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Hot Topic #10 - Biopesticides – what are they, how do they work, and will they have a major role to play in New Zealand crop protection?

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Hot Topics have been conceived to bring New Zealand agricultural and horticultural issues that need debate to the fore in a style and timeliness that cannot be achieved through traditional scientific publication approaches.

Summary

Biopesticides are pest management products derived from natural materials such as animals, plants, microorganisms, and certain minerals, offering a viable alternative to conventional synthetic pesticides. They work through a variety of mechanisms, such as predation, competition, direct toxicity, or behavioural disruption. Biopesticides are increasingly recognized for their lower toxicity, specificity to pests, and minimal environmental impact compared to synthetic pesticides, but face challenges in adoption such as perceived efficacy, cost, regulatory hurdles, and limited awareness among growers. Their integration into Integrated Pest Management (IPM) systems is crucial for more sustainable crop protection, and the sector is poised for substantial global growth, with projections indicating a doubling of the biopesticide market by 2030.

What Are Biopesticides?

Biopesticides refer to a diverse group of pest management agents sourced from nature—plants, animals, microorganisms, and minerals (*US EPA https://www.epa.gov/*). There are four main categories:

- Microbial biopesticides: Derived from bacteria, fungi, viruses, or protozoa that target specific pests. Examples include Bacillus thuringiensis, Beauveria bassiana, Pseudomonas and Trichoderma species.
- Biochemical biopesticides: Natural substances, like plant extracts or botanical oils (e.g., neem, tea tree, and thyme oils), or pheromones (e.g., codlemone) which disrupt pest mating, feeding, or development.
- Plant incorporated protectants (PIPs): Substances genetically engineered into plants, allowing them to produce their own pest defences, such as Bacillus thuringiensis (Bt) proteins.
- RNAi based products: A category that includes double stranded RNA sprays. These are molecules that target specific pest/pathogen gene expression. They are recognized as biopesticides in some countries such as the USA, specifically under the biochemical subcategory, but deemed to be chemical pesticides in other jurisdictions such as the EU.

All of these products are recognized for their natural origin and their ability to protect crops with fewer of the broad-spectrum impacts reported for conventional pesticides.

How Biopesticides Work

Biopesticides suppress pests through multiple mechanisms of action (Glare et al., 2012; Srivastava & Ratnanjali 2022):

- Direct toxicity: Microbes and plant extracts can produce or contain toxins, enzymes and/or other secondary metabolites that disrupt vital biological functions causing direct mortality. For example, Bacillus thuringiensis produces Cry and Cyt protein toxins, which when ingested by insect larvae (especially lepidopterans, coleopterans and dipterans), paralyze and destroy their gut cells causing death (Bravo et al., 2006). Similarly, Neem oil contains azadirachtin, which is toxic to a number of plant pathogens (e.g., Fusarium oxysporum), as well as a range of insect pests (e.g., aphids, whiteflies) (Campos et al., 2016).

- Predation and parasitism: Certain fungi and insects can act as natural enemies, infecting or consuming their pest hosts. For example, the entomopathogenic fungus Beauveria bassiana can penetrate an insect's cuticle, colonize its body and eventually kill it (Ortiz-Urquiza & Keyhani, 2013). Similarly, certain Trichoderma species can act as hyperparasites, coiling around the vegetative structures of their fungal host, and then penetrating and killing it by releasing cell wall degrading enzymes or antifungal compounds (Yao et al., 2023).
- Competition: Some beneficial microbes can successfully outcompete the pest or pathogen for space and/or nutrients thereby reducing infection and establishment on the plant host. The best examples of this are with certain Trichoderma species and Clonostachys rosea. These fungi are active colonizers of necrotic plant tissue and can quickly colonize dying leaf and floral parts preventing access by common necrotrophic pathogens such as Botrytis and Sclerotinia species. Competition on the root surface is also a key mechanism of biological control, with numerous rhizosphere competent microbes (e.g., Bacillus subtilis, Trichoderma atroviride, Pseudomonas fluorescens) able to outcompete root pathogens and prevent their successful infection.
- Induction of plant defences: Some biopesticides stimulate the plant's natural immune responses, making them less susceptible to attack (Flors et al., 2024). This mechanism has been reported for a range of microbes such as Trichoderma, Bacillus and Pseudomonas species as well as a number of plant extracts such as Reynoutria sachalinensis (giant knotweed). Induction of plant resistance can be localized (induced systemic resistance ISR), which is mediated through jasmonic acid (JA) and ethylene (ET) pathways, or systemic (systemic acquired resistance SAR), which is salicylic acid-dependent.
- Behavioural disruption: Some biopesticides can interfere with insect development or reproduction such as by disrupting moulting, metamorphosis or pheromone signalling. Products using synthetic insect pheromones (e.g., codlemone for codling moth) are widely applied in orchards and fields for mating disruption. These pheromones confuse males and prevent successful mating, drastically reducing the pests ability to reproduce. Other bioactives such as neem oil can disrupt feeding activity causing the insects to turn away from treated plants and fail to complete their development, and certain baculoviruses can change infected pest caterpillar behaviour causing them to climb higher in the canopy before dying, and thereby aiding virus spread amongst the pest population.

