Final report

Project title:

BY22006: Biocontrol for snail management in horticulture

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Project code:

BY22006

Funding statement:

BY22006: Biocontrol for snail management in horticulture is funded by Hort Frontiers, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation, with co-investment from Colere Group Pty Ltd and contributions from the Australian Government.

Publishing details:

Published and distributed by: Horticulture Innovation Australia Limited
ABN 71 602100149

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North Sydney NSW 2060

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www.horticulture.com.au

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Public summary

While snail and slug (from herein mollusc) pests are not recognised as a major threat to any Australian horticulture sectors, they are a significant issue for key industries, in certain regions and at specific times. The investigation and consultation undertaken in this project suggests that the impact of molluscs on crop establishment, production and harvest contamination is underestimated and unrecognised.

This project was a co-investment between Hort Innovation and Colere Group designed to investigate the specific impacts of molluscs across each of the horticultural sectors. It reviewed the current products and management options available to producers and the inherent knowledge gaps that need to be addressed for future success. In the second stage a range of products currently in development, or recommended in literature, was tested through a series of proof-of-concept trials.

Under reported, underestimated

In general, the reviewers believe that the financial impact of molluscs is significantly underrated and under reported in Australian horticulture. This partly due to the unusual nature of the pests themselves, and partially because they have moved from being a secondary to a primary pest due to changes in practices and habitat. The current annual cost of management (direct expenditure on molluscicides) has been estimated to be between AUD$7-10m per year. However, estimates of damage (direct and contamination) are purely anecdotal and vary widely from sector to sector and year to year. The reviewers could find no records of impact analysis having been done previously in Australian horticulture, but collected individual reports of field seedling losses, downgraded fruit and rejected shipments which hint to the scope of the issues.

At present producers have limited tools and, in many cases, lack the knowledge to effectively manage mollusc pests in their current systems. The future loss of a product or increased pest pressure (predicted in some regions due to climate change impacts on environmental conditions) could make mollusc management difficult for most sectors. Some holes in management relate to fundamental ecology knowledge gaps regarding the interactions of the non-indigenous molluscs with Australian production environments and therefore could be rectified. Other gaps relate to the almost total reliance on the use of baits as a single approach for mollusc control.

Future challenges

The use of molluscicide baits has been the mainstay of mollusc management for decades, however the use of baits alone does not suffice. Approaches are needed to flush snails and slugs from crops, ways to create barriers to stop them entering, and trap crops that can be used to hold and suppress numbers. In short, producers need a comprehensive range of Integrated Pest Management (IPM) tools that can be adapted to the crop, pest species and situation. Successful outcomes mean maintaining crop damage below an economic action threshold (which may be zero in some markets) to meet customer contracts and not disrupt the broader IPM of other threats.

There are several exotic invasive mollusc species that have fortunately not yet reached Australia. However, industry should be prepared for new incursions that will likely evade attempts to eradicate them prior to their establishment in Australian farming systems.

Deliverables from this project

This project delivered a comprehensive Technical Review (available through Hort Innovation) as well as specific industry sector analysis to support future industry investment in research. The evaluation (both desktop and field) of a range of current and future mollusc management products and practices will support industry and commercial company development, adaption and adoption of new options.

A series of business cases were presented to Hort Innovation and industry to support future development of two new products and two biocontrol predators.

Technical summary

Mollusc pests are likely to have an increasing impact on Australian horticultural production. Colere Group and our commercial partners has a vested interest in the development and commercialisation of products for snails and slugs and therefore were willing to co-invest with Hort Innovation in this project. The project was uniquely able to combine literature and technical investigation with product development, resulting in:

For Growers and Industry:

- A comprehensive Technical Review of snail and slug pests across their industry that will raise questions about the real impact of this pest group on their production and provide knowledge on options to try or to avoid.
- A specific Industry Analysis for their horticultural sector, identifying knowledge gaps and opportunities for further investigation and improvement.
- A clear indication to commercial product developers and commercialisers of the potential size and scope of snail and slug issues in Australian horticulture and the potential return on their future investment in this area, as well as specific examples of product and need gaps to target.

For Hort Innovation:

- A comprehensive Technical Review of snail and slug pests in the Australian horticultural industries, their impact, management options and a better understanding of their impact and biosecurity risks.
- A specific Industry Analysis to help guide each industry group in their prioritisation and management of future R&D investment to manage these destructive pests.

For the commercial partners:

- The background and context to understand the array of specific needs across the Australian horticultural sectors including the relative scope and impact of mollusc pests.
- A set of eight evaluation trials to provide early indications of conceptual targets and formulation options for new products for mollusc management.
- Confidence to invest in the further development of unique mollusc management options and make them available to the Australian market.

Key Learnings

Products and concepts

- **Some of the novel products are suggesting levels of repellence that would be commercially valuable**, but only when used with the right water rates, good coverage and correct timing. Short term repellents applied when target populations are inactive can protect plants from the odd individual from feeding.
- **Several products being promoted as being molluscicidal or repellent were shown to be ineffective and/or phytotoxic to the crop.** Vintre adjuvant, GRAZERS G2 slug & snail concentrate and PyroAg (wood vinegar) were not effective in any of a range of trial approaches including drenching, spraying and plant-dipping. Direct contact with the mollusc pest might have caused some foaming, but this did not extend to protecting the plant.
- **Trials did not support the use of the most highly regarded barrier product.** Schnexagon Slug & Snail Repellent was not effective in preventing the movement of snails across a surface. We are highly sceptical that barrier products are effective in general when surfaces are damp and molluscs are active. It also needs to be pointed out that baits are also not an effective barrier, regardless of the intensity of application, as they still rely on the mollusc being in an active feeding state.
- **The importance of biorational products being applied at the right time was highlighted by trial results.** Many of the products being considered had a limited field persistence and while could be effective when utilised correctly, will need strong product stewardship.
- **Molluscicidal baits will still remain an important tool in managing mollusc threats applied when the target is actively feeding.** Our trials still incorporated baits (albeit newer formulations) as positive controls and proved how effective they can be when used correctly.
- **Ongoing and future research needs to integrate biological knowledge of the target's activity with management options that may include products that protect crops from feeding along with other biological and / or cultural**

options. That is, can an attractive crop (canola) be planted between rows of transplants, while a repellent drench be applied to the seedlings requiring protection. In that case, populations of low activity would not damage seedlings, but provide a resource for a predator (such as carabid beetles).

Ecology and pest behaviour

- **Understanding the (pest) species X crop X environment is critical to making decisions around the solution complex being considered.** Several of our trials clearly confirm the need to match management to snail/slug activity and the poor results were evident where this did not occur. We need better systems to help growers pre-empt active periods to better use management options.
- **In species such as garden snail (*Cornu aspersum*, Műller) there is now a recognised diversity of activity levels within a population**, which is likely a survival adaption. This means that crop damage can occur when only a proportion of the population is active but also means that baiting at this time might only impact that part of the population, with the remainder then becoming active at a later date.
- Some of the changes in tillage practices and field preparation such as reduced soil disturbance and increased use of cover crops, or trends towards improving soil health/organic carbon content **have all increased the potential snail and slug habitats**. Furthermore, a reduction in the use of specific chemical pesticides such as organophosphates, has (and will) also reduce pressure on snails and slugs and hence, potentially increase their impact. Due to their biology, snails and slugs can adapt their lifecycles (speeding up generations and increasing fecundity) when the environment and food sources suit. Climate change will also likely favour these species with temperature and moisture better suit their phenotypic plasticity.

Trial technique

- **Accurate and reliable trials can only be undertaken when the right conditions are understood and matched.** Experiments conducted often highlighted the difficulty in obtaining clear conclusions due to often a proportion of the target pest population being inactive. E.g. with garden snail (*Cornu aspersum*, Műller) in an orchard this meant only beginning ahead of a storm or weather front at this is when they generally become more active. With black keeled slugs, moisture and temperature needs to be within a preferred range to see any feeding, and even then, the timing of their life history can be misaligned.
- **Utilising a positive control such as a high-quality bait helps understand potential confounding factors.** When bait mortality (in the positive control) was very low in a trial, this was a good indication that general activity or feeding levels might also be so low as to make the trial unreliable.
- **Trial design to suit regulatory packages is difficult for new concepts.** Typical designs are for efficacy in a mortality context and would utilise a currently registered bait as a positive comparison. A design that considers repellency and is focused instead on reduced damage levels or (even more complex) a lack of presence in crop as the measures of success is difficult and will need to be backed with technical argument.

