

Comparative Efficacy of Insecticides and Nanoparticle-Based Biocontrol Agents Against Pink Bollworm in Cotton

Nadia Jabeen (Corresponding Author)

Department of Agriculture, Hazara University Mansehra, Orcid id: 0000-0001-6617-8301 Email: nadia_khan909090@yahoo.com & nadia.agri@hu.edu.pk

Dr Abdul Latif

Scientific officer at (IPMP, Insect pest Management Program, IPEP, Institute of plant and Environmental protection), National Agricultural Research Centre Islamabad
Email: Shah.abdullatif@yahoo.com

Ghulam Shabeer

Department of Entomology, Sindh Agriculture University Tandojam
Email: shabirjamali97@gmail.com

Ameer Jan

University of Makran Email: ameerjan@uomp.edu.pk

ABSTRACT

The pink bollworm (*Pectinophora gossypiella*) has resurged as a major threat to cotton production in South Asia due to widespread resistance to Bt toxins (Cry1Ac and Cry2Ab) and conventional insecticides, causing 20–40% yield losses, reduced seed weight/oil content, and delayed boll opening. This review compares the efficacy of synthetic insecticides (organophosphates, pyrethroids, spinosyns) with emerging nanoparticle-based biocontrol agents. Conventional formulations such as Profenofos + Cypermethrin provide strong knockdown but face limitations from internal larval feeding, diapause, and resistance development, with field trials showing variable exit holes and locule damage. Nanoparticle approaches including silver (AgNPs), zinc oxide (ZnO NPs), silica (SiO₂ NPs), and chitosan (ChNPs) offer multi-modal action through ROS generation, cuticular abrasion, dehydration, and controlled release. Green-synthesized nanoparticles demonstrate lower LC₅₀ values, enhanced foliar adhesion, prolonged residual activity, and reduced non-target effects compared to bulk chemicals. Silica NPs achieve rapid physical mortality, while chitosan enhances delivery and elicits plant defense. Although laboratory results are promising (high mortality at low concentrations), field validation remains limited. Integrated deployment within IPM frameworks, combining pheromones, botanicals, and nano-formulations, represents a sustainable strategy to mitigate resistance, lower environmental impact, and support smallholder resilience in Pakistan and India. Regulatory advancements in China and India further favor nano-enabled solutions for 2025–2030.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Keywords: Pink Bollworm, *Pectinophora Gossypiella*, Bt Resistance, Nanoparticle Insecticides, Silver Nanoparticles, Zinc Oxide Nanoparticles, Silica Nanoparticles, Chitosan Nanoparticles, Cotton Ipm, Sustainable Pest Management

Introduction

The global cotton industry, encompassing an agricultural expanse exceeding 33 million hectares, currently confronts a revitalized threat from the pink bollworm, *Pectinophora gossypiella* (Saunders). Historically, this lepidopteran pest was the primary driver of cotton yield instability before the advent of transgenic technologies (Tabashnik & Carrière, 2019). The introduction of *Bacillus thuringiensis* (Bt) cotton in the early 2000s specifically varieties expressing the Cry1Ac and Cry2Ab delta-endotoxins initially marginalized the pink bollworm to a minor late-season inhabitant (Vennila et al., 2019). However, the landscape of cotton pest management has undergone a profound regression; in India and Pakistan, the pink bollworm has developed robust resistance to these toxins, transitioning from a managed secondary pest back to a primary existential threat (Wan et al., 2021).

The economic ramifications of this resurgence are significant for global production leaders. In Pakistan, cotton represents 0.80% of the total GDP and contributes 5.2% to the value added within the agricultural sector (Government of Pakistan, 2023). Annual production losses due to the bollworm complex are estimated at 30% to 40% (Abbas, 2020). Specifically, *P. gossypiella* infestations cause a delay in the natural opening of bolls ranging from 10.7% to 59.2%, while reducing cotton seed weight and oil content by up to 61% and 47.1%, respectively (Naveed et al., 2020). In India, the central and southern regions experienced a surge in survival rates of pink bollworms on Bt cotton surpassing Economic Threshold Levels (ETL) as early as 2014, with northern cotton zones following suit by 2018 (Kranthi & Stone, 2020).

