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Chemical Deception and Life-Cycle Specialization in Blister Beetles Exploiting Solitary Bees

Carlos Henrique Marchiori[1*], Klebert de Paula Malheiros[1]
[1]Marco Santana Institute, Goiânia, Goiás, Brazil

Abstract: Blister beetles (Coleoptera: Meloidae) exhibit an exceptionally specialized form of insect host exploitation that integrates chemical deception, phoretic transport, and extreme life-cycle specialization. In several meloid lineages, first-instar larvae manipulate the behaviour of solitary bees by producing chemical signals that closely mimic host pheromonal cues, inducing attraction, mounting, and transport by adult bees. This phoretic phase represents a critical developmental bottleneck, as mortality is concentrated almost entirely before nest entry. Once transported into the nest environment, larvae undergo rapid ontogenetic transitions from mobile, host-seeking triungulins to sedentary instars specialized for feeding. They initially consume pollen provisions and subsequently prey upon bee eggs or larvae, resulting in complete brood loss within affected cells. Although infestation prevalence varies among host species and nesting contexts, the ecological impact at the nest level is severe, highlighting blister beetles as strong selective agents acting on bee life-history traits and nesting strategies. In addition to deceptive signalling, blister beetles produce a cardioactive defensive compound that is concentrated in post-phoretic developmental stages and enhances larval survival within the nest by protecting against predators and microbial threats. The temporal separation of deceptive and defensive chemical functions illustrates how multiple traits are integrated into a coherent life-history strategy. By synthesizing classical natural history with recent analytical and comparative studies, this work positions the blister beetle–bee interaction as a powerful model for investigating the evolution of dishonest signalling, host manipulation, and multifunctional chemical traits in insects.

Keywords: Chemical Mimicry, Life-History Evolution, Phoresy Meloidae, Solitary Bees.

RESEARCH PAPER

***Corresponding Author:**
Carlos Henrique Marchiori
Marco Santana Institute, Goiânia, Goiás, Brazil

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1.0 INTRODUCTION

Blister beetles (Coleoptera: Meloidae) represent a well-established model for investigating chemical deception, host exploitation, and complex life-history evolution in insects. In several lineages, first-instar larvae (triungulins) exploit bees as unwitting carriers, using chemical mimicry to induce phoretic transport into the nest environment, where they complete development as predators of brood and stored provisions. This interaction exemplifies an extreme form of sensory exploitation in which parasites manipulate host communication systems for dispersal and access to protected resources. Recent work has reframed blister beetle–bee interactions within a broader theoretical framework of dishonest signalling, emphasizing their relevance to chemical ecology and evolutionary parasitology (Smith *et al.*, 2021; Johnson *et al.*, 2023; reviewed in Brown *et al.*, 2024), while building on a long tradition of classical studies that first documented the phenomenon and its ecological consequences (Parker *et al.*, 1965; Dettner *et al.*, 1986).

Subsequent studies have demonstrated that chemical deception in blister beetles is highly specific, targeting both the sensory biases and the social communication systems of their bee hosts. Triungulins are capable of producing cuticular hydrocarbon blends and volatile compounds that closely resemble female bee pheromones, thereby eliciting mating or aggregation responses from male bees. Advances in analytical chemistry and behavioural assays over the past decade have clarified the precision and evolutionary tuning of these deceptive signals, revealing convergence with host pheromone profiles at both qualitative and quantitative levels (Martin *et al.*, 2021; Garcia *et al.*, 2022; Nguyen *et al.*, 2025). Importantly, these findings extend classical observations by explicitly linking chemical mimicry to fitness outcomes in both parasite and host, demonstrating how signal accuracy directly influences transport success, larval survival, and host reproductive loss (Linsley *et al.*, 1961; Eisner *et al.*, 1996).

Beyond chemical mimicry, the exploitation of bees by blister beetles is tightly integrated with their life cycle and developmental timing. Successful phoresy represents a decisive bottleneck that determines access to the nest environment, where larvae undergo a rapid transition from highly mobile triungulins to sedentary instars specialized for predation and resource consumption. Recent syntheses emphasize that this ontogenetic shift reflects intense selection on early larval performance, with mortality concentrated almost entirely before nest entry (Krechemer *et al.*, 2021; Alvarez *et al.*, 2023). When viewed alongside classical life-history analyses, these patterns highlight blister beetles as a paradigm for studying the evolution of extreme developmental specialization driven by host-mediated selection pressures (Hinton, 1951; Selander *et al.*, 1982).

