Current Trends in Chemical Control: A Review of Novel Insecticide Molecules for Soybean Pest Management.

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Abstract

Soybean is one of the world's most important oilseed and protein crops, cultivated widely for food, feed, and industrial applications. Despite its economic importance, soybean productivity is severely affected by a diverse group of insect pests. The reliance on conventional insecticides over several decades has resulted in increasing resistance, environmental issues, and reduced efficacy. To address these challenges, several novel insecticide molecules with innovative modes of action have been developed in recent years. This review provides an extensive evaluation of these new chemistries, discussing their classification, efficacy against major soybean pests, advantages over traditional insecticides, and their role within integrated pest management (IPM) frameworks. Future research directions, environmental implications, and resistance management strategies are also explored, offering comprehensive insight for sustainable soybean protection.

Key Words: Novel insecticides, Soybean pest management, Chemical control and Integrated pest management (IPM).

1. Introduction

Soybean (*Glycine max*), belonging to the family Fabaceae, has gained global prominence as a multipurpose crop. Its high protein (approximately 40%) and oil content (around 20%) make it vital for the food industry, livestock feed, biodiesel production, and numerous industrial uses. However, soybean cultivation faces significant constraints due to insect pests, which can reduce yield by 20–80% depending on infestation intensity and agroclimatic conditions.

For decades, the management of these pests relied on conventional chemicals such as organophosphates, carbamates, and pyrethroids. Although these insecticides once offered effective control, their long-term continuous use has resulted in multiple drawbacks including:

- Reduced field efficacy due to pest resistance
- Non-target impacts on pollinators and natural enemies
- Soil and water contamination
- Higher application frequency and increased production costs
- Stricter regulatory bans on hazardous molecules

These challenges underscore the need for **new, highly selective, and environmentally safer insecticide molecules**. Over the last two decades, agrochemical research has introduced multiple new groups such as diamides, spinosyns, sulfoximines, ketoenols, and oxadiazines. These molecules provide targeted action, improved safety, and compatibility with IPM.

This paper presents an expanded review of these newer molecules, detailing their roles and future potential in soybean pest management.

2. Major Insect Pests of Soybean

Soybean is attacked by more than 100 insect species, but only 10–15 of them cause economically significant damage. These pests can be broadly grouped as follows:

2.1 Lepidopteran Defoliators

These pests damage foliage, reduce photosynthetic activity, and destroy pods at later stages.

- **Helicoverpa armigera (Pod borer):**
  Attacks flowers and pods; capable of causing 30–50% yield loss under severe outbreaks.
- **Spodoptera litura (Armyworm):**
  A highly polyphagous pest; dense populations can defoliate entire fields rapidly.

2.2 Sap-Sucking Pests

- **Aphis glycines (Soybean aphid):**
  Reduces plant vigor, stunts growth, and transmits viral diseases such as the soybean mosaic virus.
- **Bemisia tabaci (Whitefly):**
  Causes direct sap loss, excretion of honeydew, and indirectly promotes sooty mold growth.
- **Leafhoppers:**
  Cause "hopper burn," reducing photosynthetic efficiency and overall plant health.

2.3 Soil and Early-Season Pests

- **White grubs, wireworms, cutworms** and **stem fly** damage seedlings, roots, and stems.
  Their damage is often unnoticed until the stand loss becomes visible.

The wide range of pests necessitates insecticides with different modes of action and application techniques.

3. Challenges of Conventional Insecticide Use

Traditional insecticides have proven inadequate due to several pressing concerns:

3.1 Development of Resistance

Many soybean pests, particularly *Helicoverpa* and *Spodoptera*, have developed resistance to multiple chemical groups including pyrethroids, organophosphates, and carbamates.

3.2 Non-target and Ecological Effects

Conventional chemicals often harm beneficial insects such as ladybird beetles, parasitoid wasps, predatory spiders, and pollinators.

3.3 Environmental Persistence

Many older insecticides remain in soil and water for extended periods, leading to contamination and food residue concerns.

3.4 High Application Costs

The falling efficiency of older chemicals increases spray frequency, adding to labor and input costs.

These factors highlight the urgent need for safer, selective, and effective insecticides.

4. Novel Insecticide Molecules for Soybean Pest Control

Over the last two decades, scientists have introduced new insecticide classes with unique modes of action that reduce resistance risk and improve safety.