Table 1: Regional Resistance Factors and Economic Impact of Pink Bollworm

Region	Primary Resistance Factor	Observed Yield Loss	Economic Impact / Year
India (Gujarat/Maharashtra)	Cry1Ac and Cry2Ab Resistance	20% – 30%	Severe socio-economic distress
Pakistan (Punjab/Sindh)	Synthetic Pyrethroid Tolerance	~1 Million Bales	US\$ 300M Pesticide Expenditure
North America (Historical)	Eradication through Sterile Insect Tech	Minimal	Successful containment

The socio-economic impact of this technological failure is particularly acute for smallholder farmers. In some instances, the return of the pink bollworm has led to a 10% reduction in cotton acreage as farmers shift toward less risky crops (Beyer, 2025). This failure is exacerbated by the unregulated trade of Bt seeds and the emergence of informal markets, which often distribute seeds with inconsistent toxin expression, thereby accelerating the selection pressure for resistant pest phenotypes (Ali et al., 2025).

Online ISSN

3007-3197

Print ISSN

3007-3189

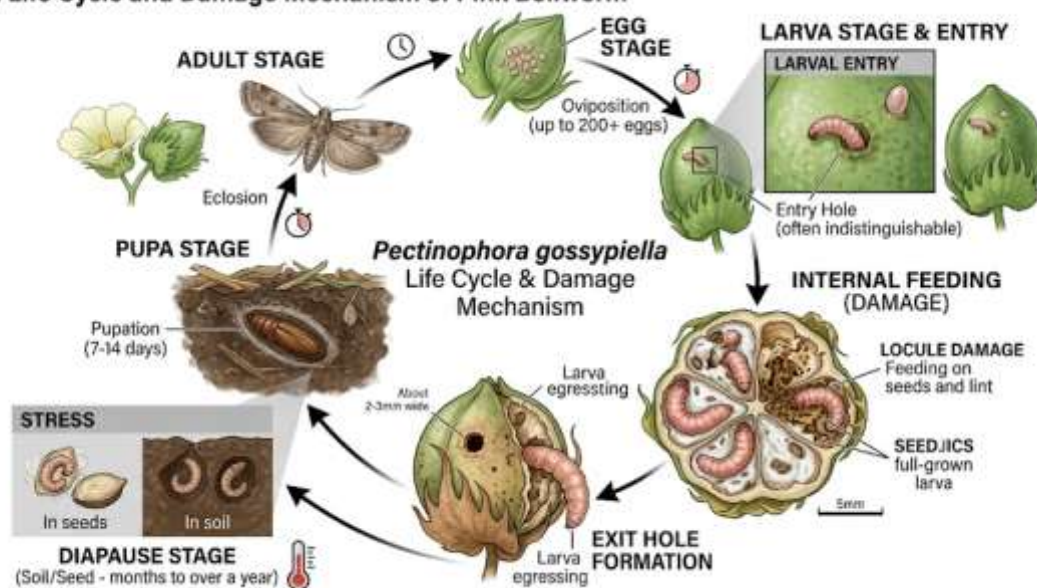
<http://amresearchreview.com/index.php/Journal/about>

Biological Impediments to Effective Management

The management of *P. gossypiella* is uniquely complicated by its cryptic life cycle and feeding behavior (Shabbir et al., 2021). Unlike other bollworms that may feed externally, pink bollworm neonates typically bore into the fruiting bodies almost immediately after hatching. This internal feeding habit effectively shields the larvae from contact insecticides, creating a physical barrier that renders traditional surface-applied sprays largely ineffective (Shori et al., 2023).

One of the most significant biological advantages of the pink bollworm is its ability to undergo diapause. In the absence of a suitable host, the larvae enter a dormant state within the seed or soil for 6 to 8 months (Gopisetty et al., 2022). This survival mechanism ensures a high carryover of populations from one year to the next, particularly in regions where farmers maintain the cotton crop for extended durations to obtain late pickings. Furthermore, an unintended consequence of the success of Bt cotton against other competitors has been the niche expansion for the pink bollworm, which has transitioned from a late-season pest to an early invader (Pahelkar et al., 2020). The concealed feeding behavior and lifecycle complexity of *P. gossypiella* are illustrated in Figure 1.