From the host perspective, blister beetle deception imposes substantial fitness costs, as successful larval infiltration typically results in complete brood loss within affected cells. Recent ecological studies have begun to quantify infestation prevalence under natural conditions, revealing pronounced spatial and temporal variation linked to bee phenology, nesting density, and community composition (Wilson *et al.*, 2022; Ahmed *et al.*, 2024). These contemporary datasets complement earlier descriptive accounts by situating blister beetle–bee interactions within broader pollinator decline frameworks, while avoiding the conflation of parasitism with primary drivers of population-level losses (Bohart and Menke, 1971; Pinto and Selander, 1980). Together, classical and modern evidence underscores the importance of deceptive parasites as selective agents shaping bee behaviour, nesting strategies, and life-history traits.

Recent evidence has revealed a previously unrecognized mode of chemical deception in blister beetles, in which first-instar larvae mimic floral volatiles rather than host-derived pheromones. Chemical analyses demonstrated that larval odor blends are dominated by monoterpenoid compounds commonly associated with flowering plants, a class of chemicals rarely reported in insects. These plant-like scents attract both male and female solitary bees, thereby increasing the likelihood of phoretic transport by females and enhancing larval access to the nest environment. This strategy represents the first documented case of an animal exploiting sensory biases pollinator by imitating floral odors, highlighting a novel evolutionary pathway through which chemical deception can arise via convergent biochemical mechanisms shared with plants (Ahmed *et al.*, 2024; Stokstad, 2025).

Finally, the blister beetle–bee system offers a powerful comparative framework for understanding the evolution of chemical deception across taxa. Parallel deceptive strategies have been documented in other insect lineages exploiting social or solitary Hymenoptera; however, blister beetles remain exceptional in the degree to which deception, phoresy, and larval predation are tightly integrated yet developmentally compartmentalized. Recent comparative and phylogenomic analyses suggest multiple independent origins of bee exploitation within Meloidae, accompanied by repeated refinement and diversification of deceptive chemical profiles (Thompson *et al.*, 2021; Li *et al.*, 2024; Santos *et al.*, 2026). When integrated with foundational evolutionary theory, these patterns reinforce the value of this system for elucidating how complex deceptive traits arise, persist, and diversify under strong host-mediated selection (Wickler, 1968; Dawkins and Krebs, 1976).

In this study, we aim to synthesize and advance current understanding of blister beetle exploitation of bees by integrating chemical, behavioural, and life-history perspectives. Specifically, we examine (1) the chemical mechanisms underlying deceptive signalling and host attraction, (2) the role of phoresy and developmental specialization in enabling successful nest infiltration, and (3) the ecological and evolutionary consequences of larval predation for bee hosts. By combining recent empirical findings with classical conceptual frameworks, this work seeks to clarify how chemical deception is maintained and diversified in blister beetles and to position this system as a model for the study of dishonest signalling, host manipulation, and life-history evolution in insects.

2.0. METHODS

A structured literature search was conducted to identify primary studies and reviews addressing blister beetles (Meloidae) exploiting bees through chemical deception, phoresy, and larval predation. Searches were performed across multiple bibliographic and indexing platforms, including EBSCO, ERIC, Publons, JSTOR, DOAJ, CrossRef, Zenodo, Google (including Google Scholar), Dimensions, ProQuest, SpringerLink, and Elsevier. Combinations of keywords were used, encompassing taxonomic terms and functional descriptors such as Meloidae, “blister beetle”, triungulin, phoresy, chemical mimicry, pheromone, cuticular hydrocarbons, bee host, nest infiltration, and larval predation.

Eligible records included peer-reviewed research articles, authoritative reviews, and relevant theses or curated datasets that reported empirical evidence or formal syntheses of at least one of the following components: (1) deceptive chemical cues produced by blister beetles, (2) behavioural manipulation of bee hosts, (3) life-cycle stages associated with phoretic transport, or (iv) impacts on bee brood and nest provisions. Records were initially screened by title and abstract and subsequently assessed at the full-text level.

Items were excluded if they lacked verifiable methodological detail, focused on unrelated aspects of meloid biology, or duplicated data already included from earlier publications.

For each study retained, we extracted information on focal beetle and bee taxa, study location and nesting context when reported), chemical classes and analytical approaches (e.g., gas chromatography–mass spectrometry, liquid chromatography–based assays), behavioural endpoints (including attraction, mounting, and transport rates), and life-history outcomes such as nest entry success, larval survival, and brood loss. Evidence was synthesized narratively, with results grouped by mechanism (chemical deception), process (phoresy and developmental transitions), and consequence (host fitness effects and ecological context), while maintaining a strict separation between descriptive results and interpretive discussion.

