter the extract.
- Spray directly or dilute before use (Gupta et al., 2010).

Examples: Tobacco leaf decoction for aphid control; garlic or onion decoctions as repellents.

Advantages: Extracts water-soluble and heat-stable bioactives; simple and traditional.

Limitations: Heat-sensitive compounds may degrade; short shelf-life.

Traditional Formulations in India

India has a long history of using botanical pesticides in traditional agriculture.

Plant/Material	Formulation Type	Target Pests
Neem seed kernel	NSKE (Neem Seed Kernel Extract)	Aphids, whiteflies
Tobacco leaves	Aqueous/Decoction	Aphids, jassids
Garlic/Onion	Extract/Decoction	Nematodes, insects
Chili	Powder/Extract	Caterpillars, aphids
Pyrethrum flowers	Powder/Extract	Lepidopterans, mosquitoes

Comparative Inference: Use of Botanical Pesticides vs Chemical Pesticides

Botanical and chemical pesticides differ markedly in their origin, mode of action, environmental behavior, and long-term impact on agro-ecosystems. Botanical pesticides are plant-derived products that primarily act as antifeedants, repellents, growth regulators, or ovicides, whereas chemical pesticides are synthetically produced compounds designed for rapid pest mortality. While chemical pesticides provide immediate and broad-spectrum pest control, botanical pesticides offer safer, eco-friendly, and sustainable alternatives suitable for Integrated Pest Management (IPM) systems.

The comparative evaluation indicates that botanical pesticides are more sustainable and environmentally benign than chemical pesticides, making them ideal for long-term pest management and organic farming systems. However, due to their slower action and lower immediate efficacy, botanical pesticides are most effective when used preventively or in early pest infestation stages and as components of IPM programs. Chemical pesticides, although effective for rapid pest suppression, pose serious risks related to resistance development, ecological imbalance, pesticide residues, and human health hazards. Therefore, a judicious and need-based integration of botanical pesticides, with restricted and rational use of chemical pesticides, is strongly recommended for sustainable agricultural production.

Comparison Between Botanical and Chemical Pesticides

Aspect	Botanical Pesticides	Chemical Pesticides
Source	Plant-based natural products	Synthetic chemical compounds
Examples	Neem, karanj, pyrethrum, garlic	DDT, chlorpyrifos, carbaryl
Mode of action	Antifeedant, repellent, growth regulator	Neurotoxic, metabolic inhibition

Speed of action	Slow and gradual	Rapid knock-down
Persistence	Biodegradable, short residual life	Persistent, long residual effect
Resistance development	Low due to complex mixtures	High due to single active ingredient
Effect on non-target organisms	Generally safe to beneficial insects	Harmful to pollinators and natural enemies
Environmental impact	Eco-friendly, minimal pollution	Soil, water, and air contamination
Human health risk	Low toxicity	High toxicity and residue risk
Cost and availability	Locally available, low cost	Expensive, market-dependent
Suitability for IPM/organic farming	Highly suitable	Limited or restricted

Significance of Botanical Pesticides

- Eco-friendly, biodegradable, and safe for humans and livestock.
- Minimal residues on food, supporting food safety.
- Low toxicity to beneficial organisms.
- Multiple modes of action prevent rapid resistance development.
- Cost-effective and compatible with traditional farming practices.
- Widely used in IPM and organic farming systems.
- Reduce dependence on synthetic pesticides, supporting sustainable agriculture.

Limitations of Botanical Pesticides

- Slower action and shorter residual effect.
- Frequent applications needed for effective pest management.
- Efficacy may vary with plant source, season, and preparation method.
- Quality standardization is limited, especially for on-farm extracts.
- Large quantities of plant material required, with short shelf-life.
- Lower effectiveness under high pest infestations.

- Regulatory approvals may be time-consuming, and farmer awareness is limited.

Conclusion

Botanical pesticides are eco-friendly, sustainable alternatives to chemical pesticides, utilizing plant-derived bioactive compounds to manage a wide range of pests through multiple modes of action. In India, their use is rooted in traditional practices and is now integrated into modern IPM and organic farming systems. They are biodegradable, safe for non-target organisms, and reduce pest resistance, making them suitable for sustainable agriculture. However, limitations such as slower action, short residual life, and variability in efficacy remain. With proper standardization, research, and awareness, botanical pesticides can play a vital role in promoting environmentally safe, cost-effective, and resilient agricultural practices.

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