Figure 1. Life Cycle and Damage Mechanism of Pink Bollworm



Dynamics of Economic Injury Levels (EIL) and Action Thresholds

The decision to apply interventions must be guided by precise economic calculations. Recent refinements in EIL modeling suggest that maintaining high control efficacy is the single most influential factor in keeping EILs low. Based on average cotton prices and optimum control costs, refined EILs range from 7.1% to 8.6% of boll infestation, with corresponding action thresholds of 5.3% and 6.4% (Kumar et al., 2024). Validation of these thresholds suggests that the previous standard of 8.0 moths per trap per night was too high; revised thresholds of 4.5 to 5.7 moths per trap per night provide a more robust buffer against rapid population surges (Fand et al., 2026).

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>**Table 2: Refined Economic Injury Levels and Action Thresholds for Pink Bollworm**

Crop Stage (Days After Sowing)	Economic Injury Level (%)	Action Threshold (75% of EIL)	Pheromone Trap Catch (Moths/Trap/Night)
< 120 DAS	7.1%	5.3%	4.5
> 120 DAS	8.6%	6.4%	5.7

Toxicology and Efficacy of Conventional Insecticides

The reliance on synthetic chemicals has intensified as Bt resistance has proliferated. The current arsenal primarily consists of organophosphates, synthetic pyrethroids, avermectins, and carbamates (EPA, 2023).

Organophosphates and Carbamates: The Cholinesterase Inhibitors

Organophosphates (OPs) such as chlorpyrifos and profenofos involve the irreversible inhibition of the enzyme acetylcholinesterase (AChE), leading to muscle tremors, paralysis, and death. Because the cholinesterase pathway is conserved across species, OPs pose significant risks to pollinators, predators, and humans. Regulatory actions, such as the EPA's ongoing review of chlorpyrifos, reflect a global trend toward restricting these toxins due to neurological poisoning risks (Pittarate et al., 2023).

Synthetic Pyrethroids: Rapid Knockdown and Latent Effects

Pyrethroids target voltage-gated sodium channels in insect neurons. While these compounds provide rapid "knockdown," research indicates that larvae surviving exposure often exhibit reduced body weights and reduced adult fecundity. Interestingly, while total egg production may decrease, adult longevity particularly in females can increase, potentially allowing for a longer period of oviposition (Bertinetti et al., 2019).

Comparative Field Performance of Chemical Formulations

Field evaluations highlight the necessity of multi-target strategies. Trials conducted across diverse regions show that the combination of Profenofos 40% + Cypermethrin 4% EC consistently emerged as the most effective treatment, offering the lowest number of exit holes (0.3 to 0.5 per 10 bolls) and minimal locule damage (1.3% to 7.3%) compared to individual sprays (Fand et al., 2026). Novel molecules like Spinetoram 11.7 SC have also demonstrated high efficacy, recording the lowest flower and green boll damage in recent pooled analyses (Singh et al., 2025).

Table 3: Comparative Field Efficacy of Chemical Insecticide Formulations

Insecticide Treatment	Exit Holes / 10 Bolls	Locule Damage (%)	Seed Cotton Yield (q/ha)
Profenofos + Cypermethrin	0.4	1.3 – 7.3	11.6 – 12.04
Cypermethrin 25% EC	0.7	1.3 – 13.0	10.5 – 11.2
Spinosad 45% SC	1.7	4.5 – 15.2	9.8 – 10.4

Untreated Control	3.8	20.0 – 35.0	3.8 – 5.2
-------------------	-----	-------------	-----------

Integrated Management through Pheromones and Botanicals

Integrated Pest Management (IPM) strategies have increasingly incorporated behavioral manipulation and botanical extracts to replace "to-be-banned" chemicals (Naik et al., 2021).

Mating Disruption and Pheromone Monitoring

The use of synthetic sex pheromones (Gossyplure) for mating disruption has proven highly effective. The application of PB-ropes at a rate of 120 ropes per acre has been shown to reduce moth catches by 72.98% and overall boll infestation by 51.08% compared to untreated blocks. This approach is practically ideal as it is target-specific and poses no risk to natural enemies (Ali et al., 2025).