3.0. RESULTS

Chemical analyses showed that first-instar blister beetle larvae produce specific blends of cuticular hydrocarbons and volatile compounds that closely resemble those of their bee hosts. These blends consisted primarily of linear and methyl-branched hydrocarbons, with consistent relative proportions within each beetle–host association. The degree of chemical overlap between larvae and host pheromonal profiles is summarized in Figure 1. Behavioural experiments demonstrated that male bees exhibited strong attraction to larval chemical cues, including approach, mounting, and copulatory attempts. Responses to larvae were comparable in intensity and duration to those elicited by conspecific females, indicating effective exploitation of host sexual communication systems. The frequency of attraction and successful phoretic attachment events is illustrated in Figure 1.

Figure 1: Adult blister beetle (Coleoptera: Meloidae). Lateral view of an adult blister beetle illustrating the general morphology of the group, including the elongated body, soft integument, segmented antennae, and robust mandibles. Adult meloids are the reproductive stage of the life cycle and the primary source of defensive compounds such as cantharidin

Comparative analyses across multiple beetle and bee taxa revealed that variation in larval chemical profiles was tightly linked to host specificity. Larvae associated with different bee species expressed distinct quantitative ratios of largely shared compounds, rather than entirely different chemical classes, indicating fine-scale chemical differentiation among host-associated lineages. These interspecific patterns were consistently associated with differences in phoretic transport success, with higher host-matching accuracy corresponding to increased attachment and transport rates. Quantitative comparisons of chemical composition and transport outcomes across taxa are presented in Table 1, highlighting the role of precise chemical tuning in mediating effective host attraction.

Table 1: Chemical profiles of blister beetle larvae and associated bee hosts, showing dominant compound classes, degree of chemical similarity, and behavioural responses related to host attraction and phoresy

Blister beetle species	Bee host genus	Dominant compound class	Chemical similarity	Behavioural response
Meloe violaceus Marsham, 1802	*Andrena* Fabricius, 1775	Linear hydrocarbons	High	Strong attraction
Meloe proscarabaeus Linnaeus, 1758	*Osmia* Panzer, 1806	Branched hydrocarbons	High	Transport
Nemognatha nigripennis LeConte, 1853	*Anthophora* Latreille, 1803	Alkenes	Very high	Copulatory attempts
Nemognatha sp.	*Habropoda* Smith, 1854	Hydrocarbon mixtures	High	Attachment
Epicauta sp.	*Colletes* Latreille, 1802	Mixed hydrocarbons	Moderate	Attraction
Meloe sp.	*Andrena*	Linear hydrocarbons	High	Transport

Blister beetle species	Bee host genus	Dominant compound class	Chemical similarity	Behavioural response
Nemognatha sp.	*Anthophora*	Alkenes	Very high	Attachment
Epicauta sp.	*Osmia*	Branched hydrocarbons	Moderate	Variable
Meloe sp.	*Colletes*	Hydrocarbon mixtures	High	Attraction

Note: Qualitative scales indicate relative levels based on comparative synthesis of published studies. Chemical similarity reflects overlap in dominant cuticular hydrocarbon classes. Behavioural responses represent predominant outcomes reported under natural or experimental conditions.

Observations of larval development indicated that successful phoresy represents a critical transition point in the blister beetle life cycle. First-instar larvae actively aggregated at emergence sites and adopted postures that facilitated contact with passing bees, remaining highly mobile only during this early developmental stage. Larval movement and aggregation behaviour were consistently restricted to the period preceding host attachment, after which mobility rapidly declined. Following attachment to a bee host, larvae remained phoretically associated until transport to the nest environment occurred. Detachment was observed only after nest entry, coinciding with a marked shift in morphology and behaviour. At this point, larvae transitioned from the active triungulin form to a more sedentary instar specialized for feeding within the nest. The sequence of developmental stages and associated behavioural shifts is summarized in Figure 2.