Unlike chemical pesticides, biopesticides often exert their effects selectively, having limited impact on beneficial flora and fauna. This reduces negative side effects.

Formulation and Application

Biopesticides require careful formulation to maintain the biological viability and effectiveness of their active ingredients, which are often living organisms or fragile metabolites. Their shelf-life is often limited compared to chemical pesticides, and stable formulations that preserve viability for more than one year are technically demanding to develop (Batu et al., 2022). Common biopesticide formulations include dry formulations (including dusts, seed dressing powders, granules, water dispersible granules and wettable powders) and liquid formulations (including suspension concentrates, oil dispersions, emulsions and capsule suspensions). The addition of adjuvants and carriers are key considerations to enhance product stability, efficacy and user safety.

Common application methods include seed treatment, soil application via granules or drenches, in-furrow applications, root dips, irrigation system delivery or foliar sprays. Challenges with the application of biopesticides include clogging of spray equipment (due to microbial slime), restricted timing of application (high temperatures, winds can reduce the viability of live microbes), and lack of product rain-fastness requiring repeat applications. Overcoming these challenges is essential for broader and more reliable use of biopesticides.

Benefits Over Synthetic Pesticides

The advantages of biopesticides over traditional synthetic chemicals include:

- Lower toxicity: Biopesticides generally pose fewer health risks to humans and non-target organisms (Daraban et al., 2023). There have been only occasional reports of mild allergic reactions, respiratory or skin irritation or eye discomfort by users. This typically occurs as a result of improper handling or exposure at high concentrations. There are no reports linking biopesticide use to long-term health effects such as cancer, endocrine disruption or neurotoxicity (Cai & Dimopoulos 2025). The US EPA and other regulatory agencies generally classify biopesticides as posing negligible risks to consumers and the general public, when used according to label directions.

- Eco-friendliness: Biopesticides generally do not persist or bioaccumulate in the environment, reducing the risks associated with long-term exposure. Their rapid biodegradation leaves minimal residues on food crops, or in the surrounding environment, and this allows for shorter re-entry and pre-harvest intervals, facilitating safer handling and harvest.
- Specificity: Biopesticides are often highly specific, targeting only the pests or pathogens intended and thus leaving beneficial insects, animals and surrounding plants unharmed. This specificity supports greater biodiversity and pollinator health in agroecosystems.
- Lower resistance risk: Because biopesticides often utilise diverse modes of action, this reduces the risk of pests developing resistance (Siegwart et al., 2015). However, there are reports of resistance to some biopesticides that have single modes of action, particularly those that produce a single toxin. For example, at least 27 insect species have developed resistance to Bt toxins which are the most common microbial biopesticides globally (Afzal et al., 2024). Resistance has also been observed to baculoviruses and botanical bioinsecticides (e.g. neem), though at a slower rate and less frequently than with chemical pesticides. While resistance to biopesticides is less prevalent than to synthetics, it is increasing as biopesticide use expands. This highlights the continued need for effective resistance management strategies. Strategies to reduce biopesticide resistance include rotating products with different modes of action and increasing crop diversity, much like that recommended for synthetic pesticides.

Challenges to Adoption and Uptake by Growers

Despite their potential, biopesticides face significant adoption hurdles:

- Perceived efficacy and speed: Biopesticides are perceived to be less effective than synthetic pesticides, especially as their effects often manifest more slowly compared to chemical options. Performance is often heavily dependent on environmental factors such as temperature, humidity, light, soil pH and organic matter content, particularly for products containing live microbes. This can often lead to inconsistent results across sites and seasons.
- Economic factors: Higher production costs, particularly those requiring microbial fermentation and specialized formulation can make some biopesticides too expensive for broad acre systems and restrict their use to high value horticultural crops.
- Storage, shelf-life and distribution: Biopesticides often have specific storage and handling requirements, and may have shorter shelf lives, complicating supply chains and making them less easy to use by the growers.
- Regulatory challenges: Registration costs for agricultural compounds are generally very high and this can limit the ability of small biopesticide companies to take their products to market. The regulatory processes and standards for biopesticides can vary between countries, creating difficulties for commercial companies and slowing down the market introduction of new products (Frederiks & Wesseler 2018).
- Knowledge and awareness gaps: Many growers are unfamiliar with biopesticides, and lack practical training in their use. The ease of use and speed of performance delivered by synthetic chemicals can deter growers from trying more complex biologically-based crop protection strategies. This is exacerbated by the fact that there is limited access to reliable advisory services about biopesticide use, which makes growers hesitant to switch.