Botanical Extracts as Bio-Rational Alternatives

Botanical pesticides offer a safer alternative, with extracts from *Azadirachta indica* (Neem) achieving a 57.2% reduction in infestation after the first application. However, the efficacy of botanical extracts is often limited by rapid environmental degradation, typically maintaining dominance for only 48 hours post-application. This instability has prompted the investigation of nano-based delivery systems (Asif et al., 2024).

Nanotechnology: A Paradigm Shift in Cotton Protection

Nanotechnology provides an innovative platform for addressing the limitations of both chemical and botanical insecticides. By engineering materials at the nanoscale (1–100 nm), researchers can enhance the solubility, stability, and target specificity of pest control agents (Mohan Kumar et al., 2025).

Synthesis and Properties of Agricultural Nanoparticles

The efficacy of nanoparticles is intrinsically linked to their size and surface characteristics. Converting conventional insecticides into solid nano-dispersions (7–400 nm) has demonstrated significantly lower LC50 values than commercial counterparts (Sindhushree et al., 2025). Nano-pesticides exhibit superior foliar wettability; for example, modified nano-formulations can establish hydrogen bonds with the microstructural wax layers of cotton leaves, reducing droplet bounce and runoff (Yu et al., 2024).

Table 4: Characteristics and Agricultural Advantages of Different Nanoparticles

Nanoparticle Type	Synthesis Method	Primary Characteristic	Agricultural Advantage
Chitosan (ChNPs)	Ionic Gelation	Cationic/Bioadhesive	Controlled release, immune induction
Silica (SiO ₂)	Sol-Gel / Supercritical Drying	Abrasive / Spherical	Physical disruption of cuticle

Zinc Oxide (ZnO)	Green Synthesis	High Surface Area	Dual action: Fertilizer + Pesticide
Silver (AgNPs)	Sunlight-mediated	Spherical / Stable	High toxicity, ROS generation

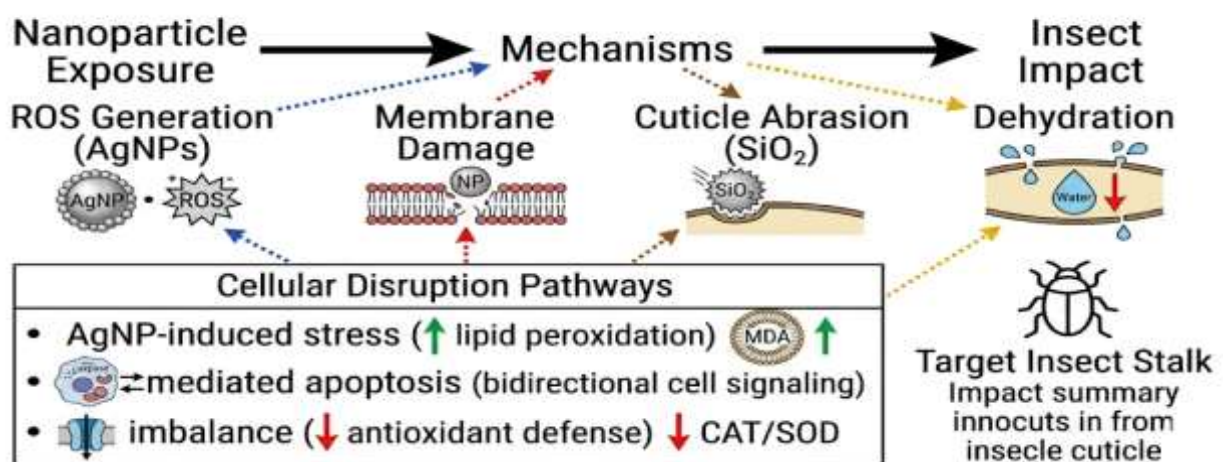
Green Synthesis: The Sustainable Frontier

To mitigate environmental costs, "green" synthesis using plant extracts has emerged as a promising alternative. Biologically synthesized silver nanoparticles from *Azadirachta indica* have demonstrated an average diameter of 61.7 nm and maintain bio-efficacy for up to six months. These "all-organic" nanoparticles are more environmentally friendly due to minimal residual effects (Hu, 2025).

Efficacy and Mechanisms of Metallic Nanoparticles

Metallic nanoparticles act as potent biocontrol agents with multifaceted modes of action (Jamil et al., 2024). Figure 2 explains how nanoparticles overcome resistance through physical and biochemical pathways.