Extension and Communication

- Much of the information being provided to growers is out of date and incorrect, as it is based on systems that are no longer being used or products that have proven ineffective. The Industry Gap Analysis highlighted and prioritised the specific work required in each sector.

Keywords

Mollusc pests, snails, slugs,

Integrated Pest Management, biosecurity, baits, biocontrol, predators,

Leafy vegetables, strawberries, stone fruit, grapes, citrus, pome fruit, raspberries, nurseries, protected cropping

Introduction

Terrestrial molluscs, comprising slugs and snails, are prominent pests across many horticultural sectors, causing significant direct and indirect damage to plants and contamination of produce. While chemical molluscicides delivered via baits and various practices such as hygiene and tillage have traditionally been used for control, a lack of cost-effective control, increasing concerns over the environmental and market impacts of baits have increased the need for alternative option.

This project provided a comprehensive investigation and overview of mollusc control for horticulture in Australia, including the effectiveness, mechanisms, and challenges associated with their implementation. The preliminary Technical Review was designed to provide a situational analysis and identify potential options for the Australian Horticultural industry sectors that are cost-effective, complementary to current (and future) practices and which give growers more tools to enhance mollusc management.

A key question that needs to be asked of each and every crop management situation is "What does success look like?". While this seems simple and obvious, with pests such as snails and slugs, it leads to asking if the use of the one registered molluscicidal tool, that is baits, will lead to the outcome required. Success could be any strategy that can help avoid loss; (a) repellent/barrier properties, i.e., the pest does not come in contact with the crop; (b) irritant properties, i.e., the pest moves away after coming in contact with the crop; (c) antifeedant properties, i.e., the pest does not feed on the crop and (d) traditional approaches based on molluscicides that kill the pest.

The role of this project was both to review and investigate and then develop potential future strategic direction for the industry in relation to this challenge. The technical review and product development framework investigated the issue of pest snails and slugs both from the problem and the solution, seeking paths to connect the two. With a pragmatic and holistic approach that was agnostic to type of solution (pesticidal, predatory, or practice based).

Methodology

The structure and approach taken in this project was an unusual one, being a combination of technical review, product development assessment and proof of concept testing, all in one project. Our goal was to identify the specific issues and needs (in relation to pest snails and slugs) across each horticultural market sector and then look to match those to potential new products/practice concepts that might provide future solutions.

This project is unique in that we have been open to explore multiple products and ideas, without commercial or process limitations. Our goals are focused fully on finding new and novel ways to manage snails and slugs in the field, rather than being wedded to a specific product(s). This flexibility has resulted in a different way of approaching the strategy and trialling framework.

- Since the project began, the investigation stage and the industry knowledge used for the work has uncovered several new and novel products for testing.
- It is clear from our consultation and investigation stages what success looks like. Products or concepts that seem unlikely from first assessment to reach this bar have been discarded (sometimes until rethinking is possible, some permanently).
- We have been able to use simple repellence and mortality trial designs to test multiple products, with rates and applications bounded by our understanding of the practicalities and economics of industry needs.
- Where the product being assessed is fully formulated, we have utilised a trial design that would provide quality and accuracy of data that will satisfy regulatory requirements. This means that our work will directly support the product's owners towards a registration of the product for industry use.
- The uses cases being explored are not traditional approaches to snail management (i.e. molluscicide bait) and would therefore incur a dramatic departure from both the role of the product with an integrated management approach and the path to market/regulatory pathway.

Technical Report

The Technical Report was produced through a combination of a deep literature review, summarisation of previous work and interviews with key industry contacts across the relevant sectors. It is not a literature review as such, although wherever possible we have included citations and links to reference materials. The role of the investigation, industry interviews, literature and patent search were to cast the net wide as possible to seek potential solutions. Gathering information from journals, patents, interviews and web searches, it narrowed down concepts that are likely to be used, those that are technically feasible and cost-effective in the Australian horticultural context. In parallel, we have endeavoured to identify the specific applications of any new and novel concept.

A search of the peer reviewed literature using Web of Science with the search term “Molluscicide” returned 277 papers published since 2013. Of those 138 were selected as being relevant for this review.

Industry Gap Analysis

Building on the Technical Review, the Industry Gap Analysis applies the knowledge to individual industry sectors and was designed to provide direct guidance to each of the Australian horticultural sectors and includes brief case studies and recommendations. It also examined what each industry sector considers the current best practices and the knowledge available to growers to determine what tools growers have, how successfully options are being employed, and where knowledge gaps exist. In total thirteen industry sectors are covered, with reporting on:

- Current industry situation- How great an impact do mollusc pests have, how do these impacts manifest and what are producers currently doing?

- Case Studies- Specific farmer examples of pest snail and slug issues from our consultations.

- Recommendations- What should this sector do in regard to this pest, and how high is the priority compared to other major challenges.

Product Development Framework

The review and consultation process identified many of the grower needs, alongside the local constraints that any new technology, product or practice would likely need to operate within. In addition, the learnings, experiences and success of other Australian industries (grains and dairy), have helped frame the best (potential) concepts and approaches for management of snails and slugs in the various horticultural crops. In this third report, the Colere Group team utilises our extensive product development and commercialisation experience to present a framework to compare potential product and practice concepts that may have potential in horticulture.

6.1 Concept 1: Short term repellent

SOLUTION/CONCEPT

A clear need identified in the Technical Review was to provide a short term (2-4wks) repellency to slugs and snails, as a way to protect establishing seedlings or prevent pre-harvest damage. The product would need to be water soluble (or easily suspended), non-phytotoxic and ideally not leave a detectable residue.

This concept would test a small range of actives that have been identified in literature and product searches, to develop a proof-of-concept that would underpin commercial development and investment.

- Use as a seedling dip – to give a two-week protection window, would likely need to be incorporated with other practices.
- Spray on crop within 14 days of harvest to repel slugs and snails to prevent contamination and/or cosmetic damage.
- Use as part of push-push-trap strategy.

Background and need

Early damage in seedlings by slugs and snails is difficult to counter with baits and has a significant impact on the crop viability and value. Crops such as head lettuce, cabbage and cauliflower can hide slugs that then can cause rejection in the market. Repelling molluscs and deterring them from entering the crop area/feeding would be an effective short-term way of establishing the crop free of pest pressure.

Current Progress

A saponin based product (RAPPEL®) has been commercialised as a seed dressing other countries including New Zealand. Other compounds including several essential oils/components (Clove Oil, Cinnamamide, Fenchrone) have also displayed strong repellent effects. Formulations need to be developed that are stable, compatible with other products and cost effective to be used in larger volumes. Trials have been conducted in the Australian broadacre sector with limited success on conical snails (Micic 2022 https://www.agric.wa.gov.au/wheat/will-anything-repel-conical-snails)

Needed for success	Fit into current IPM	Benefits
1) Identify the product or recipe for a formulation of compounds for trialling in a managed field situation. 2) Demonstrate a basic proof of concept with the trial products in a controlled environment study. 3) Evaluate the market potential, path to market cost and barriers. 4) Present to industry and potential investors to test commercial readiness of product.	• Ideally the product is not disruptive to other beneficials. Potential – disruption to natural enemies would need to be tested. • Will require natural enemies, or other cultural controls, in the production system to regulate mollusc populations.	• Potentially easily applied. • Market acceptance as a biorational product and seen as consumer friendly. • Plant extracts that are easily obtained from a renewable resource. **Limitations** • Limited field life • Some of the options are not cheap. • Phyto issues? • Residual taste/smell on crop?
IP Owners/Potential Partners/Roles	**Potential Grower Costs**	**Assumptions**
One of the products being considered has IP and has progressed through rego in NZ. There are several other products available with component that might make them interesting, however we believe the precise and best formulated product has yet to be made.	• Target of $30 – 100 /ha per application, higher in orchards/vineyards. Price relative to baiting, but with different goals and ability to target more carefully.	• Customers' acceptance as a biorational product. • Product will be able to be registered for use in the areas needed. • Costs and availability of raw ingredients is acceptable.

Potential Project/Investment/Business Model

1. We believe this concept is one suited to Colere's Stage 2 evaluation.
2. IP developed in any stage 2 assessment would be jointly owned unless product owners would be willing to sufficiently contribute to the trials and assessments.
3. Colere has already contacted the owners of the RAPPEL® product as well as two others. All would be available for testing.