4.1 Diamides (Ryanodine Receptor Modulators)

Examples: **Chlorantraniliprole, Flubendiamide, Cyantraniliprole**

- Mode: Disrupt calcium regulation in muscle cells, causing paralysis.
- Targets: Lepidopteran larvae (*H. armigera*, *S. litura*)
- Features: Highly selective, long residual activity, low toxicity to mammals and beneficial insects
- Significance: Among the most successful modern insecticide classes due to superior performance.

4.2 Spinosyns

Examples: **Spinosad, Spinetoram**

- Derived from natural soil actinomycetes
- Mode: Disrupt nicotinic acetylcholine receptors → rapid paralysis
- Targets: Caterpillars, thrips, some leafminers
- Features: Biologically derived, quick knockdown, relatively low resistance potential

4.3 Neonicotinoids

Examples: **Imidacloprid, Thiamethoxam, Clothianidin**

- Mode: Act on nicotinic acetylcholine receptors
- Targets: Aphids, whiteflies, leafhoppers
- Uses: Widely used in seed treatments
- Benefits: Systemic action provides long-lasting protection in early growth stages

4.4 Sulfoximines

Example: **Sulfoxaflor**

- Mode: Unique action on nAChR receptors distinct from neonicotinoids
- Targets: Resistant sap-feeders, especially aphids
- Benefits: Useful where neonicotinoid resistance is widespread

4.5 Ketoenols (Tetronic/Tetramic Acid Derivatives)

Examples: **Spiromesifen, Spirotetramat**

- Mode: Inhibit lipid biosynthesis in insects
- Targets: Whiteflies, mites, and other soft-bodied pests
- Features: Translaminar movement and high ovicidal activity

4.6 Oxadiazines

Example: **Indoxacarb**

- Mode: Blocks sodium ion channels
- Targets: Lepidopteran pests
- Benefit: Reduced impact on parasitoids and predators due to selective toxicity

4.7 Pyridine Azomethines

Example: **Pymetrozine**

- Mode: Inhibits feeding behavior in sap-feeders
- Targets: Aphids and whiteflies
- Strength: Very safe for pollinators and natural enemies

5. Role of Seed Treatment in Soybean Pest Management

Seed treatments using neonicotinoids and diamides have revolutionized early-season pest control. Treated seeds provide:

- Uniform protection during germination
- Effective suppression of aphids and soil pests
- Reduced need for early foliar sprays
- Lower environmental contamination
- Improved crop establishment

Common seed treatment molecules include **thiamethoxam, imidacloprid, and cyantraniliprole**.

6. Resistance Management Strategies

To sustain the effectiveness of new molecules, resistance must be managed through:

6.1 Rotation of Modes of Action

Avoid repeated use of the same class within a single season.

6.2 Threshold-Based Application

Spray only when pest populations reach economic threshold levels.

6.3 Integration with Biological Control

Use parasitoids, predators, and bio-pesticides to reduce chemical reliance.

6.4 Avoiding Tank Mixtures of Similar Chemistries

Improper mixtures may accelerate resistance development.

6.5 Use of Selective Molecules

Helps conserve beneficial insects, strengthening natural pest suppression.

7. Environmental and Human Safety Considerations

New insecticide molecules generally offer:

- Higher selectivity for target pests
- Reduced toxicity to natural enemies
- Lower soil and water persistence
- Improved applicator safety
- Reduced risk of harmful residues in food products

Their compatibility with IPM makes them environmentally responsible alternatives to older chemistries.

8. Future Prospects in Soybean Pest Management

Emerging trends include:

8.1 RNAi-Based Insecticides

Gene-silencing technology targeting specific pest genes.

8.2 Nanotechnology Formulations

Improved absorption, reduced dosage, and controlled release.

8.3 Botanical and Microbial-Based Next-Generation Molecules

Eco-friendly alternatives with promising efficacy.

8.4 Digital and Precision Agriculture Tools

Drone-based spraying, pest forecasting models, and smart sensors.

8.5 Multi-target Synthetic Molecules

Designed to delay resistance and increase control spectrum.

These innovations may dramatically transform soybean pest management in the coming decades.

9. Conclusion

The development and adoption of novel insecticide molecules have significantly improved the efficiency, selectivity, and sustainability of soybean pest management. These modern chemistries offer unique modes of action, reduced environmental risks, and compatibility with integrated pest management systems. While they present tremendous advantages, their long-term success depends on responsible use, regular resistance monitoring, and integration with biological and cultural control methods. Continued research and innovation will be essential for meeting the future challenges of soybean protection in an era of climate change, resistance evolution, and growing food demand.

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