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Green Strategies for Insect Pest Management in Natural Dye Yielding Trees

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Abstract

Natural dye-yielding plants, essential for sustainable and eco-friendly colorant production, are increasingly vulnerable to insect pest infestations that compromise not only dye quality but also crop yield. The reliance on conventional synthetic insecticides for pest management poses significant challenges, including environmental contamination, adverse effects on non-target organisms, and the accumulation of toxic residues, which fundamentally conflict with the environmentally sustainable principles of crop management. Sustainable and eco-friendly pest management practices such as biological control, botanical insecticides, cultural and mechanical practices offer effective alternatives. Adoption of Integrated Pest Management (IPM) combining these eco-friendly approaches but excluding pesticides can not only help in environmental sustainability, but also safeguard the tree health, besides preserving biodiversity and ecological integrity. This transition is essential for advancing natural dye production and supporting environmentally conscious markets. The present paper discusses major pests affecting natural dye yielding trees and pro-environmental strategies for managing the same.

Keywords:

Dye yielding trees, eco-friendly methods, insect pests, green strategies

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1. Introduction

Synthetic dyes predominantly produced from petroleum-based compounds pose significant environmental and health hazards despite their widespread industrial usage. These dyes contribute to severe water pollution, as effluents from dye manufacturing and textile industries often contain toxic substances, including heavy metals and aromatic amines. Many synthetic dyes are non-biodegradable, persist in the environment and disrupt aquatic ecosystems. Furthermore, certain synthetic dyes have been linked to carcinogenicity, mutagenicity and also cause other adverse health effects in humans. Exposure to these dyes can cause skin irritation, respiratory issues, and long-term organ toxicity. The hazardous impact of synthetic dyes necessitates a critical reassessment of their use, especially in industries like textiles, cosmetics, and food coloring

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(Siva, 2007; Bhattacharya and Shah, 2000).

Natural dyes, derived from eco-friendly sources such as trees, plants, minerals, insects and microorganisms offer a sustainable alternative to synthetic dyes. These colorants, traditionally employed for textiles, cosmetics, and food, are biodegradable, non-toxic, and free from harmful synthetic chemicals. Unlike synthetic dyes, natural dyes reduce environmental pollution, as they can be obtained from simple methods like water extraction and fermentation. India is a global leader in natural dye production, with traditional practices rooted in eco-friendly processes (Kumaresan et al., 2011). Rajasthan (henna, indigo), Tamil Nadu (indigo, turmeric), and Madhya Pradesh (arjuna bark, safflower) are the major dye producing states in India (Siva, 2007). These dyes are not only sustainable but also support biodiversity (Siva, 2007; Kumaresan et al., 2011) besides mitigating the adverse impacts associated with synthetic dyes. In India, natural dyes also hold cultural significance, being integral to traditional crafts like Kalamkari, Bandhani, and Ajrakh. They also support rural economies by providing livelihoods through the cultivation of dye-yielding plants and artisanal dyeing practices. The subtle differences between natural and synthetic dyes are furnished hereunder in Table 1.

Table 1: Comparison between natural and synthetic dyes

Parameters	Natural dyes	Synthetic dyes
Source	Derived from natural materials like plants, minerals, insects and microorganisms	Manufactured chemically, often from petroleum derivatives
Environmental impact	Eco-friendly, biodegradable, and non-toxic	Non-biodegradable, often toxic, and contributes to environmental pollution
Color range	Narrow range and is limited to earthy and subtle tones	Wide range of vibrant and consistent colors
Fixation	Requires mordants (e.g., alum, tannins) for color fixation	Easily fixed on fibers without additional treatments
Cost	Typically more expensive due to labor-intensive extraction and processing	Cost-effective, with large-scale production
Health impact	Safe for human use, non-allergic and non carcinogenic	Can contain harmful chemicals; some are carcinogenic or allergic
Durability	Colors may fade over time with washing and sunlight	Durable with strong resistance to washing and UV exposure

2. Insect Pest Constraints in Natural Dye Yielding Plants and Eco-Friendly Management

Despite multifarious benefits, natural dye-yielding trees face significant biotic stress due to insect pests, which can severely reduce their yield and quality. Certain insect pests directly target the dye-producing parts of plants, rendering them unsuitable for dye extraction and processing (Table 2). For instance, seed borers (*Caryedon serratus*) infest *Bixa orellina* seeds, reducing their viability and dye content. *Indigofera tinctoria* is affected by leaf-eating caterpillars (*Spodoptera litura*) and aphids (*Aphis craccivora*), which cause defoliation and nutrient loss, respectively. Such pest infestations not only lower the economic value of the affected plant parts but also disrupt the overall dye production chain, necessitating effective and sustainable pest management strategies (Siva, 2007).