Comments

- Residues and taste/smell could be an issue, particularly on crops like leafy greens.
- Would need to really get good penetration of some crops as this will likely be a contact product (although volatility maybe be an additional factor).

Work on this concept would be early-stage development, however the need area is strong and there is already strong evidence that a product with the right attributes is possible. PROGRESS FOR CONSIDERATION

Tables (such as shown above) in sections 6,7 and 8 of the Product Development Framework present potential concepts for consideration. Each spell out the end use it is designed for, the progress made in the area to date, positives and negatives foreseen and how it might fit in the current farming systems. To establish broad value propositions of the concepts across the different horticultural sectors and based on their current and likely future needs, a Market-by-Use-by-Fit approach has been used to help prioritise these concepts for deeper investigation.

Proof-of-Concept Trials

Dr Michael Nash is considered perhaps Australia's foremost expert on mollusc pests in agriculture/horticulture, and it was through his expertise and experience we were able to secure a range of experimental products for trialling. Dr Nash has been working in this field for over twenty-five years and is convinced that we need to expand our range of grower options. The eight individual trials run in this experimental series were individually designed to establish technical viability and narrow down where more than one product option exists. Each trial protocol was written to a level whereby the data gained would be potentially of value to a commercialiser as part of a regulatory package. The goal was also to give the product owners confidence to commercialise products in Australia by demonstrating in realistic situations.

Results and discussion

Results and discussion- Technical Review

The following is a brief overview of key findings from the Technical Review.

Snail and Slug Pests

All of the pest species found in Australian horticultural areas are exotic, originating from Europe and/or Americas. Monitoring and managing snail and slug pests is different and potentially more complex than insect species. Unlike insects, they do not have a set lifecycle, and breed when conditions are favourable. Their phenotypic plasticity allows them to adapt to conditions and respond quickly. All snails and slugs survive as adults by slowing their metabolic rate and seeking refuge from dry conditions, hence their breeding can be considered either annual or biannual depending on the season and location they proliferate.

We have six snail species of significance:

- Common Garden Snail- *Cornu aspersum* (Müller 1774)
- Vineyard or Common White Snail- *Cernuella spp*.
- White Italian snail- *Theba pisana* (Müller, 1774)
- Small conical or small pointed snail- *Cochlicella barbara* (L.)
- Small brown snail- *Microxeromagna* spp.
- Green Snail- *Cantareus apertus* (Born 1778)

And six slug species of significance:

- Black Keeled slug- *Milax gagates* (Draparnaud, 1801)
- Grey Field or Reticulated slug- *Deroceras reticulatum* (Müller, 1774)
- Marsh or Meadow slug- *Deroceras leave* (Müller, 1774)
- Brown field slug- *Deroceras invadens* (Reise, Hutchinson, Schunack and Schlitt, 2011)
- Striped slug- *Ambigolimax spp*.
- Tropical leatherleaf slug- *Laevicaulis alte* (Férussac, 1821)

Few farmers and agronomists can identify the various species or have a strong understanding of the differences in their habits.

Industry Impact

Snails and slugs pose significant challenges to Australian horticultural industries, not only within the farm gate but also in the broader context of biosecurity, markets, and international trade. Their presence and the damage they inflict extend far beyond the immediate agricultural landscape, affecting economic, regulatory, and ecological aspects on a much larger scale.

The cost of losing access to premium markets should not be underestimated. Even the identification and publication of a pest species being found in a region can create the opportunity for a trade barrier to be placed by an export partner. Because of the potential for restricting market access, the reviewers see no benefit in identifying areas suitable certain species of snail or slug, or specific detail of where they have been found.

Despite that fact that snails and slugs are almost ubiquitous in all horticultural crops and regions, there are specific areas where their feeding, presence, or residue (excrement) cause economic loss. The lack of quantifiable loss beyond control expenditure, in the authors of the review's opinion, is reflected a paucity of management guidelines specific to each crop type. Those that are available are outdated and focused on meeting biosecurity requirements of customers, not how to increase saleable yield.

Industry sector specific impacts include:

- Direct damage from crop establishment onwards. Transplant loss and heavy seedling losses in direct seeded crops. Slugs may be already present in the field, snails often migrating from irrigation ditches and headlands.
- Crop rejection at harvest due to direct contamination of pest or from the residue/excrement they leave behind. May create a need for head trimming and subsequent loss in weight/size of produce. Shipment rejections do occur.
- The wounds created by these pests can become entry points for fungal pathogens, such as grey mould (Botrytis cinerea). This disease can spread rapidly, especially under the humid conditions favoured by snails and slugs and can devastate entire crops.
- Use of bait late in the crop is unadvised but does occur, this can result in contamination of produce with bait residue.

The cost of snail and slug impact across the horticultural sectors is likely underestimated and under-reported.

Pesticide Options

The overwhelming majority of molluscicidal applications in Australia are of a bait formulation designed to kill the target. There are currently nine registered actives across 57 products for snail and slug control in Australia, although these are based effectively on only four modes of action.

- Copper compounds (Present as a buffered compound, as copper sulfate and a silicate compound)
- Iron compounds (In an EDTA complex, powered form and iron phosphate)
- Metaldehyde
- Methiocarb

Regardless of the active ingredient used, baits have specific challenges (pros and cons) that mean the user needs to understand both the environment and the target pest to get an optimum result. The role of baiting is to ensure the delivery of the active, in a palatable form, easily encountered, at the right rate and the correct timing. Even then there are challenges including bait degradation, issues with bait palatability/attractiveness, bait predation and off-target effects.

Much of the current industry-specific information around bait application, rates and timing is out of date and inaccurate. Industry representatives highlighted areas where mollusc control was needed but baits were inappropriate or ineffective.

Practice based options

Monitoring is usually the basis for the broader Integrated Pest Management (IPM) strategy, however, monitoring of mollusc pests in most horticultural crops is haphazard, irregular, and usually post the point of being useful (e.g. close to harvest). For example, slugs are difficult to monitor because their activity at the soil surface is primarily nocturnal and only become active when conditions are suitable. New technologies are being developed for active monitoring for snail pests based on image analysis and AI learning (further detail in Recommendations).
There is a lack of clear connection between monitoring and subsequent recommendation for farmer options and actions.

Habitat management (e.g. Landscape by Design) is an ecologically based approach to suppress pest densities, utilising properties of non-crop vegetation to improve the impact of natural enemies or to directly affect pest behaviour. Research in this approach has escalated dramatically this century including horticulture in Australia (e.g. Hort Inov VG16062). These principles have been extending to some crops with grower interest, but adoption in Australia has been much lower than overseas. Australian agroecological studies have also not observed the same success of pest suppression at a landscape scale, most likely due to differences in productive landscapes: Australia has greater homogenisation with large paddocks and limited edges in comparison to block size. There has been a recent trend in many vine crops to plant the interrow with cover crops (e.g. Eco Vineyards). It is not known if the species being used will either help or hinder pest mollusc species or their predators.
The concept of beetle banks is used in Europe to conserve natural enemy function, in particular carabid beetles. Trials in Australia to date have not validated the beetle banks but do suggest that natural predators such as carabids could be useful to manage and suppress mollusc numbers throughout the year. This is explored further in a business case.

Recent trial results demonstrated that slug populations fed a diet high in nitrogen increased at a greater rate, i.e. pest numbers responded to crop nutrition. It is not clear as to how this can be utilised as part of management but could potentially inform concepts around trap-crop plantings.

Biocontrol Agents

Three potential options in the way of biocontrol agents were identified as having reasonable potential; predatory nematodes, carabid beetles and a facultative parasite called *Tetrahymena rostrata*.

Several species of predatory nematode from the Heterorhabditidae family have been studied and commercialised for their potential as control agents against slugs and snails and are used broadly in Europe. In interesting research finding was that in addition to being active predated, many species of slugs actively avoid the nematode *P. hermaphrodita*, being able to sense when they were close by in the soil.

Carabid beetles are generalist predators and prey on slugs and snails, either by actively hunting adults or consuming their eggs and juveniles. Some also have juvenile stages that also predate the eggs or young of slugs and snail. The direct knowledge of whether these beetle predators could sufficiently manage to hold pest numbers below an economic threshold is very limited, with only one example from Australian farming systems. **The likelihood of being able to introduce new (exotic) species of either as classic biocontrol agents into Australia is very low and should be disregarded as an option.** The potential for further use of native carabid and rove beetles as biological control products (as opposed to classic biocontrol releases) in situations where the beetle predators were reared artificially and introduced ahead of likely snail and/or slug outbreaks could be considered, if commercially it would be viable given their extended breeding times.

