Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 04 (JULY-AUG, 2026)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Biological Strategies for San Jose Scale Suppression in Kashmir

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The apple (*Malus* × *domestica* Borkh.), a member of the Rosaceae family and genus Malus, is one of the most widely grown temperate fruit crops in the world. Often referred to as the "King of Temperate Fruits," it flourishes in a variety of temperate climates in both the Northern and Southern hemispheres and is a major player in the production and commerce of fruits worldwide. The apple is prized for its outstanding nutritional profile in addition to its economic importance. It is a great source of antioxidants, flavonoids and dietary fiber, all of which support human health and wellbeing. High concentrations of phytochemicals such quercetin, catechin, phloridzin and chlorogenic acid are linked to lower risks of diabetes, asthma, cardiovascular disease and several types of cancer (Boyer & Liu, 2004).

The San Jose scale (*Quadraspidiotus perniciosus* Comstock) is a notorious scale insect that has become a major pest of apple orchards in Kashmir. Its ability to infest twigs, branches and fruits leads to reduced vigor, blemished produce and significant economic losses. Conventional chemical control has provided temporary relief but has also triggered resistance, residue concerns and ecological imbalance. This has shifted attention toward biological suppression strategies, which offer sustainable, eco-friendly solutions tailored to the unique agro-climatic conditions of Kashmir.

There are currently over 1,400 biopesticidal products registered globally, most of which fall under microbiological categories (Marrone, 2007). These include viruses from the Baculoviridae family, bacteria like *Bacillus thuringiensis* and *Lysinibacillus sphaericus*, fungi like *Beauveria bassiana* and *Metarrhizium anisopliae* and entomopathogenic nematodes from the Heterorhabditidae and Steinernematidae families (Lacey *et al.*, 2015; Kachhawa, 2017). Additionally, neem (*Azadirachta indica*) formulations and other plant-derived botanicals are frequently employed to control pests. The biological control agents are typically more selective, frequently target-specific and have no toxicity to people, animals and beneficial species. Their application enhances biodiversity, lowers pesticide residues and promotes better agricultural environments (Damalas & Koutroubas, 2018). Augmentative releases, conservation of indigenous biocontrol agents and habitat manipulation through selective cultural practices are increasingly emphasized as eco-friendly alternatives. These approaches not only reduce dependence on chemical inputs but also align with global trends toward sustainable orchard management.

Biological control of San Jose Scale

- *Beauveria bassiana* was the most potent, achieving 76–77% mortality at a concentration of 15×10^5 conidia/ml.
- *Lecanicillium lecanii* followed closely, causing 73–75% mortality at the same formulation level.
- *Metarhizium anisopliae* sensu lato was comparatively less effective, with mortality ranging between 47–67% across sites (Buhroo, 2014).

- *B. bassiana* and *L. lecanii*, as promising biological control agents for managing San Jose scale populations in apple orchards (Buhroo *et al.*, 2016).
- *Chilocorus infernalis* Mulsant (Coleoptera: Coccinellidae) can reduce the San Jose scale in apple orchards (Khan, 2010).
- The aphelinid wasps *Encarsia perniciosi* and *Aphytis* spp. parasitize San Jose scale, which helps to decrease natural populations. Early-season monitoring using sticky or pheromone traps can aid in timing biological control operations (Ahmad *et al.*, 2021).

Augmentative and Conservation Approaches

Habitat manipulation

- Establishing flowering strips and hedgerows provides nectar and pollen, enhancing parasitoid survival.
- Maintaining ground cover vegetation supports alternative prey, stabilizing predator populations.
- Avoiding broad-spectrum insecticides conserves beneficial arthropods.

Augmentative Releases

- Mass rearing of *Chilocorus bijugus* has been attempted in Kashmir, with periodic releases in infested orchards showing promising reductions in scale density.

Integration with cultural practices

- Pruning of heavily infested branches reduces pest load and exposes hidden colonies to natural enemies.
- Whitewashing tree trunks with lime discourages crawler settlement, indirectly aiding biological agents.
- Orchard sanitation (removal of pruned material and infested debris) prevents reinfestation and supports predator efficiency.

Challenges in Kashmir

- Climatic constraints: Harsh winters reduce survival of certain natural enemies.
- Farmer practices: Inconsistent adoption of IPM and reliance on chemical sprays limit biological control effectiveness.
- Infrastructure gaps: Lack of mass rearing facilities for predators and parasitoids restricts augmentative releases.
- Awareness: Farmers often underestimate the role of natural enemies, leading to unnecessary pesticide use.

Future prospects

- Classical biological control: Introduction of exotic parasitoids adapted to temperate climates could strengthen suppression.
- Molecular tools: DNA barcoding and molecular diagnostics can help monitor parasitoid diversity and effectiveness.
- IPM integration: Combining biological agents with selective horticultural oils and reduced-risk insecticides ensures synergistic suppression.
- Farmer training: Awareness programs and demonstration orchards can promote adoption of biological strategies.

Conclusion

Biological suppression of San Jose scale in Kashmir apple orchards highlights the promise of eco-friendly pest management. Entomopathogenic fungi such as *Beauveria bassiana* and *Lecanicillium lecanii* have shown high mortality rates, while predators like *Chilocorus infernalis* and parasitoids (*Encarsia perniciosi*, *Aphytis* spp.) contribute to natural regulation. Habitat manipulation, augmentative releases and cultural practices like pruning and sanitation further strengthen orchard resilience. However, harsh winters, limited mass-rearing facilities, and farmer reliance on chemical sprays remain key challenges. Future prospects lie in classical biological control, molecular monitoring tools and integration into IPM frameworks.

Farmer training and awareness programs will be crucial to encourage adoption of these strategies. Collectively, these approaches can reduce pesticide dependence, conserve biodiversity and ensure sustainable apple production in Kashmir.

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