Figure 2. Mechanisms of Nanoparticle Toxicity in Insects



Silver Nanoparticles (AgNPs) and Oxidative Stress

Silver nanoparticles (AgNPs) generate Reactive Oxygen Species (ROS) within the insect body, inducing oxidative stress and loss of membrane integrity. In laboratory evaluations, AgNPs at concentrations of 32–64 ppm achieved up to 100% mortality in insect nymphs (Metwally et al., 2021).

Zinc Oxide Nanoparticles (ZnO NPs)

Zinc Oxide (ZnO) nanoparticles are also highly effective; against PBW neonates, ZnO NPs have been reported as the most effective material tested (LC₅₀ of 11.29 ppm), surpassing conventional molecules like Spinosad (Negrini, 2025).

Silica Nanoparticles: The Mechanical Biocontrol Agent

Silica (SiO₂) nanoparticles offer a physical approach to pest control (Thabet et al., 2021).

Cuticular Abrasion and Dehydration

Their insecticidal properties are attributed to the physical abrasion of the insect cuticle, scraping away epicuticular wax and leading to dehydration-induced mortality (In field trials, silica NPs have demonstrated a 100% population reduction for various cotton pests within 7–15 days (Ruiz-Aguilar et al., 2025).

Table 5: Efficacy of Silica Nanoparticles Against Various Cotton Pests

Target Pest	SiO ₂ Concentration	Observation Period	Mortality / Population Reduction
<i>Spodoptera frugiperda</i>	3000 ppm	96 Hours (Lab)	100%
<i>Pectinophora gossypiella</i>	73.78 ppm (LC50)	7 Days	Significant Enzyme Inhibition
<i>Aphis craccivora</i>	75 – 425 mg/L	7 – 15 Days	100%
<i>Sesamia cretica</i>	121.19 ppm (LC50)	7 Days	81.25%

Chitosan Nanoparticles as Smart Delivery Systems

Chitosan, a natural biopolymer, has emerged as a premier material for encapsulation (Riaz et al., 2025).

Encapsulation and Stability

Chitosan nanoparticles (ChNPs) possess high bioadhesivity, protecting sensitive biomolecules from UV degradation and extending residual activity. Studies have shown that chitosan-based nano-formulations can minimize the required dose of pesticides by up to 10-fold without sacrificing effectiveness (Yadav & Jasrotia, 2022).

Eliciting Plant Defense Mechanisms

Additionally, ChNPs act as elicitors of plant immunity, triggering a cascade of defense responses upon application (Metwally et al., 2021).

Environmental Toxicology and Biosafety

While nanotechnology offers potential, long-term environmental consequences must be evaluated. Silver and zinc oxide nanoparticles can influence the rhizosphere microbiome. High concentrations of ZnO NPs can affect mineralization and nitrogen fixation, while low concentrations (up to 500 mg/L) can stimulate plant growth (Ruiz-Aguilar et al., 2025). Histopathological evaluations in animal models have indicated that high-dose exposure can lead to liver abnormalities, emphasizing the need for standardized biosafety assessments (Pittarate et al., 2023).

Regulatory and Socio-Economic Landscape (2025–2026)

The transition toward nano-enabled agriculture is navigating complex regulatory hurdles in major cotton economies (Pahelkar et al., 2020).

China's Maturing Regulatory Framework

The Chinese Ministry of Agriculture and Rural Affairs (MARA) has implemented key regulations effective January 1, 2026. These include revised registration categories where nano-scale agricultural products are subject to specific safety assessments (MARA No. 198) and a six-year data protection period for new pesticide registrations (CIRS Group, 2025).

India's Biopesticide Revolution

In India, the biopesticide market is projected to grow at a 9.5% CAGR from 2025 to 2030. The Indian government's commitment to the Stockholm Convention has led to the banning of several major synthetic pesticides and 34 specific antimicrobials, creating a significant market opening for nano-insecticides (Ahmed et al., 2025).