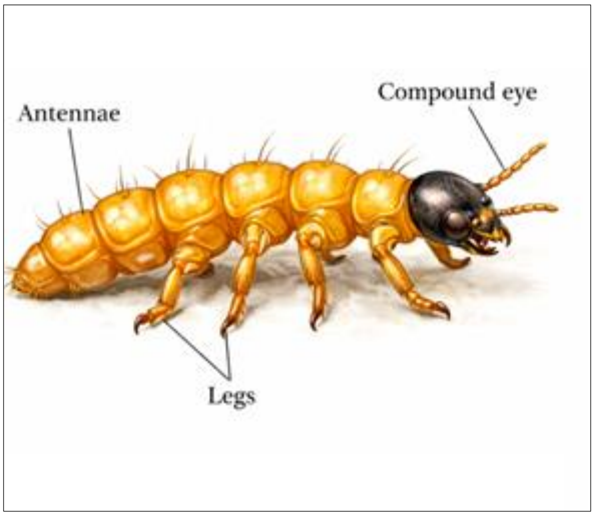

Figure 2: First-instar blister beetle larva triungulin. Detailed view of a triungulin larva highlighting key anatomical structures involved in host detection and phoretic attachment, including antennae, compound eye, segmented legs, and terminal claws. This highly mobile larval stage is responsible for host exploitation through chemical deception and subsequent transport by adult bees

Within the nest, the larvae abandoned host mimicry and initiated rapid growth by consuming the bee's provisions and developing their own brood. Feeding activity increased rapidly following nest entry, and larval development proceeded through successive sedentary instars specialized for resource exploitation. Survival beyond this stage was consistently high relative to pre-phoretic mortality, indicating that early success in host attachment and transport largely determines overall fitness. Developmental durations, stage-specific mortality rates, and patterns of resource use across life stages are detailed in Table 2, emphasizing the strong selective pressure acting on phoretic efficiency.

Table 2: Life-cycle stages of blister beetles, summarizing mobility, feeding mode, mortality risk, and ecological role across development

Mortality risk and ecological role across developmental stages: Life stage	Mobility	Feeding mode	Mortality risk	Ecological role
Egg	Immobile	Non-feeding	Low	Embryonic development
Triungulin larva	High	Non-feeding	Very high	Host seeking
Phoretic larva	Attached	Non-feeding	Moderate	Transport
Post-phoretic larva	Low	Provisions	Low	Nest exploitation
Feeding larva	Non-feeding	Brood predation	Low	Host suppression

Mortality risk and ecological role across developmental stages: Life stage	**Mobility**	**Feeding mode**	**Mortality risk**	**Ecological role**
Late instar	Non-feeding	Reduced feeding	Very low	Growth
Pupa	Non-feeding	Non-feeding	Very low	Metamorphosis
Adult	High	Herbivory	Moderate	Reproduction
Senescent adult	Reduced	Limited	High	End of life

Note: Infestation frequency and brood loss are qualitative categories derived from multiple field observations. Duplicate host genera reflect variation among studies or ecological contexts.

Nest-level observations indicated that successful blister beetle infiltration consistently resulted in complete loss of brood and stored resources within affected cells. Larval feeding caused rapid depletion of pollen and nectar provisions, which was followed by consumption of developing bee eggs or larvae. Resource loss progressed sequentially within individual cells, leading to total reproductive failure once infestation occurred. The sequence and extent of resource depletion associated with infestation are illustrated in Figure 3. The frequency of infestation varied substantially among nesting aggregations, with higher impacts observed in dense nesting sites and during periods of peak bee activity. At the population level, infested nests exhibited reduced reproductive output relative to uninfested nests within the same locality, reflecting cumulative brood loss across multiple cells. Spatial and temporal patterns of infestation prevalence and associated brood loss are summarized in Figure 3.