Tetrahymena rostrata is a free-living ciliated protozoan and is a facultative parasite of some species of terrestrial molluscs. The University of Melbourne developed an early proof of concept to manage snails and slugs with the locally derived ciliates. Using these protozoa as a viable product has knowledge gaps that need addressing (including but not limited to trial data, regulatory permissions and cost points) before the commercial potential is understood.

Alternative Actives

The review considered an extensive range of potential actives, some of which have previous use in this area, while others were considered a potential due to toxicology profile. Compounds that may not be directly toxic to molluscs, but instead provide repelling capabilities were also investigated. Biorationals including essential oils, and other plant extracts were also included in the evaluation due to potential for a lower off-target toxicology and residue issue.
Based on literature and user experience the short list was reduced to:

- Saponins
- Pyroligneous acid (Wood Acid/Vinegar)
- Eugenol, Limonene and Linalool essential oils

Novel Concepts

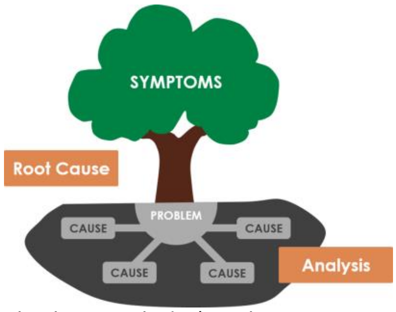
The Technical Review investigated a range of cutting-edge technologies including RNAi, short-chain peptides, gene drives, nanomaterials and pheromone/attractant lures. Aside from the latter, all of these options (while offering real potential) are likely to be at least a decade from reality. This is not to diminish their priority in any list of potential future industry investments, as in particular RNAi and peptides, offer an environmentally benign and highly target specific approach in a world where new pesticidal opportunities are limited and costly.
A close watching brief should be kept on this area to leverage opportunities if they arise.

Results and discussion- Industry Gap Analysis

This Industry Gap Analysis was designed to provide direct and specific guidance to each of the Australian horticultural sectors. Covering thirteen of the industry sectors (Almonds, Apples and Pears, Blueberry, Cherries, Citrus, Nurseries, Potato, Pyrethrum, Raspberry/Blackberry, Strawberry, Summer fruit, Table Grapes, Vegetables) they examine current best practices and knowledge available to growers by sector to determine what tools growers have, how successfully they are being employed, and where knowledge gaps are. Brief case studies provide examples from growers of the issues and impacts they face and what they believe is needed. Each provides recommendations for that industry sector on future investment in R&D and communications.

Results and discussion- Product Development Framework

Being unconstrained in the type of solution this project was able to consider, Colere was able to begin the product development stage with an articulation of the industry needs (rather than just retrospectively trying to fit an existing solution). The consultation phase of the industry gap analysis enabled the deeper questioning of growers around the root cause of their mollusc related issues. This helped identify the specific cause of impact, timing and unpacked how current approaches were failing.



Four specific measures of success were identified, with associated needs:

1. **Crops free of molluscs at harvest.**

The harvest of mollusc-free product is critical for many vegetable industries, particularly those where the product is field packed (into bags or boxes), where there is no washing stage prior to packing, and crops that offer individual slugs and snails places to hide (e.g. lettuce, cabbage). In addition, these crops need to be free from the molluscs for a period prior to harvest to ensure nil contamination to produce from various diseases that can be vectored by slugs or snails: for example, listeria spp. in leafy veg.

Needs

- A product that can be applied in field, directly to a crop, within weeks/days of harvest, that will repel slugs/snails. Will need a very high success rate to be acceptable, and work across all species.
- A product capable of forcing snails/slugs out of a crop, that is non-phytotoxic and doesn't leave residues, or taint, on the harvested product.
- Products don't disrupt beneficials, such as natural enemies that prevent unstable pest flares.

2. **Preventing loss of seedlings and emerging plants.**

Seedling losses can result in the direct cost of re-seeding, sub optimal plant numbers leading to poor crop uniformity in maturity and size, and lost opportunity costs due to inability to secure/meet contracts. Currently this is achieved by applying baits, however as with any bait application there are many factors that reduce efficacy: for example, timing, application, pest numbers, product choice. Management of high-pressure situations has few tools and is expensive. Often, not enough knowledge of how the system's ecology further hinders successful control. Ideally management needs a range of tools they can tailor solutions to their situation.

Needs

- Reduce the pressure on baits and their need to stop large pest incursions.
- Manage snails and slugs at additional points in their lifecycle, such as eggs and juveniles, especially when populations are endemic in the field/orchard/vineyard.
- Increase the effectiveness of overall Integrated Pest Management outcomes: that is, products and practices that don't increase other threats.
- Additional tools such as predators and trap crops to work into ecologically tailored solutions.

3. **Reducing damage at key points.**

For some crops, the damage from snails and slugs throughout the growing cycle is minimal and does not reach economic thresholds, however when those crops approach harvest, they are contaminated still, leading to economic loss due to the rejection of saleable produce. Currently, prophylactic baiting throughout the season is seen as the only option, despite the poor return on investment.

Needs

- Reducing the buildup of slug and snail numbers throughout the season, in cost effectively and passive way.
- Repel slugs/snails out of the crop at critical points to reduce damage and contamination potential.
- Knock-down and eliminate slugs and snails prior to critical periods to protect saleable produce.
- Attract and kill slugs and snails out of crops to eliminate or suppress.

4. **Preventing molluscs from entering a crop or climbing trees/vines.**

Once snails or slugs enter tree or vine canopies, they are difficult, if not impossible to be controlled. This can also be the case for certain crops where baits can't be used: for example, baby leaf production. Therefore, the management of the snails and slugs before they enter or deterring them from entering canopies/fields is critical.

Needs

- Barrier concepts for alongside fields to reduce incursions from irrigation ditches and other harbours. Ideally able to withstand rainfall and irrigation and can be applied to a range of surfaces including bare and semi-grassed patches.
- Barrier concepts that can prevent incursions into trees and vines and can be combined with concepts to thin/supress numbers.
- Knowledge around the impact on snails and slugs of new inter-row planting concepts being utilised in fields and orchards; are they helping or hindering, are some species better than others.
- Push-Push-Trap concepts that repel or deter snails/slugs from leaving a strip and pushing them to where combinations of crop, predator and product can reduce numbers.
- Attract and kill concepts that can be used at sensitive periods to supress numbers and reduce outbreaks, without impacting crop, leaving residues or upsetting beneficials.

Results and discussion- Proof of Concept Field Trials

The eight trials undertaken were done over a five-month period, with progressive work expanding the understanding of the products and finetuning their use. While more trials are definitely needed, we had sufficient information to begin writing the business cases that would support further investment (by the product owners or industry).

The following sets out the summary of the results each of the trials (full Trial Reports were provided to Hort Innovation) and spells out a series of learnings from the trials and surrounding observations. Some of these learnings further question the current approach to baiting and emphasises the need for growers to clearly identify the pest species they are addressing.

Trial 1: Slug olfactory ques

B1_P14_24

Slugs primarily use olfaction to locate preferred food plants and avoid undesirable ones. Push-pull companion cropping is a system of pest control that exploits a pest's sense of olfaction, using the volatile organic compounds (VOC) plants produce, 'pushing' pests away from the cash crop and 'pulling' them to a sacrificial plant. Previous laboratory experiments show promise of a push-pull intervention for snails. Here, we investigated the potential of push-pull companion cropping to protect seedlings from slugs.

- To test feeding differences due to plant species, a two-choice feeding assay was used to measure the acceptability, assessed using an acceptability index (AI), of a potential plant in reference to canola.
- To test if plant volatiles had significant influence over slug behaviour a y-tube olfactometer experiment was conducted using five different plant species.

1/ Slug species (P<0.01) and plant species (P<0.05) were significant factors for the acceptability of the different plants compared to the reference to plant (canola). Only the grey field slug found attractive plants as an acceptable alternative to canola, with lettuce being the most acceptable (AI = 0.67 ± 0.08 SE, n = 10). Garlic and canola were universally unacceptable to all slug species tested and the garlic exhibited a strong antifeedant effect on brown field slugs.

2/Garlic and coriander exhibited strong repulsion effects on grey field and brown field slugs, in the olfactometer experiment, with no choice being the most likely outcome (P=0.05, n = 15). However, no other plant had influence in this experiment.