The reliance on synthetic insecticides for pest management has several adverse effects which include environmental pollution, toxicity to pollinators and natural enemies, and the development of insecticide resistance in insect pests. Further, residual toxicity pose health hazards to human beings, especially when the dyes are used in cosmetics and textiles. Hence, there is a great need to adopt eco-friendly strategies-for managing insect pests in natural dye-yielding trees (Dhaliwal et al., 2015). The details of major insect pests of dye yielding trees and

Table 2: Major insect pests and their eco-friendly management in natural dye yielding tree species

Natural dye-yielding plant	Dye yielding part	Dye colour	Name of the insect pest	Scientific name	Nature of damage	Symptoms of damage	Eco-friendly management
Butea monosperma	Flower/ gum	Orange	Bark eating caterpillar	*Indarbela quadrinotata* (Figure 1)	Bore into bark, feed on tissues	Sawdust-like frass at tree base, wilting, and drying of branches	Remove and destroy infested bark and use biopesticides like *Beauveria bassiana* @ 5 g litre^{-1} of water.
			Leaf defoliator	*Spodoptera litura* (Figure 12)	Defoliation of leaves	Irregular holes on leaves, often skeletonizing them. Defoliation, leaving only midribs in severe infestations	Spray *Bacillus thuringiensis* @ 2 g litre^{-1} of water; introduce egg parasitoids like *Trichogramma* spp..
Terminalia bellerika	Bark	Light brown colour	Tussock caterpillar	*Euproctis fraterna* (Figure 2 and 13)	Defoliation	Skeletonized leaves, reduced photosynthesis	Release egg parasitoids (*Trichogramma* spp.), spraying with Azadirachtin 1500ppm @ 5 ml litre^{-1} of water
			Bark borer	*Indarbela tetraonis*	Bore into bark, causing drying of branches	Bore holes in bark, leading to damage to vascular tissues Drying of branches, often accompanied by frass accumulation around the tree base.	Use neem-based biopesticides, remove and destroy affected branches
Punica granatum	Rind Flowers	Yellow and brown Red	Pomegranate butterfly	*Deudorix isocrates* (Figure 3)	Bore into fruits, feed on pulp	Premature fruit drop, oozing of gum from fruit, reduced market value	Bagging of fruits, spray neem-based pesticides Azadirachtin 1500 ppm @ 5 ml litre^{-1} of water, introduce larval parasitoids (*Bracon hebetor*)
			Aphid	*Aphis punicae*	Suck sap from leaves, reducing plant vigor	Leaf curling and yellowing due to sap-sucking activity. Sticky honeydew secretion, which attracts sooty mold development.	Spray neem-based solutions, encourage natural predators like ladybird beetles (*Coccinellidae*)
Eucalyptus sp.	Bark	Brown	Gall wasp	*Leptocybe invasa* (Figure 4)	Formation of galls on leaves and twigs	Galls visible on young shoots and leaves, stunted growth, reduced productivity	Release parasitoids (*Quadrastichus mendeli*), prune and destroy affected twigs

Table 2: Continue...