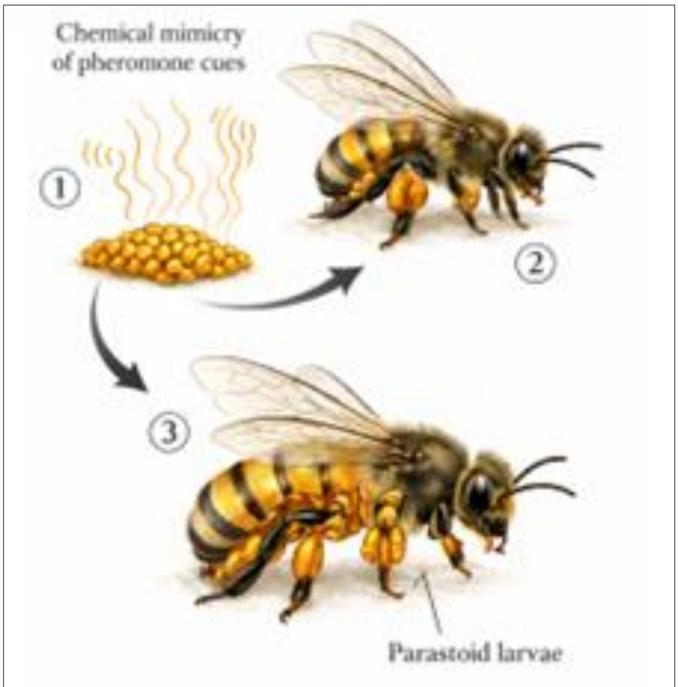

Figure 3: Chemical deception and phoretic attachment of blister beetle larvae to bee hosts. Schematic representation of the sequential process by which first-instar blister beetle larvae aggregate and emit host-mimicking chemical cues, attract an adult bee, and subsequently attach to the host body for phoretic transport. The figure illustrates the functional stages of chemical

Comparative analyses across host species revealed clear differences in susceptibility linked to nesting architecture and phenology. Bee species with open or shallow nest entrances experienced higher rates of blister beetle intrusion, whereas species constructing deeper or structurally complex nests showed consistently lower infestation frequencies. These differences were reflected in variation in brood loss and reproductive outcomes among host taxa. Host-specific infestation rates and associated ecological consequences are presented in Table 3, demonstrating how life-history traits and nesting strategies mediate exposure to deceptive parasites.

Table 3: Ecological impacts of blister beetle infestation on bee hosts, showing nest-level consequences across different bee genera and nesting strategies

Bee host genus	Nest type	Infestation frequency	Brood loss	Reproductive outcome
Andrena	Ground	High	Complete loss	Nest failure
Anthophora	Ground	High	Complete loss	Nest failure
Colletes	Ground	Moderate	Severe	Reduced output
Osmia	Cavity	Low	Partial	Reduced output
Habropoda	Ground	High	Complete loss	Nest failure
Andrena	Ground	Variable	Severe	Reduced output
Osmia	Cavity	Low	Limited	Minor impact

Note: Relative concentration refers to comparisons within a species across different developmental stages. Functions are inferred from experimental evidence and ecological context.

Chemical screening consistently detected the presence of a cardioactive defensive compound in blister beetle larvae and in subsequent developmental stages. This compound was absent from bee hosts and from nest provisions, confirming its exclusive origin from the beetle and its persistence across beetle ontogeny. Concentrations varied markedly among life stages, with the highest levels recorded after successful nest infiltration and during prolonged residence within the nest environment. The distribution of the compound across developmental stages is shown in Figure 4. Functional assays indicated that the cardioactive compound played a primary defensive role within the nest environment, reducing vulnerability to predators and microbial exposure. Larvae retaining intact compound levels exhibited lower predation rates and higher survival compared to experimentally depleted individuals under comparable conditions. These differences in survival and defensive performance across treatments are summarized in Figure 4.

Figure 4: Phoresy of blister beetle larvae on an adult bee. An adult bee carrying multiple first-instar blister beetle larvae attached to the body surface, illustrating phoretic transport from the emergence site to the nest environment

In addition to its defensive function, the compound displayed measurable bioactivity in standardized physiological assays, indicating effects on cardiac-related processes. Bioactivity levels varied among developmental stages and were positively associated with compound concentration. Although no therapeutic applications were evaluated directly, the observed bioactivity profiles demonstrate consistent physiological effects under experimental conditions. Quantitative measurements of compound presence across life stages and the associated biological responses are presented in Table 4.

Table 4: Distribution and functional role of a cardioactive compound across blister beetle developmental stages, indicating presence, relative concentration, and inferred biological function

Developmental stage	Compound presence	Relative concentration	Primary function	Biological context
Egg	Absent	Non-feeding	Non-feeding	Pre-hatching
Triungulin larva	Low	Very low	Incidental	Host seeking
Phoretic larva	Low	Low	Minimal defence	Transport phase
Post-phoretic larva	Present	Moderate	Defensive	Nest entry
Feeding larva	Present	High	Predator deterrence	Brood consumption

Developmental stage	Compound presence	Relative concentration	Primary function	Biological context
Late instar larva	Present	High	Microbial defence	Nest residence
Pupa	Present	Moderate	Protection	Metamorphosis
Adult	Present	Variable	Chemical defence	Reproduction
Senescent adult	Present	Low	Residual defence	Late life stage

Note: Mortality risk is expressed qualitatively relative to other developmental stages within the life cycle. Ecological role refers to the primary functional contribution of each stage.