The three slug species tested had clear and independent preferences, between species and across plants. The black keeled and brown field slugs demonstrated strong preferences to canola, suggesting higher specialisation to brassica plants. Garlic had the lowest acceptability, and antifeedant and repulsion effects, likely due to allicin, concordant with recent literature.

Attractive plants, such as lettuce and canola, are likely needed to have a strong influence over slug behaviour through VOC and cannot be selected on acceptability alone. Given the high variability in individual species acceptance, management needs to be tailored to the targeted pest slugs. Plants with repellent properties had a more universal effect on slug behaviour and demonstrated a potential to reduce damage, however, further investigation is required to maximise efficacy.

While preliminary, these trials provide valuable underlying understanding to support push-pull approaches in lettuce production, utilising sacrificial brassicas and repellence products. The different responses across mollusc species is a critical factor that needs to be considered in future trials or commercial application.

Trial 2: Repellence of grey field slugs in lettuce

B1_P15_24

A fully randomised replicated field trial was conducted September 2024 to test efficacy of novel slug repellents applied as a foliar spray on reducing grey field slug damage to cos lettuce transplants. Three novel repellents were applied: a novel Saponin product being developed in Australia, a commercial product from New Zealand (SLUG-EM) and an Australian developed wood vinegar (PyroAg).

Table 1: Products utilised in Trial 2.

Product name	Active Ingredient	Concentration
Protect-us Mineral Snail and Slug Killer	Iron Powder	10 g/kg
Novel Saponin	Saponin	NA
SLUG-EM	Tea Saponins	212 g/l
PyroAg	Pyroligneous Acid	1 l/l

No live slugs were observed at the end of the trial (16 DAA) in the plots treated with the positive control, an iron-based bait (ProtectUs). There were no significant differences detected in the number of live slugs at the end of the trial between the foliar treatments and the untreated control. No conclusions can be drawn regarding mortality of grey field slugs in response to the application of novel sprays aimed at repelling slug feeding on lettuce transplants. This was due to the high natural mortality, as detected in the untreated controls, hence no significant differences in the number of live grey field slugs were observed at end of this trial.

Figure 1: Field mesocosm used in Trial 2.

Despite the lack of live slugs at the end of the trial, significant damage to transplants and loss of lettuce transplants was observed when compared to plant control and the positive control (ProtectUs). The foliar products tested failed to protect lettuce transplants from grey field slug herbivory even in the short term (4 – 6 days).

No conclusions can be drawn regarding mortality of grey field slugs in response to the application of novel sprays aimed at repelling slug feeding on lettuce transplants. This was due to the high natural mortality, as detected in the untreated controls, hence no significant differences in the number of live grey field slugs were observed in this trial.

Trial 3: Mortality of grey field slugs in lettuce

B3_P16_24

A fully randomised replicated field cage trial was conducted October 2024 to test efficacy of novel molluscicides applied as a foliar spray on reducing grey field slug numbers and damage to cos lettuce transplants. One novel molluscicide was applied at four rates. The number of live and moribund slugs was assessed on four occasions: 2, 4, 6, & 8 days after application of treatments in conjunction with plant assessments.

No live slugs were observed at the end of the trial (16 DAA) in the plots treated with the standard control, an iron-based bait (ProtectUs), or in those plots treated with higher rates of the novel molluscicide. Despite some natural mortality, the foliar application of the novel molluscicide resulted in significantly less live grey field slugs, equivalent to a standard bait. Significantly greater mortality was also observed by the number of dead slugs collected over the eight days after application of treatments, with most mortality occurring in the first two days.

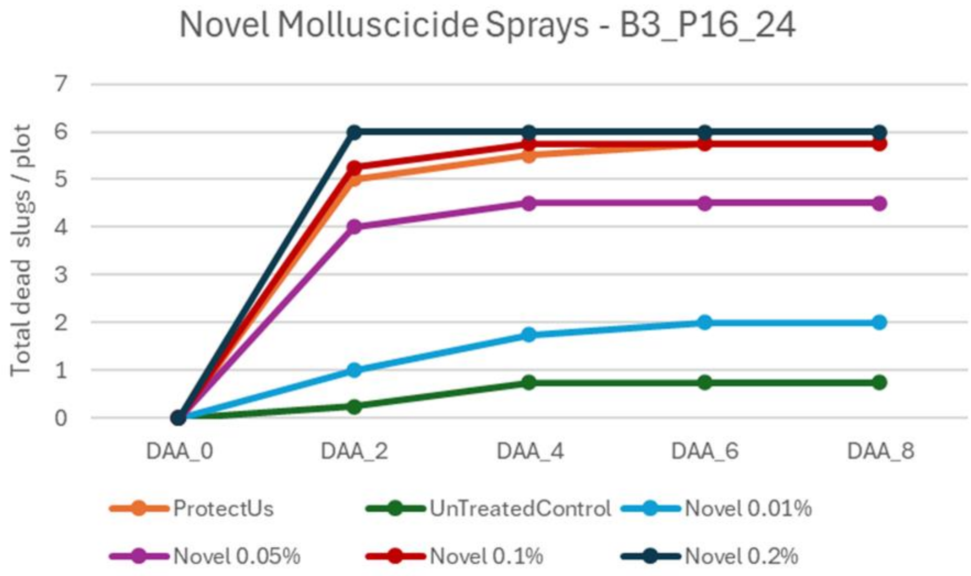
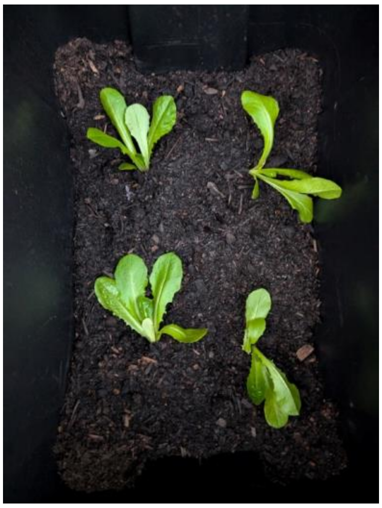


Figure 2: Grey field slugs' response to Novel Molluscicide application

Despite the lack of live slugs at the end of the trial, significant damage to transplants was observed in the untreated arenas when compared to plant control and treatments. The novel molluscicide tested provided significant protection of lettuce transplants from grey field slug herbivory for eight days. Limited slug activity was observed during this trial; hence no significant loss of transplants was observed due to grey field slug herbivory.

It is recommended further trials are needed based on a 0.05% rate of novel molluscicide, with higher water rates and pressure to ensure better contact.



Trial 4: Saponin as seedling drench

B1_P17_24

Saponin is available in New Zealand as a seed treatment to prevent slugs feeding on establishing crops, such as canola. The aim of this experiment was to test efficacy of saponin to protect cos lettuce transplants from slug and snail feeding applied as a seedling drench. A fully randomised, replicated paired field cage trial was conducted Oct 2024. Damage and transplant number were scored daily for nine (9) days after transplanting two treated and two un-treated seedlings into 0.12 m2 mesocosms (tubs).

Both garden snails and grey field slugs were tested. Garden snails did cause the greatest damage, hence transplant loss. Drenching cos lettuce seedlings with a saponin product did not prevent snail or slug feeding, nor transplant loss in the case of garden snails.

It is recommended this experiment be repeated as product formulation is suspected to have confounded results, as did the high natural mortality of grey field slugs.

Trial 5: Repellence of Garden snail in lettuce

B1_P18_24

A fully randomised replicated field trial was conducted Nov 2024 to test the efficacy of novel snail repellents applied as a foliar spray on reducing garden snail damage to cos lettuce transplants. Four novel repellents were applied: a novel Saponin product being developed in Australia, a commercial product from New Zealand (SNAIL-EM), a commercial product from the UK (Grazers) and an Australian developed wood vinegar (PyroAg).

Live garden snails were observed in all treatments at the end of the trial (16 DAA). The application of the Iron based bait ProtectUs resulted in significantly less live snails at the end of the trial. No conclusions can be drawn regarding mortality in response to the application of novel sprays aimed at repelling feeding on lettuce transplants. This was due to inactivity of individual snails during the trial, despite irrigation and rainfall during the trial.

Despite live snails being aggravated by some foliar applications, producing excessive mucus that did not result in mortality. Significantly greater moribund and dead snails were observed in the plots treated with the bait, ProtectUs. Natural mortality was observed in this trial, equivalent to the foliar treatments applied.