Natural dye-yielding plant	Dye yielding part	Dye colour	Name of the insect pest	Scientific name	Nature of damage	Symptoms of damage	Eco-friendly management
			Eucalyptus leaf beetle	*Chrysomela* spp.	Chews leaves, reduces photosynthetic ability	Notched or chewed leaf edges, reducing photosynthetic area Skeletonized leaves, as beetles feed on the soft leaf tissue	Apply neem oil @ 5 ml litre^{-1} of water, handpick and destroy beetles
Terminalia arjuna	Bark	Brown	Arjuna leaf webber	*Eutectona machaeralis* (Figure 5)	Webbing of leaves, feeding on chlorophyll	Leaves appear webbed, yellowing, and defoliation	Application of biopesticides (*Bacillus thuringiensis*) @ 2 g litre^{-1} of water, conserve natural predators like spiders and coccinellid beetles
			Bark borer	*Indarbela tetraonis*	Bore into bark, causing drying of branches	Boreholes in bark, leading to damage to vascular tissues. Drying of branches, often accompanied by frass accumulation around the tree base	Use neem-based biopesticides, remove and destroy affected branches
Caesalpinia sappan	Heart wood	Red	Pod borer	*Helicoverpa armigera* (Figure 6)	Feeds on pods and seeds	Pods with boreholes, reduced seed quality	Spray Azadirachtin 1500ppm @ 5 ml litre^{-1} of water and release egg parasitoids like *Trichogramma chilonis* @ 50,000 per release.
			Defoliator	*Spodoptera litura*	Feeds on leaves, reducing photosynthetic ability	Irregular holes on leaves, often skeletonizing them. Defoliation, leaving only midribs in severe infestations.	Spray *Bacillus thuringiensis* @ 2 g litre^{-1} of water
Conocarpus erectus	Bark		Termites	*Odontotermes* spp. (Figure 7)	Feed on woody tissues	Hollowing of branches, weakening of the tree	Application of neem-based insecticides, maintain field sanitation, avoid water stress

Table 2: Continue...

Natural dye-yielding plant	Dye yielding part	Dye colour	Name of the insect pest	Scientific name	Nature of damage	Symptoms of damage	Eco-friendly management
			Stem borer	*Batocera rufomaculata*	Bores into stems, weakens the tree	Boreholes in stems and branches. Drying and dieback of branches due to internal feeding	Prune and destroy infested stems, apply neem oil @ 5 ml litre^{-1} of water
Bixa orellina	Seed	Red	Mealybug	*Maconellicoccus hirsutus* (Figure 8)	Suck sap from leaves and twigs	Stunted growth, leaf curling, honeydew secretion leading to sooty mold	Spray soap solutions or neem oil, introduce predators like ladybird beetles (*Cryptolaemus montrouzieri*)
			Aphids	*Aphis gossypii*	Sap-sucking, reduces plant vigor	Yellowing and curling of leaves due to sap-sucking activity. Honeydew secretion, which promotes the growth of sooty mold	Apply neem-based solutions Promote the conservation or mass release of natural predators such as *Cryptolaemus montrouzieri* (mealybug destroyer) and syrphid flies (hoverflies)
Indigofera tinctoria	Plant/leaf processed to fermented cake form	Blue	Aphids	*Aphis craccivora* (Figure 9)	Sap-sucking	Yellowing and curling of leaves, reduced plant vigor	Apply neem-based sprays. Encourage natural enemies like lacewings (*Chrysoperla* spp.)
			Thrips	*Thrips tabaci* (Figure 10)	Feeds on leaves, causing silvery streaks	Silvery streaks on leaves due to feeding damage	Use of blue sticky traps @ 50 ha^{-1} Spray *Beauveria bassiana* @ 5 g litre^{-1} of water
Lawsonia inermis	Leaves and stems	Reddish-brown	Whitefly	*Bemisia tabaci* (Figure 11)	Suck plant sap, vector viral diseases	Yellowing, stunted growth, reduced photosynthesis	Spray neem oil @ 5 ml litre^{-1} or *Lecanicillium lecanii* @ 5 g litre^{-1} of water , remove and destroy affected plants.
			Thrips	*Thrips tabaci* (Figure 10)	Feed on young leaves and flowers	Silvery streaks on leaves due to feeding damage Flower abortion, leading to reduced yield.	Use of blue sticky traps @ 50 ha^{-1} Spray *Beauveria bassiana* @ 5 g litre^{-1} of water.

their sustainable solutions are listed in Table 2 (Prakash and Rao., 2018).

3. Nature Friendly Strategies for insect pest Management in Natural Dye-Yielding Trees

Integrated Pest Management (IPM) is a sustainable approach that combines various techniques to manage pest

Figure 1: *Indarbela quadrinotata*

Figure 2: *Euproctis fraterna*

Figure 3: *Deudorix isocrates*

Figure 4: *Leptocybe invasa*

Figure 5: *Eutectona machaeralis*

Figure 6: *Helicoverpa armigera*

Figure 7: *Odontotermes* spp.