Incorporation Into Integrated Pest Management (IPM) Systems

Integrated Pest Management (IPM) involves combining various pest control methods—cultural, biological, and chemical—for sustainable agriculture. Biopesticides can be used in IPM systems to deliver a number of benefits (Chandler et al., 2011):

Rotation tool Use of biopesticides as the initial pest management option, when pest/disease pressure is low, can provide a biological-based foundation of pest control with minimal impact on beneficial insects.

Resistance management tool Alternating biopesticides with synthetic chemicals helps prevent the build up of pest resistance and extends the performance life of the synthetic products.

Lower environmental impact Incorporating biopesticides into the crop protection programme reduces chemical usage, and lowers the risk of loss of biodiversity, soil contamination, and chemical residues in the food supply chain.

However, to deliver effective IPM programmes will require the development of best management practice guidelines, specific performance data to optimise biopesticide use and a major expansion of grower education training programmes.

Future Potential and Sector Growth

The biopesticide sector is projected for rapid expansion:

- Valued at between $8 and $10 billion USD in 2025, it is expected to grow rapidly, reaching as much as $25-28 billion USD by 2032, with strong annual growth rates between 10% and 15%. (Fortune Business Insights, 2025 *https://www.fortunebusinessinsights.com*)
- The EU, US and many other countries have imposed stricter regulations and bans on synthetic pesticide ingredients and reduced the allowable residues, thereby incentivising the registration and use of biologically-based crop protection solutions.
- The increasing global demand for reduced pesticide in food production systems is driving financial support for sustainable farming practices that encourage greater biopesticide adoption. Complementary to this is the rising demand for organic food, which is also fuelling biopesticide sales (Yadav et al., 2022).
- Innovations in microbial technologies, RNA-interference, and formulation science are improving biopesticide efficacy, shelf-life, and cost-effectiveness, making them more attractive to growers
- Asia-Pacific is anticipated to be the fastest-growing region for biopesticide use, while North America remains the largest market due to its established infrastructure and regulatory frameworks.
- Future growth depends on policies promoting IPM, consumer demand for sustainably grown food, and ongoing research to enhance product consistency and reduce operational barriers.

The New Zealand situation

- New Zealand is considered a relatively immature biopesticide market compared to many overseas countries. For example, the USA has over 2000 registered biopesticide products, the EU has 900 and Brazil is quickly catching up with new registrations increasing by 20% year-on-year over the last five years ((Fortune Business Insights, 2025 *https://www.fortunebusinessinsights.com*). In contrast, New Zealand only has approximately 49 registered biopesticide products, with numbers growing very slowly. This is compounded by the fact that many of the registered products have similar active ingredients and are predominantly marketed for use in a limited number of high value horticultural crops with similar claims against a narrow range of pests and diseases.

There are a number of factors that have contributed to this situation. The first and most important is that there has been limited funding available for biopesticide product development in New Zealand. While biopesticide research has been active since the late 1980's, investment in commercialisation has been low, the small size of the New Zealand market being a key contributor to this lack of venture capital. Small market size is also a key contributor to the low number of overseas products being imported into New Zealand for sale, the return on investment being considered marginal for many target markets. Lengthy regulatory timeframes and high costs also deter international companies from bringing products to New Zealand, particularly those that have living microbes as the active ingredient where additional requirements under New Zealand's new organisms legislations can add time and cost.

Not withstanding the commercial factors that have limited the biopesticide industry in New Zealand, there has been surprisingly little demand from New Zealand consumers, or growers, to adopt the use of biopesticides. Those biopesticide products that are commercially available, make up a small percentage of the respective market, with the exception of a few products used in the horticulture sector for control of a select group of economically important pests and diseases (e.g. Aureo Gold® for control of Psa on kiwifruit).

A recent industry survey highlighted the lack of available products, concerns about product efficacy, a lack of willingness by growers to change current practices, and the complexity of integrating biologicals into crop protection programmes as the key factors constraining the adoption of biopesticides by New Zealand growers (Scarlatti report, 2025 *https://a-lighter-touch.co.nz*). This is very similar to those constraints reported from overseas.

However, given increasing customer and consumer demand for low pesticide food production systems (the loss of some active ingredients due to health concerns and the reduced performance of some commonly used pesticides due to the build up of pest resistance), it is imperative that New Zealand gains access to a wider range of biopesticides to enable our plant-based sectors to continue to be competitive in international markets. An increase in investment in the development of new biopesticides in New Zealand is important, particularly for the biological control of specific pests and diseases, but New Zealand will not be able to make substantive progress in transitioning to more biologically-based crop protection systems without the commitment by multinational companies to bring their products here, which will require timely and cost-effective importation and approval processes, and market revenue potential that provides an acceptable return on investment. Without access to new innovative crop protection products, the New Zealand plant-based sectors will be at risk of falling behind their overseas competitors in promoting the quality and sustainability of our food production systems.

Summary conclusions

With increasing environmental and regulatory scrutiny on synthetic chemicals, biopesticides represent a pivotal shift towards a more biologically-based crop protection system, but broader adoption will require continued innovation, investment, and, most importantly, grower education.

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