Foliar applications did not stop garden snails causing limited damage to transplants. However, damage observed was not consistent between treatments, with greater variation in damage observed within treatment groups. There was a non-significant trend with lower damage observed in the plant control, ProtectUs and Graziers treatments when compared to the Untreated Control.

Figure 3: Pyro Ag did cause some leaf burn, as indicated by slightly greater damage score.

Two foliar applications did not limit transplant loss. This may be due to other factors causing a reduction in transplant numbers, such as sclerotinia.

This trial highlights the importance of understanding snail behaviour, as snails that are not in a feeding stage in their life history will not actively interact with the crop, baits or other foodstuffs, regardless of stimulation with moisture (usually associated with the lack of activity). The positive control, an otherwise well regarded molluscicidal bait, also didn’t perform to normal expectations. Timing with repellence trials and indeed future field use, will likely need to be based on close monitoring and observation rather than based on crop timing.

Trial 6: Vintre to control snails

B3_P20_24

Vintre is an alcohol ethoxylate based surfactant and adjuvant, which some growers have claimed to control (or at least disrupt) snails in vineyards. The aim of this trial was to test the efficacy of novel molluscicide applied with Vintre as a foliar spray to control snails. A fully randomised mark recapture experiment was conducted in a citrus orchard when conditions were conducive to snail activity. Different treatments were applied to each tree along one row, with bait applied as a buffer to adjacent rows.

Figure 4: Painted shells made tracking of individual snails possible within the tree canopy.

Considerable movement was observed during the trial with odd individual gardens snails moving 10 m in one week, hence it was not possible to conduct further assessments.

The application of Vintre alone or with the addition of clove oil did not control garden snails during wet conditions when populations are active, as determined by the number of live snails / trees remaining, the proportion of marked live snails recaptured and the proportion of dead snails recaptured one week after treatments. Despite live snails being aggravated by foliar applications as observed by producing excessive mucus, that did not result in mortality.

IRONMAX Pro applied when garden snails were active resulted in significant control of garden snails in a Citrus orchard. Corrected mortality (Henderson-Tilton's formula) after one week in this trial was 81%.

It is recommended that information be provided to industry that the practice of applying surfactants to control snails is not effective. Additional trials when snails are inactive is needed to support extension. It is possible that inactive snails within the canopy may be "annoyed" by products that penetrate and interact with their mucous.

Figure 5: Untreated tree where garden snails were tracked over a two-week period in citrus orchard.

Trial 7: Slug response to novel microbial foliar molluscicide

B3_P21_24

A biological preparation based on the SK007 strain of *Bacillus* sp. was tested as a potential molluscicide aimed at controlling black keeled slugs. Secondary aims were to assess protection of lettuce transplants and assess phytotoxicity. These were tested in a laboratory with constant conditions and using slugs of a known age in a fully replicated, randomised trial.

Due to several factors, the results from this trial can only be related to the efficacy of the novel biological molluscicide applied at different rates as a foliar spray to control slugs. This trial didn't provide conclusive data supporting SK007 as a molluscicidal spray, but anecdotally provided some interesting effects in repelling slugs from seedlings. Further field trials should be considered.

The application of an Iron based bait, IRONMAX Pro, resulted in significantly less live black keeled slugs at the end of the trial. As with other trials the varying amount of activity of the slugs was a significant component in predicting results, i.e. as the activity dropped, feeding reduced and mortality dropped. This again reinforced the importance of bait timing.

Figure 6: Black keeled slugs and lettuce at the end of trial 7.

Field Trial 8: Snail repellent coating

B1_P22_24

Schnexagon Slug & Snail Repellent Coating had been touted in the literature (see Technical Review) as one of the more reliable barrier products for snails and slugs. Made in Germany, it is based on a complex mixture of plant extracts and minerals (linseed oil, wood, castor oil, tree resins in a natural oil).

The ability of Schnexagon Slug & Snail Repellent Coating to stop garden snail dispersal was tested in a commercial citrus orchard. A remote sensing device was used to assess individual movement within an open top enclosure coated with the repellent coating. Assessments were repeated (n=8) from Nov 21 2024 until Nov 30 2024.

Trialling was specifically designed to closely replicate potential situations in an orchard with normal irrigation and rainfall events creating increases in snail movement and activity. We utilised an artificial surface rather than directly applying to tree trunks to ensure uniform application and a complete barrier. The 1m^2 containment was specifically made bare to encourage movement outwards.

A limited number of individual garden snails crossed the "barrier" during conditions favourable for their activity.

It is recommended not to pursue commercialisation of Schnexagon Slug & Snail Repellent Coating for Australian horticulture due to garden snails only being active in wet conditions and the widespread use of overhead irrigation.

Figure 7: Wall of containment clearly showing a snail above the treated barrier.

Proof of Concept trial- Learnings

Products and concepts

- **Some of the novel products are suggesting levels of repellence that would be commercially valuable**, but only when used with the right water rates, good coverage and correct timing. Short term repellents applied when target populations are inactive can protect plants from the odd individual from feeding. Colere plans to continue to trial at least two of the novel formulations and progress them towards commercial reality.
- **Several products being promoted as being molluscicidal or repellent were shown to be ineffective and/or phytotoxic to the crop.** Vintre adjuvant, GRAZERS G2 slug & snail concentrate and PyroAg (wood vinegar) were not effective in any of a range of trial approaches including drenching, spraying and plant-dipping. Direct contact with the mollusc pest might have caused some foaming, but this did not extend to protecting the plant.
- **Trials did not support the use of the most highly regarded barrier product.** Schnexagon Slug & Snail Repellent was not effective in preventing the movement of snails across a surface. We are highly sceptical that barrier products are effective in general when surfaces are damp and molluscs are active. It also needs to be pointed out that baits are also not an effective barrier, regardless of the intensity of application, as they still rely on the mollusc being in an active feeding state.
- **The importance of biorational products being applied at the right time was highlighted by trial results.** Many of the products being considered had a limited field persistence and while could be effective when utilised correctly, will need strong product stewardship.
- **Molluscicidal baits will still remain an important tool in managing mollusc threats applied when the target is actively feeding.** Our trials still incorporated baits (albeit newer formulations) as positive controls and proved how effective they can be when used correctly.
- **Ongoing and future research needs to integrate biological knowledge of the target's activity with management options that may include products that protect crops from feeding along with other biological and / or cultural options.** That is, can an attractive crop (canola) be planted between rows of transplants, while a repellent drench be applied to the seedlings requiring protection. In that case, populations of low activity would not damage seedlings, but provide a resource for predatory beetles. Only when weather conditions are favourable for activity would an organic iron-based bait need to be applied to retard population numbers.

Ecology and pest behaviour

- **Understanding the (pest) species X crop X environment is critical to making decisions around the solution complex being considered.** Several of our trials clearly confirm the need to match management to snail/slug activity and the poor results were evident where this did not occur. We need better systems to help growers pre-empt active periods to better use management options.
- **In species such as garden snail (*Cornu aspersum*, Műller) there is now a recognised diversity of activity levels within a population**, which is likely a survival adaption. This means that crop damage can occur when only a proportion of the population is active but also means that baiting at this time might only impact that part of the population, with the remainder then becoming active at a later date.

Trial technique

- **Accurate and reliable trials can only be undertaken when the right conditions are understood and matched.** Experiments conducted often highlighted the difficulty in obtaining clear conclusions due to often a proportion of the target pest population being inactive. E.g. with garden snail (*Cornu aspersum*, Műller) in an orchard this meant only beginning ahead of a storm or weather front at this is when they generally become more active. With black keeled slugs, moisture and temperature needs to be within a preferred range to see any feeding, and even then, the timing of their life history can be misaligned.
- **Utilising a positive control such as a high-quality bait helps understand potential confounding factors.** When bait mortality (in the positive control) was very low in a trial, this was a good indication that general activity or feeding levels might also be so low as to make the trial unreliable.
- **Trial design to suit regulatory packages is difficult for new concepts.** Typical designs are for efficacy in a mortality context and would utilise a currently registered bait as a positive comparison. A design that considers repellency and is focused instead on reduced damage levels or (even more complex) a lack of presence in crop as the measures of success is difficult and will need to be backed with technical argument.

Additional Challenges

Conducting experiments with garden snails, and to a lesser extent slugs, is challenging due to their behaviour. That is, only a proportion of the population is active at one time. This inactivity was evident during our set of experiments, and several attempts were abandoned when timing was obviously poor.