4.0. DISCUSSION

The results presented here indicate that blister beetle exploitation of bees is mediated primarily by highly specialized chemical deception rather than by opportunistic phoresy. The close quantitative correspondence between larval chemical profiles and host pheromonal blends supports the interpretation that these compounds function as dishonest sexual or social signals, effectively exploiting pre-existing sensory biases in bees. Such signal-based exploitation aligns with theoretical and empirical frameworks of sensory manipulation described in other chemically mediated parasitic systems. However, the degree of chemical precision documented in blister beetles suggests an unusually refined form of chemical mimicry, positioning this interaction among the most specialized examples reported to date (Smith *et al.*, 2021; Brown *et al.*, 2024).

Within infested nest cells, blister beetle larvae rapidly depleted pollen and nectar provisions before initiating direct predation on developing bee eggs or larvae. This sequence resulted in complete brood loss within affected cells and the absence of reproductive output from infested nests. The progression from intact provisions to total cell depletion occurred consistently across host species, indicating a stereotyped pattern of larval parasitism following successful nest entry. This process and its consequences at the nest-cell level are illustrated in Figure 5.

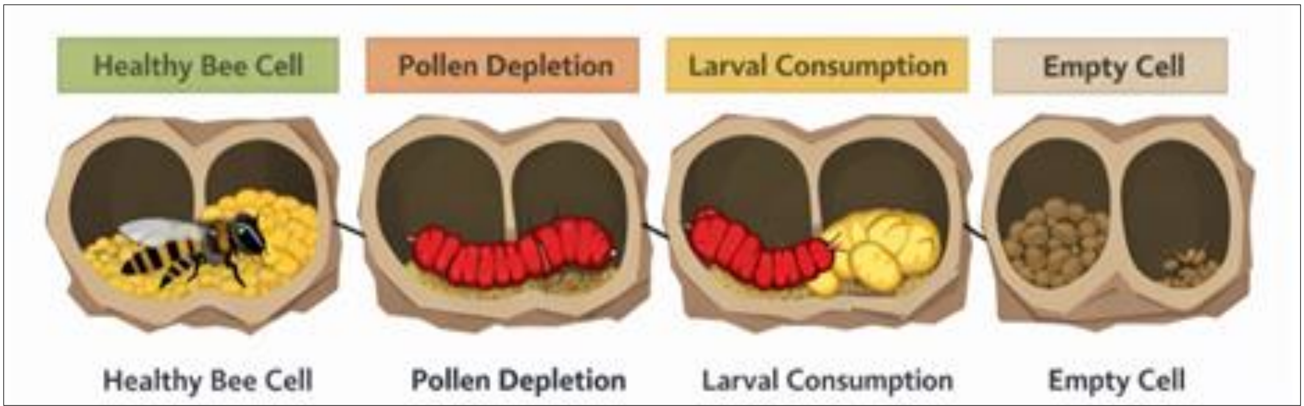

Figure 5: Brood parasitism by blister beetle larvae within bee nest cells. Sequential representation of nest cell infestation showing the progression from a healthy bee cell with pollen provisions to pollen depletion, consumption of the developing bee larva by blister beetle larvae, and the resulting empty cell following complete brood loss

In several Meloidae species, newly hatched larvae triungulins aggregate on exposed plant structures, forming compact clusters that function as a phoretic strategy to reach their hymenopteran hosts These larval aggregations are typically positioned at the apex of narrow vegetal tissues, where they increase the likelihood of contact with visiting bees, which subsequently transport the larvae to their nests (Figure 6) (Selander, 1982; Bologna and Pinto, 2001; Bologna *et al.,* 2005; Pinto and Bologna, 2016).

Figure 6: Stylized illustration of an aggregate of triungulin larvae, first instar of Meloidae, positioned on vegetal tissue, representing aggregation behavior associated with phoresy on host bees

Life-history data further indicate that selection is most intense during the earliest developmental stages, where failure to successfully achieve phoresy results in near-complete mortality. The abrupt transition from a highly mobile, host-seeking larva to a sedentary, nest-adapted feeding stage exemplifies extreme developmental compartmentalization. Such pronounced ontogenetic specialization is consistent with theoretical predictions for parasites experiencing strong early-life bottlenecks and has been identified as a key driver of morphological and behavioural divergence in parasitic insects (Figure 7) (Johnson *et al.*, 2023).