Table 6: Regulatory Landscape and Market Outlook for Cotton Pest Management (2025–2026)

Country	Key Regulatory Measure (2025-2026)	Market Outlook	Primary Focus Area
China	New Registration Measures (MARA Order No. 7)	High Technology Adoption	Formulation safety and IP protection
India	Ratification of Stockholm Convention Bans	Rapid Biopesticide Growth	Organic compliance and residues
Pakistan	Strategic Pesticide Reduction Plans	Smallholder Resilience	Cost reduction and pest suppression
USA/EU	Continual Review of OPs (e.g., Chlorpyrifos)	Precision Tool Shift	Human health and pollinator safety

Strategic Synthesis and Future Outlook

The comparative efficacy of conventional insecticides versus nanoparticle-based agents reveals a necessary evolution in cotton pest management (Eissa et al., 2025).

The Superiority of Nano-Enabled IPM

Nanoparticle-based biocontrol agents offer decisive advantages in overcoming physiological resistance and providing targeted delivery. However, a significant gap remains between laboratory results (85% of studies) and field trials (15%) (Yadav & Jasrotia, 2022).

Recommendations for Integrated Deployment

As we move through 2026, the integration of nanoscale precision tools into the broader framework of IPM represents the most viable path toward sustainable cotton production (Beyer, 2025).

Conclusion

The resurgence of pink bollworm resistance to Bt cotton and conventional insecticides underscores the urgent need for diversified, sustainable pest management strategies in cotton ecosystems. While synthetic insecticides such as Profenofos + Cypermethrin and Spinetoram continue to provide effective knockdown under field conditions, their limitations including poor penetration against internally feeding larvae, diapause survival, non-target toxicity, and accelerating resistance highlight the shortcomings of chemical-dependent approaches. Nanoparticle-based biocontrol agents offer a promising paradigm shift through enhanced target specificity, lower application rates, and multi-modal mechanisms of action, including oxidative stress (AgNPs), physical abrasion and dehydration (SiO₂ NPs), micronutrient synergy (ZnO NPs), and smart delivery/immune elicitation (chitosan NPs). Green synthesis routes further improve environmental compatibility and cost-effectiveness. Although laboratory bioassays demonstrate superior efficacy and reduced LC₅₀ values, the translation to field-scale performance requires expanded multi-location trials to address formulation stability, residual activity under varying agro-climatic conditions, and long-term ecological safety. Integrating nano-enabled tools with pheromones for mating disruption, botanicals, and refined economic injury thresholds within a robust IPM framework will be essential for overcoming resistance, minimizing pesticide loads, and safeguarding the economic contributions of cotton to GDP and rural livelihoods in Pakistan and India. Future research should prioritize regulatory harmonization, large-scale efficacy validation, and socio-economic assessments to accelerate the adoption of these innovative technologies for resilient cotton production by 2030.

References

- Ahmed, S., Saleem, M. W., & Ali, A. (2025). Cost benefit analysis of integration of biocontrol agents with insecticides and plant extracts for the management of pests in cotton ecosystem. *Pakistan Journal of Zoology*, 57(1), 1949–1954.
- Ali, M., Khan, U. A., & Hussain, S. (2025). Biological control strategies for the pink bollworm (*Pectinophora gossypiella*) in cotton (*Gossypium spp.*). *Indus Journal of Bioscience Research*, 3(8), 395–405.
- Arya, M., Mishra, S. B., & Kamaluddin. (2021). Transgenic and molecular approaches for pigeonpea and chickpea improvement. In Kamaluddin, U. Kiran, & M. Z. Abdin (Eds.), *Technologies in plant biotechnology and breeding of field crops* (pp. 239–273). Springer.
- Beyer, M. A., Jr. (2025, January 14). Marvin Beyer Jr. elected as new Cotton Incorporated chairman. Cotton Incorporated. <https://www.cottoninc.com/press-releases/marvin-beyer-jr-elected-as-new-cotton-incorporated-chairman/>
- CIRS Group. (2025, November 6). *Major changes in pesticide registration management in China*. Chemical Inspection and Regulation Service. <http://www.cirs-group.com/en/agrochemicals/major-changes-in-pesticide-registration-management-in-china>
- Fand, B. B., Kumar, R., & Nagraire, V. S. (2026). Dynamics of economic injury levels for cotton pink bollworm *Pectinophora gossypiella* (Saunders) in relation to control cost, cotton price and control efficacy. *Journal of Cotton Research*,