Poor spring rains in 2024 meant difficulty in collecting good numbers of each slug and snail species and disease pressure (ciliates) in the slugs made several of the experiments challenging and they had to be repeated. We suspect that utilising mesocosms could be increasing the pressure from ciliates as slug/slug contact and contact with faeces and slime is higher than might be found in the field. A clean culture of Black Keeled Slugs was eventually established to run further experiments.

Two of the products being assessed were early prototype formulations and have not proven to be very stable. In one case the lack of sufficient biocide in the mixture of predominately organic compounds allowed for a level of contamination and fermentation to occur. This was likely to have disrupted the activity of the compounds. New batches were ordered, and reformulation was needed. These are not uncommon challenges in new product development, as rates, application and formulation of an active is effectively being resolved on the fly.

Results and discussion- Business Cases

Development of Concepts

Of the eleven concepts presented to Hort Innovation in 2024, we have narrowed down to four that we will continue to develop through trials, product development and market analysis. The selection of these was based three main factors: industry sector need (as shown in the Industry Gap Analysis), concept viability, and ability of Colere to make meaningful progress on the concept. The following are brief summaries of each of the Business Cases presented to Hort Innovation.

Concept 1: Short-term repellent

This concept is still the highest priority for our project and future work, and the majority of field trials were focused on this concept.

Product Concept

Our research identified an opportunity for a product that repelled molluscs out of a crop or dissuaded them to enter. Regardless of whether the product was lethal, the value in the concept was ensuring the pest was not in the crop at harvest or pushing the pests to where they could be managed (with baits or other methods). For example, once snails or slugs enter tree or vine canopies, they are difficult, if not impossible, to control. This can also be the case for certain crops where baits cannot be used: for example, baby leaf production, where baits could be caught up in the foliage or need to be applied too close to harvest.

Scope

- Consider sprayable barrier concepts for alongside fields to reduce incursions from irrigation ditches and other harbours. Ideally able to withstand rainfall and irrigation and can be applied to a range of surfaces including bare and semi-grassed patches.
- Consider barrier concepts that can prevent incursions into trees and vines which can be combined with other? concepts to thin/supress numbers.
- Consider Push-Push-Trap concepts that repel or deter snails/slugs from leaving a strip and pushing them to inter-row areas where combinations of crop, predator and product can reduce numbers.
- Repel slugs/snails out of the crop at critical points to reduce damage and contamination potential.
- Reduce the reliance on baits in the need to stop large pest incursions.
- Increase the effectiveness of overall Integrated Pest Management outcomes: that is, products and practices that do not increase other threats.

Results to date
Trial results from the field and small lab tests narrowed down potential products:

Table 2: Concept 1 trial summary

Product	Comments
Grazers G2[1]- A micronutrient-based product that is registered and sold in the UK and EU as a slug and snail deterrent.	• Inconclusive results overall, but not effective in any trials. It could perhaps be re-tested as drench, but we did not see anything from this product that suggests it will be effective in our conditions. **No further testing.**
Slug-EM®[2]- A saponin based product, registered in New Zealand as a seed treatment designed to reduce losses to molluscs at sowing and establishment.	• Instability in the version of formulation caused issues and creates questions around results. New batches have been made but will not arrive before project is finalised. • Two rates tested and the higher rate looked interesting. **Re-test as drench and part of a push-pull approach.**
CGX100- A trial formulation of saponin products formulated in Australia and being considered for development.	• Trial was compromised by diseased slugs but showed some effectiveness. • Owner reformulating for additional tests and will look to use as a seedling drench. **Colere will progress**
PyroAg- Australian developed wood vinegar.	• Not effective. High rates likely to have phytotoxic effects. **No further testing.**
Schnexagon from Lugato (a German company) contains Linseed, wood, castor oil, tree resins in a natural oil.	• Not effective as a barrier. **No further testing.**
CGX200- A combination of potassium-based lipids and essential oils that has been successfully trialled on scale and mealy-bugs.	• Not yet tested as rates need to be confirmed. **Colere will look to trial as soon as we can see slug snail activity in**

[1] https://www.grazers.co.uk/grazers-products/

[2] https://hnt.co.nz/rappel/

	autumn 2025.

Business Case Conclusions

Enough was seen in the proof-of-concept trials to suggest that a product that repels slugs and snails, at least for a period of time, is indeed possible and commercially viable. The two companies that worked with us during this project are both continuing to develop their formulations and are committed to evaluating future products utilising the same trial protocols and market targets provided.

Concept 2: Predatory nematodes

The use of predatory nematodes as a farmer-applied product has been popular in Europe for several decades and has a strong following in several sectors such as orchards, turf, and protected cropping. Use against molluscs is mostly focused on the intensive vegetable and flower/nurseries sectors. A number of nematode species are slug parasites, yet *P. hermaphrodita* is the only species to have been formulated as a commercial biocontrol agent.

Scope

- Manage snails and slugs at additional points in their lifecycle, such as eggs and juveniles, especially when populations are endemic in the field/orchard/vineyard.
- Reduce the buildup of slug and snail numbers throughout the season, cost effectively and in a passive manner.
- Identify a product that can be applied in-field, directly to a crop, within weeks/days of harvest, and which will repel slugs or snails. Will need a very high success rate to be acceptable, and work across all slug or snail species.

P. hermaphrodita has been imported from Europe previously, however our recent attempt to secure an import permit has not been successful. AQIS and Biosecurity Australia cannot find evidence that this species is in Australia and therefore require a full biosecurity assessment. Given that *P. hermaphrodita* is known to predate a wide range of slugs, it seems likely that it would also attack Australian native species. Knowing this, obtaining approval for import is unlikely.

Alternatives/Options

- We are speaking to Australian nematode specialist to see if they have recorded sighting of *P. hermaphrodita* in Australia to support an application.
- Isolate Australian native species of nematode from slugs/snails, and look to breed them in a similar approach. There are many examples of predatory nematodes being isolated from snails and slugs in Australia.

Business Case Conclusions

The business case considers the domestic production of predatory nematodes to supply a range of Australian horticultural markets for the control of snail and slug pests. With scalable production, no regulatory barriers (provided local strains are used) and providing a chemical residue-free solution; predatory nematodes make logical sense for many of the key markets identified. Predatory nematodes are not seen as a replacement for baits but rather fit many of the large gaps and roles that baits are incapable of filling.

If the cost of production can be brought down with domestic production and just-in-time delivery, to allow for a retail price of under AUD$50/100million, then they offer growers a compelling option other than baits.

The Australian biopesticide company, **BioLogical-Ag** is currently assessing the potential to build and operate a substantial nematode production facility in Queensland with a view to supplying several species to the market. In working on this business case with them, we hope to have provided them with valuable background, context and confidence to progress.

Concept 3: Breeding predatory beetles

These beetles prey on slugs and snails, either by actively hunting adults or consuming their eggs and juveniles. Some also have juvenile stages that also predate the eggs or young of slugs and snails. with one example from Australian farming systems.

The most likely species for consideration will be a Rove beetle. Rove beetles (Staphylinidae) are a large and diverse family and Australia has an estimated 900 to 1500 species. There is very little research into rove beetles as a specific predator of slug and snails, although it is known that they will opportunistically feed on them. They are considered important generalist predators in agricultural ecosystems, consuming a range of insect prey including pests of crops.

Scope

- Commercial supply of predatory beetles seasonally (in a similar manner to parasitoids like trichograma and predatory mites) for release into fields and orchards/vineyards prior to seasonal build ups in snail numbers and as a way of maintaining a suppression of numbers.

- Methods and knowledge around how to best establish the beetles in the field, support them and help them breed will be needed.

- Predators may be able to keep numbers in check and prevent rapid build ups. The right predators (those that target multiple life stages) can have a substantial and ongoing impact on pest numbers. Generalist predators, those who will eat a wide range of prey, are also useful in that the right environment should be able to support good numbers throughout the year, ensuring enough predators are present when conditions for mollusc breeding is good.

- The concept is a very strong fit to good IPM practices and as general predators will have knock on benefits across a range of pests.

- An established population (perhaps with seasonal top up) could put a dent in numbers and reduce pressure at key times. Monitoring of snail/slug numbers would be needed to be effective.

Business Case Conclusions

Discussions with Australian biocontrol company **Ecoinsects** have led us to believe that there may be a role for breeding predators in key horticultural use cases. The concept of direct biocontrol is growing in Australian agriculture, the use of biocontrol agents in targeted and regular introductions (rather than classic biocontrol where introductions are assumed to establish and naturally moderate pest numbers over time).