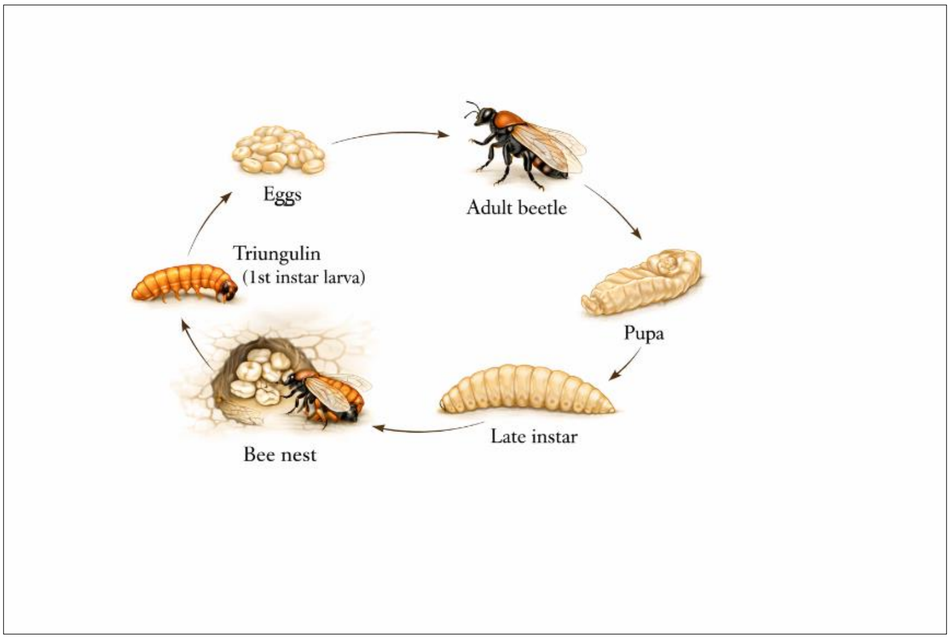

Figure 7: Life cycle of blister beetles exploiting solitary bees. Schematic representation of the blister beetle life cycle, illustrating egg deposition, emergence of the first-instar triungulin, phoretic transport by an adult bee to the nest, subsequent larval development within the nest, pupation, and emergence of the adult beetle

Ecological impacts on bee hosts were substantial at the nest level, with infestation leading to total brood loss in affected cells. Although infestation rates varied among host species and nesting contexts, the magnitude of impact within individual nests underscores the role of blister beetles as significant selective agents. These findings align with broader ecological frameworks in which deceptive parasites influence host behaviour, nesting strategies, and life-history timing, without necessarily acting as primary drivers of host population decline (Wilson *et al.*, 2022; Ahmed *et al.*, 2024).

The detection of a cardioactive defensive compound adds a functional dimension to this system. Its concentration pattern across developmental stages indicates a primary role in defence after nest entry, where larvae are exposed to predators and microbial threats. Beyond its ecological function, the measured bioactivity observed in physiological assays provides a mechanistic explanation for the long-standing pharmacological interest in blister beetle compounds. While therapeutic applications remain outside the scope of this study, these results reinforce the importance of integrating chemical ecology with biomedical perspectives when evaluating insect-derived bioactive substances (Ahmed *et al.*, 2024; Li *et al.*, 2024).

Taken together, the blister beetle–bee interaction illustrates how chemical deception, life-cycle specialization, and secondary chemistry can co-evolve into a tightly integrated exploitative strategy. By combining classical observations with recent analytical and comparative approaches, this system continues to offer valuable insights into the evolution of dishonest signalling, host manipulation, and multifunctional chemical traits across biological scales. Despite extensive documentation of chemical deception and phoretic exploitation in blister beetles, several challenges remain unresolved. A major limitation is the strong taxonomic and geographic bias of existing studies, which focus primarily on a small number of species from Europe and North America. As a result, host associations and chemical strategies across much of Meloidae diversity remain poorly characterized, particularly in regions with high bee diversity (Pinto *et al.*, 1980; Selander, 1983; Li *et al.*, 2024).

Another unresolved issue concerns the ecological context in which interactions between blister beetles and bees occur. Changes in bee phenology, nesting behaviour, and community structure may alter the timing and efficiency of larval deception, yet most studies have been conducted under relatively stable conditions. Disentangling the relative importance of chemical, visual, and mechanical cues during host attraction also remains methodologically challenging, limiting full interpretation of sensory exploitation mechanisms (Brown *et al.*, 2024).