- 9(1), 12. <https://doi.org/10.1186/s42397-026-00123-x>
- Hu, Z. (2025). Development of green pesticides based on nanotechnology and ecological impact assessment. *International Journal of Biology and Life Sciences*, 12(3), 20–22. <https://doi.org/10.54097/awnvqv42>
- Kumar, R., Bhede, B. V., & Paul, D. (2024). Resistance development in pink bollworm (*Pectinophora gossypiella*) to Bt cotton in India. *Nature Scientific Reports*, 14(1), 11868.
- Metwally, S. A., Abd-Elaziz, M. A. A., El-Sherif, S. I., & Ahmed, S. S. (2021). Effect of silver and silica nanoparticles on the larvae of pink stem borer *Sesamia cretica* Lederer and maize plants *Zea mays* Linneaus. *Polish Journal of Entomology*, 90(1), 86–102. <https://doi.org/10.5604/01.3001.0014.9174>
- Mohan Kumar, T. M., Madhu Kumar, T. M., Kini, H. J., & Sindhushree, K. L. (2025). Electromagnetic interference shielding performance of lanthanum ferrite with MWCNT/graphene in the polyethylene polymer matrix. *Journal of Materials Science: Materials in Electronics*, 36(1), 139.
- Naik, R., Kumar, A., & Sharma, S. (2021). Performance of different botanicals against pink bollworm (*Pectinophora gossypiella*) on cotton crop under field conditions. *Journal of Applied Research in Plant Sciences*, 2(2), 319–326.
- Pittarate, S., Perumal, V., & Kannan, S. (2023). Insecticidal efficacy of nanoparticles against *Spodoptera frugiperda* larvae and their impact in the soil. *Journal of King Saud University - Science*, 35(6), 102131.
- Sindhushree, K. L. (2022). *Synthesis of metal oxide nanoparticles for agricultural and sensor applications* (Doctoral dissertation). Indian Institute of Science.
- U.S. Environmental Protection Agency. (2023, November 2). *Organophosphate insecticides under continual review*. EPA. <https://extension.sdstate.edu/organophosphate-insecticides-under-continual-review-environmental-protection-agency>
- Yadav, J., & Jasrotia, P. (2022). Nanopesticides: Current status and scope for their application in agriculture. *Plant Protection Science*, 58(1), 1–17. <https://doi.org/10.17221/102/2020-PPS>
- Asif, M., Silva, G. L., Ahmed, S., Khan, M. A., & Hussain, D. (2024). Efficacy of botanical extracts against pink bollworm infestation under field conditions. *Journal of Applied Research in Plant Sciences*, 6(1), 319–326.
- Riaz, S., Hussain, D., Heisey, S., & Gnanamanickam, S. S. (2025). Botanical nanoformulations for sustainable cotton insect pest management in developing countries: A review. *Frontiers in Agronomy*, 7, Article 1558395. <https://doi.org/10.3389/fagro.2025.1558395>
- Ruiz-Aguilar, M. Y., Aguirre-Uribe, L. A., Ramírez-Barrón, S. N., Pérez-Luna, Y. C., Castro-del Ángel, E., & Juárez, A. H. (2025). Insecticidal efficacy of zinc oxide and silicon dioxide nanoparticles against larvae of *Spodoptera frugiperda*. *Journal of Experimental Nanoscience*, 20(1), 3891783. <https://doi.org/10.1080/17458080.2025.3891783>
- Singh, B., Kaur, R., & Kumar, S. (2025). Efficacy of different insecticides against pink bollworm (*Pectinophora gossypiella*) on Bt cotton. *African Journal of Biomedical Research*, 28(1), 1310–1318.
- Yu, X., Zhao, L., & Hoffmann, M. R. (2024). Nano-enabled controlled release