Ecoinsects are exploring this concept, including some modelling and budgeting to understand what a mass-rearing facility would entail. Early trials would also need to establish direct knowledge of whether these beetle predators could sufficiently manage to hold pest numbers below an economic threshold and provide a reasonable value proposition for horticultural producers.

Concept 3: Sprayable molluscicide

Most farmers spoken to in our initial investigation would prefer a product that was specifically able to kill molluscs, ideally as a single application timed to maximise field results. The Technical Review covered several compounds that had a contact molluscicidal effect, however in most cases the literature was not conclusive or overly compelling. Drawing on what we found Colere has several conceptual products to investigate specifically as sprayable molluscicides. Trial reports numbered B3 focus on this concept.

None of the products being considered have begun any type of evaluation or regulatory process. The trials will only focus on establishing a proof of concept that the products (or ones like them) could be potentially developed for the industry.

Scope

- Mollusc reactions (e.g. feeding) will be noted over 48hr post application, with ideally an immediate stop in feeding and death within this period.
- Contact or low-level ingestion impact with total (highest) rates of no more than 4L per ha of product.

Table 3: Concept 4 trial summary

Product	Comments
Slug-EM®- A saponin based product, registered in New Zealand.	• High rates were not molluscicidal in trials, however product owner suggests could be on some slug species. Product may have been compromised and re-test is needed. • Foaming and loss of mucus sheath was seen, which might be detrimental in field conditions. **Colere will retest in Autumn 2025**
CGX100- A trial formulation of saponin products formulated in Australia.	• High rates were not molluscicidal in trials. • Tweaking of formulation underway. **Colere will retest in Autumn 2025**
Bacillus preparation **SK007**- Potential Biopesticidal product.	• Double recommended rates failed to achieve slug mortality after 28 days **Need to consult with Australian developer**
Eugenol +	•
PyroAg- Is based on wood vinegar from liquid condensate derived from the pyrolysis of biomass.	• High rates were not molluscicidal in trials. **No further work.**
Tetrahymena rostrata (protozoa) applied as a spray.	• Experimental formulation being developed. APVMA permit being sought for small scale field trials. **Colere will test in Autumn 2025**

Colere is looking to progress some of this work beyond the life of the project, at least to finalise the assessment of several of the above in semi-commercial field situations.

Business Case Conclusions

The Technical Review identified a long list of potential actives from literature, previous projects the team are aware of and various grey literature. These were narrowed down based on several key questions:

- **Has the active undergone any type of toxicology and safety review/analysis?** This is often an expensive and longwinded process and an unlikely investment for a non-proprietary active. Food grade or cosmetic actives might get a pass in this area.

- **Is a mode of action known (or at least suspected)?** This may also point to similar related compounds that have improved efficacy but have yet to be tested.

- **Does the literature show efficacy of this active in a realistic trial situation?** Many of the published trials use excessively large volumes or use unreliable protocols.

- **Could the active be formulated and applied in a cost-effective and reliable way.** This points to product stability and rates that might make certain actives unviable or too expensive as a product.

There is a strong demand from many producers and their markets for products that are based on plant or microbial extracts and have a potentially lower environmental impact. The lower efficacy of such products may be acceptable, however this does not reduce the costs and barriers to registration.

A regulatory case needs to be presented to APVMA that would allow the bar for registration to be lowered in terms of total kill and speed of kill, if the biologicals or biorationals are to consider being subjected to the registration process.

Currently they would be compared against a positive control of the only registered product, a bait, and likely fair poorly.

Outputs

Table 4. Output summary

Output	Description	Detail
Technical Review	Comprehensive review of the impact and management of snails in Australian horticulture.	A "for publication" and confidential version of the Technical Review were provided to Hort Innovation in January 2024.
Industry Gap Analysis	A gap analysis covering thirteen of the horticultural industries.	The Industry Gap Analysis was provided to Hort Innovation in May 2024. This is intended to be shared with relevant industries to guide their future investment in snail and slug management.
Product Development Framework	A methodology for narrowing down prospective snail and slug management concepts.	The Product Development Framework was provided to Hort Innovation in May 2024 along with a workshop session to explain how it was used.
Trial Updates	Updates on the progress and results of field and lab trials.	Two update reports were provided to Hort Innovation (Nov 2024 and Jan 2025) relating to the progress of field trials and selection of Business Cases.
Final Report	This final report for the project.	Provided to Hort Innovation in March 2025.
Business Cases	Four brief Business Cases outlining how and why new concepts could progress to commercialisation.	Provided to Hort Innovation in March 2025.

Outcomes

Table 5. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Provide the background and knowledge for Hort Innovation to make informed decisions in relation to pest mollusc investments.	Supports Hort Innovation strategic imperatives 1.2 and 1.3.	The Technical Review and Industry Gap Analysis provides specific recommendations and prioritisation of mollusc issues for thirteen sectors.	Both reports were delivered to Hort Innovation.
All four of the novel concepts that were developed into Business Cases are now in the hands of commercial companies who are working on	Aligned to the goals of Frontiers investment, to support and encourage innovative R&D to market and collaboration with private industry.	Four business cases written (partly) in partnership with specific private companies interested in developing these concepts.	Four Business Cases and contacts provided to Hort Innovation.

bringing to market.			

Recommendations

Future Directions

The confidential version of the Technical Review included a sub-section called Future Directions in each section covering the current and potential slug and snail management options. These are summarised below:

Current Pesticidal Options

1. The industry is likely to lose Metaldehyde as a registered active in the medium to long term. New actives (mostly iron based) have come to the market, but little is known about their specific pros and cons in the wide range of horticultural uses.
    a. *Industry investment in a project that focuses on highest priority sectors and develops best-practice information for iron-based and other new bait products.*
2. New bait products have generic labels and little industry specific detail to help producers.
    a. *Work with product providers to provide stewardship and best practice knowledge to producers. This is successfully being done in other industries.*
    b. *Sector specific knowledge also encourages product developers to enhance the functionality of their products as the market understands and will pay for improvement.*

Practice Based Management

3. There are not established protocols and approaches for monitoring snails and slugs in horticultural sectors and economic thresholds seem mostly arbitrary. This is leading to mistimed baiting and over or under use of baits, with poor outcomes.
    a. *Invest in the development of monitoring protocols and economic thresholds for snail and slugs in highest priority crops.*
    b. *Investigate new technology being developed for remote monitoring of snails and how it could be adapted for use in key crops.*
4. In crops and situations where mollusc pests can harbour and breed freely (planted interrow in orchards, drainage ditches and under nursery benches) create opportunities for large migratory infestations.
    a. *These areas would likely also be ideal for establishment of predators such as nematodes or carabid beetles.*
    b. *Develop management strategies for sectors that are utilising IPM approaches that include these types of areas.*
    c. *Combinations of barriers, repellent volatiles and trap crops could be applied in certain field situations to create a push-push-trap method.*

Biocontrol Agents

5. Macro agents (e.g. insects) do not require APVMA registration and can therefore be brought into an industry quickly and at moderate establishment cost. Their success however usually relies on a deeper level of ecology and IPM background work to ensure they are utilised correctly and deliver reliable results.
   a. *Look to support the companies developing predatory nematodes and carabid beetles once they have established that mass rearing at commercial levels is possible.*
   b. *If nematodes are made commercial, co-invest in the development of stewardship to maximise their impact and successful adoption in priority industry sectors.*
   c. *Investigate concepts such as "banker crops", habitat management and trap crops as ways of supporting biocontrol within IPM systems.*

Other new Actives and Biopesticides

6. The Australian horticultural sector is diverse and unfortunately small from a global perspective, meaning new options, products and concepts often are not initiated here or brought to our market without assistance.
   a. *Maintain a watching brief on areas such as RNAi and peptide development and be prepared to support the bridging of project concepts that would allow them to consider an Australian market.*
   b. *Work closely with GRDC on specific snail and slug investment where there is opportunity to collaborate and coinvest.*

Extension and communication for industry sectors

The Industry Gap Analysis identified priority sectors and geographic regions in relation to knowledge gaps that would enable improved packages of information to be provided to growers. In several cases the guidance they are currently using or receiving is outdated and ineffective.

Intellectual property

This project did not produce specific IP for commercialisation, however, did produce confidential information pertaining to the products provided by commercial partners. Trial results etc have been shared with the relative parties but will otherwise be maintain commercial in confidence by Colere and Hort Innovation.