Figure 8: *Maconellicoccus hirsutus*

Figure 9: *Aphis craccivora*

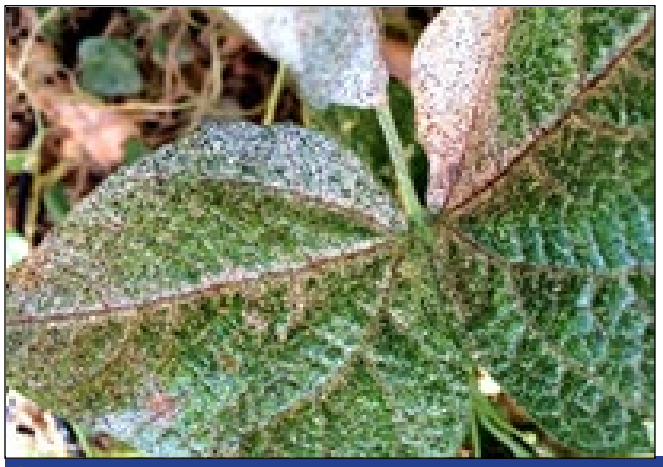

Figure 10: *Thrips tabaci*

Figure 11: *Bemisia tabaci*

populations effectively while minimizing environmental harm. The following strategies can be employed to ensure the health of natural dye-yielding plants:

3. 1. Cultural practices

Cultural methods focus on modifying the crop environment to make it less favorable for pests:

• **Diversity Planting:** Encouraging biodiversity by growing a variety of plant species around dye plants

Figure 12: *Butea monosperma*-*Spodoptera litura* damage

Figure 13: *Terminalia*-Leaf webber damage

creates a natural ecosystem that deters specific pests. The presence of companion plants can mask the host plant's attractiveness or provide habitats for beneficial organisms.

• **Crop Rotation:** Rotating dye-producing plants with other crop species disrupts the life cycles of pests that rely on continuous availability of a single host. For example, alternating between *Indigofera tinctoria* and a non-host crop can help control soil-borne pests.

3. 2. Monitoring

Effective pest management begins with regular monitoring to detect infestations early:

• Conduct frequent inspections to identify pests, diseases, or damage symptoms.

• Use small devices or tools like yellow sticky traps, pheromone traps or light traps to monitor pest populations and assess intervention thresholds. Early detection helps minimize damage and ensures timely application of control methods.

3. 3. Biological control

Harnessing natural predators and parasitoids is a cornerstone of eco-friendly pest management:

• Introduce beneficial insects, such as ladybirds (*Coccinellidae*) and lacewings (*Chrysopidae*), to prey on pests like aphids or whiteflies.

• Utilize parasitoids such as *Trichogramma spp.* to target eggs of lepidopteran pests, preventing larval damage to plant parts.

• Employ entomo-pathogenic fungi, such as *Beauveria bassiana*, to naturally infect and kill pests.

3. 4. Mechanical control

Manual and physical methods can directly reduce pest populations:

• **Hand-Picking:** Remove visible pests like caterpillars or beetles by hand to control infestations in smaller plantations.

• **Pruning and Sanitation:** Cut off infested plant parts and dispose of them properly to prevent pest spread. This is effective especially for borers in trees like *Curcuma longa*.

3. 5. Soil and nutrient management

Healthy plants are more resilient to pest attacks:

• Improve soil quality by adding organic compost, biofertilizers and maintaining proper pH levels.

• Use balanced fertilization to strengthen plant defenses, ensuring the production of high-quality dye compounds.

• Avoid waterlogging or drought conditions, which can stress plants and make them more susceptible to pests.

3. 6. Education and awareness

Engaging and educating stakeholders ensures the effective adoption of IPM strategies:

• Conduct training programs for farmers and local communities on sustainable pest management techniques and their benefits.

• Highlight the ecological and economic importance of natural dye-yielding plants to promote their cultivation and conservation.

4. Conclusion

Implementing eco-friendly pest management strategies in natural dye-yielding tree species promotes a sustainable production by reducing use of chemical inputs, preserving

beneficial organisms, and strengthening plant resilience to pest attacks. A holistic approach to pest management can be achieved by combining cultural, biological, and mechanical methods with community engagement.

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