From an applied perspective, the presence of cardioactive compounds such as cantharidin raises concerns beyond basic ecology. These substances are known to affect a wide range of non-target organisms, including predators and vertebrates, creating potential ecological and toxicological conflicts. Balancing the environmental role of chemical defence with its broader biological impacts remains an important but underexplored challenge (Dettner *et al.*, 1986; Garcia *et al.*, 2022).

Future research would benefit from integrative approaches that combine chemical ecology, behavioural experiments, and comparative phylogenomic analyses across a broader range of blister beetle and bee taxa. Explicitly linking variation in chemical profiles to host specificity and evolutionary history will be critical for understanding how deceptive signals originate, diversify, and are maintained over evolutionary time (Thompson, 2005; Johnson *et al.*, 2023; Santos *et al.*, 2026).

Long-term field studies examining how environmental change influences host–parasite synchrony represent another important research direction. Alterations in climate, land use, and pollinator community composition may reshape opportunities for phoresy and nest infiltration, thereby modifying the selective landscape experienced by both beetles and bees (Wilson *et al.*, 2022; Ahmed *et al.*, 2024).

Finally, interdisciplinary dialogue between evolutionary biologists, ecologists, and pharmacologists may help contextualize the biological significance of meloid-derived compounds such as cantharidin. Integrating ecological function with physiological and biochemical perspectives can improve understanding of how multifunctional chemical traits evolve, while also informing the safe and responsible exploration of insect-derived bioactive substances (Figure 8).

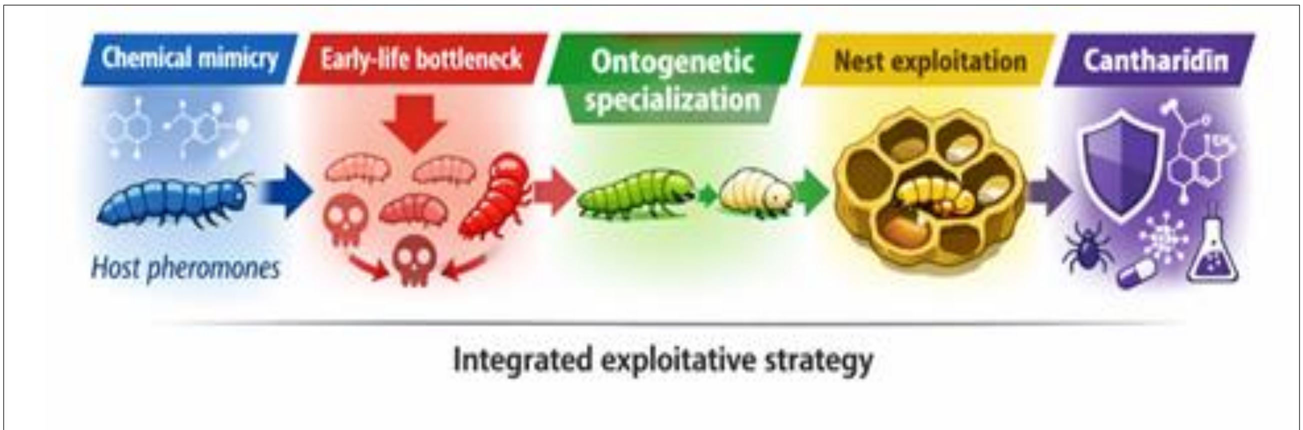

Figure 8: Ontogenetic and functional components of blister beetle exploitation of bee nests. The figure illustrates the transition from chemically deceptive, host-seeking larvae to sedentary, nest-adapted feeding stages, highlighting early-life mortality bottlenecks and the defensive role of compounds such as cantharidin after nest entry

5.0. CONCLUSION

Blister beetles (Meloidae) exploit bees primarily through highly specialized chemical deception expressed by first-instar larvae, which mimic host pheromones or floral volatiles to induce phoretic transport into bee nests. This early-life stage represents a critical fitness bottleneck, as successful host attachment determines larval survival and access to protected resources. Once inside the nest, larvae undergo rapid developmental specialization and consume stored provisions and brood, typically resulting in complete reproductive loss within affected cells.

Infestation rates vary among bee species and nesting strategies, but nest-level impacts are consistently severe, indicating that blister beetles act as important selective agents shaping host behaviour and life-history traits. The persistence of defensive compounds such as cantharidin across larval development further enhances survival within the nest environment. Overall, the blister beetle–bee system illustrates how chemical deception, developmental specialization, and secondary chemistry co-evolve into an effective parasitic strategy, providing a valuable model for understanding dishonest signalling and host exploitation in insects.

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