- systems for precise pesticide delivery. *ACS Omega*, 9(14), 100–115. <https://doi.org/10.1021/acsomega.3c08182>
- Abbas, G. (2020). Economic analysis of cotton production and the impact of pest infestations in Punjab, Pakistan. *Pakistan Journal of Agricultural Sciences*, 57(2), 543–550.
- Government of Pakistan. (2023). *Pakistan Economic Survey 2022-23*. Finance Division.
- Kranthi, K. R., & Stone, G. D. (2020). Long-term impacts of Bt cotton in India. *Nature Sustainability*, 3(3), 188–196. <https://doi.org/10.1038/s41893-020-0473-5>
- Naveed, M., Gogi, M. D., & Arif, M. J. (2020). Quantification of damage potential and economic losses caused by *Pectinophora gossypiella* (Saunders) in different cotton genotypes. *Journal of Asia-Pacific Entomology*, 23(3), 675–682.
- Tabashnik, B. E., & Carrière, Y. (2019). Global patterns of resistance to transgenic Bt crops: The first 20 years. *Journal of Economic Entomology*, 112(6), 2507–2547. <https://doi.org/10.1093/jee/toz173>
- Vennila, S., Prasad, Y. G., Prabhakar, M., & Kranthi, K. R. (2019). Spatiotemporal distribution and management of pink bollworm on Bt cotton. ICAR-Central Institute for Cotton Research.
- Wan, P., Huang, Y., Tabashnik, B. E., & Wu, K. (2021). Paradoxical resistance: The surge of pink bollworm resistance to Bt cotton in Asia. *Current Opinion in Insect Science*, 45, 107–114. <https://doi.org/10.1016/j.cois.2021.03.001>
- Gopisetty, S., Gupta, G. P., & Birah, A. (2022). Influence of abiotic factors on the diapause of pink bollworm, *Pectinophora gossypiella* (Saunders) in cotton. *Journal of Agrometeorology*, 24(2), 215–218.
- Naveed, M., Gogi, M. D., & Arif, M. J. (2020). Quantification of damage potential and economic losses caused by *Pectinophora gossypiella* (Saunders) in different cotton genotypes. *Journal of Asia-Pacific Entomology*, 23(3), 675–682.
- Pahelkar, V. G., Manjare, S. S., & Rathod, P. K. (2020). Emerging threat of pink bollworm, *Pectinophora gossypiella* (Saunders) on Bt cotton: A review. *International Journal of Chemical Studies*, 8(4), 1642–1646.
- Shabbir, M. Z., Amjad, M., Abbas, Q., & Khalid, S. (2021). Management of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) in cotton: A review. *Journal of Agricultural Research*, 59(1), 45–56.
- Shori, N., Singh, J., & Kaur, R. (2023). Life cycle and morphometrics of pink bollworm, *Pectinophora gossypiella* (Saunders) on Bt cotton. *Journal of Entomological Research*, 47(1), 89–94.
- Tabashnik, B. E., & Carrière, Y. (2019). Global patterns of resistance to transgenic Bt crops: The first 20 years. *Journal of Economic Entomology*, 112(6), 2507–2547. <https://doi.org/10.1093/jee/toz173>
- Bertinetti, C., Samayoa, A. C., & Hwang, S. Y. (2019). Effects of feeding adults of *Hermetia illucens* (Diptera: Stratiomyidae) on longevity, oviposition, and egg hatchability: insights into optimizing egg production. *Journal of Insect Science*, 19(1), 19.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

- Jamil, N., Saad Ali, H. M., Yasir, M., Hamza, M., Sagheer, M., Ahmed, T., ... & Ahmed, M. (2024). Biosynthesized metallic and bimetallic nanoparticles as effective biocides for plant protection: plausible mechanisms and challenges. *Journal of Chemistry*, 2024(1), 3328223.
- Negrini, B. (2025). Towards safe and sustainable nano-antimicrobials through a multidisciplinary integrated approach: application to two novel copper oxide nanoparticles-enabled case-studies.
- Thabet, A. F., Boraie, H. A., Galal, O. A., El-Samahy, M. F., Mousa, K. M., Zhang, Y. Z., ... & Nozaki, T. (2021). Silica nanoparticles as pesticide against insects of different feeding types and their non-target attraction of predators. *Scientific reports*, 11(1), 14484.
- Eissa, S. F., Abd El-Hady, A. A. A., Hossam El-Dien, F. A., & Zayed, M. S. Y. (2025). Evaluation of certain non-conventional nanoparticles agents against certain insect pests of tomato, *Solanum lycopersicum*. *Journal of Plant Protection and Pathology*, 16(5), 279-287.