



Review Article

Unconventional Reservoirs of Antibacterial Compounds from Insects, Snails, and Earthworms

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ABSTRACT

The rapid emergence of antimicrobial resistance poses a significant global health challenges; thereby limit the efficacy of conventional antibiotics and increasing the burden of infectious diseases. Review focuses on unconventional biological sources, including insects, snails, and earthworms, as potential reservoirs of novel antimicrobial agents. Bacterial resistance mode of action such as enzymatic drug inactivation, target modification, efflux pump activation, and biofilm formation contribute to persistent infections and treatment failure. Biofilm formation, in particular, enhanced survival of microorganisms and resistance to immune responses of host and antimicrobial agents. Insects produce antimicrobial peptides that are small cationic molecules which has broad spectrum activity against both Gram-positive and Gram-negative bacteria, viruses, and fungi. Similarly, bioactive compounds from insects, snails and earthworms, including glycoproteins, lysozyme, and lumbrokinase exhibit antimicrobial, anti-inflammatory, and wound healing activities. These natural compounds demonstrate low toxicity and reduced likelihood of developing resistance compared to conventional antibiotics. The review highlights the therapeutic potentials of these macroorganisms as alternative sources for drug development. However, challenges such as limited clinical validation, standardization, and large-scale production need to be addressed. Further research into their mechanisms of action and biotechnological applications is essential for developing effective strategies to combat multidrug-resistant pathogens.

Keywords: Antimicrobial peptides; Antimicrobial resistance; Biofilm; Earthworms; Insects; Multidrug resistance; Snails

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INTRODUCTION

The increasing incidence of antibiotic resistance has become a major obstacle in the effective management and treatment of topical infections. This challenge is particularly evident in chronic skin and soft tissue infections, where resistant microorganisms contributed to the progression and persistence of conditions such as diabetic foot ulcers, chronic wounds, burn injuries, and post-operative infections. Among these pathogens, *Acinetobacter baumannii* has emerged as a clinically significant Gram-negative bacterium associated with a varieties

of antibiotic resistant infections, including skin and wound infections, urinary tract infections, pneumonia, and bacteremia (Neshani *et al.*, 2020). Bacterial pathogens possess numerous mechanisms that enable them to evade host immune defenses, making their pathogenicity a major focus of scientific investigation. In natural environments, bacteria commonly exist as structured microbial communities enclosed within a self-produced extra-cellular polymeric matrix known as a biofilm (Flemming *et al.*, 2016). Within clinical settings, biofilm-forming bacteria readily colonize wounds, scar tissues, and

medical devices. Due to their sessile mode of growth, biofilm-associated bacteria exhibit greater tolerance to antimicrobial agents than their free-living planktonic counterparts, contributing to persistent and difficult-to-treat infections. Infectious diseases continue to represent a significant cause of morbidity and mortality globally. Although the introduction of antibiotics revolutionized the treatment of bacterial infections, their excessive and inappropriate use has accelerated the emergence and dissemination of antimicrobial resistant bacterial strains (Manniello *et al.*, 2021). Consequently, antimicrobial resistance has become a critical public health concern, compromising the effectiveness of existing therapeutic options and increasing the burden of infectious diseases.

Biofilm formation is recognized as one of the most important survival strategies employed by microorganisms in hostile environments and is frequently associated with chronic and recurrent infections (Zharkova *et al.*, 2019). Biofilms provide protection against host immune responses by reducing the activity of antibodies, antimicrobial peptides, and phagocytic cells. In addition, the extracellular matrix acts as a physical barrier that limits antibiotic penetration, thereby decreasing antimicrobial efficacy. Factors such as inadequate drug distribution and the presence of metabolically inactive-persister cells then further contribute to therapeutic failure and infection recurrence (Neshani *et al.*, 2019). Given the growing prevalence of antimicrobial resistance and the declining availability of effective antibiotics, there is an urgent need to identify and develop alternative therapeutic approaches. Despite substantial investment in antimicrobial drug discovery, relatively few new antibiotics have been successfully introduced into clinical practice in recent decades. As a result, research attention has increasingly shifted toward unconventional biological resources, including plants, earthworms, cockroaches, wasps, and black soldier flies. Investigations by Kongkham *et al.* (2020) and Chassagne *et al.* (2021) have demonstrated the antibacterial potential of plant-derived compounds and emphasized their importance in addressing antimicrobial resistance. The exploration of natural products has resulted in the identification of numerous biologically active compounds with therapeutic value. Among these, bioactive peptides have emerged as promising alternatives because of their high antimicrobial efficacy, low toxicity, and reduced tendency to induce resistance. Antimicrobial peptides (AMPs), typically consisting of 10–100 amino

acid residues and synthesized by a wide variety of organisms, are particularly attractive candidates for antimicrobial drug development because of their broad spectrum activity and ability to target resistant pathogens (Barra *et al.*, 2020). Throughout evolutionary history, these peptides have maintained their effectiveness against microbial threats, and some have additionally demonstrated anticancer activities, leading to their classification as anticancer peptides (ACPs) (Qin *et al.*, 2019).

Plants also constitute a valuable source of antimicrobial agents through the production of secondary metabolites such as alkaloids, phenolic, and terpenoids compounds. Many of these phytochemicals exhibit potent antimicrobial activity and have been investigated extensively for pharmaceutical applications (Radulovic *et al.*, 2013, Osuntokun *et al.*, 2016). Consequently, both plant-derived compounds and AMPs have gained significant attention as potential solutions for combating multidrug-resistant (MDR) bacterial infections. Structurally, most AMPs are cationic and amphipathic, characteristics that facilitate their interaction with microbial membranes and enhance their antimicrobial effectiveness against resistant microorganisms.

Insects (Figure 1) represent another abundant and largely underexplored reservoir of bioactive molecules. With more than one million described species, insects produce a wide array of biologically active substances, including antimicrobial peptides that have been utilized in traditional medicine for centuries (Buonocore *et al.*, 2021). These peptides are particularly attractive because they generally exhibit a lower tendency to induce bacterial resistance compared with conventional antibiotics. Consequently, ongoing research is focused on the discovery, characterization, and large-scale production of insect-derived antimicrobial compounds for applications in human medicine, agriculture, and veterinary science (Manniello *et al.*, 2021).

Similarly, earthworms possess sophisticated defense mechanisms and synthesize a variety of bioactive compounds with antibacterial, antiviral, antifungal, and anti-inflammatory activities. Studies have demonstrated that earthworm-derived extracts can reduce inflammation associated with infections while simultaneously promoting tissue repair and wound healing. These properties underscore their potential as alternative therapeutic agents for the management of infectious diseases. Recent investigations have further revealed that earthworm

extracts contain several important bioactive molecules, including G-90, lysenin, and lumbrakinase, which exhibit diverse pharmacological activities such as antimicrobial, antitumor, and wound-healing effects. Continued research aimed at understanding

the mechanisms of action and therapeutic applications of these compounds further emphasizes the importance of natural biological resources in the discovery and development of novel antimicrobial agents (Deng *et al.*, 2019).

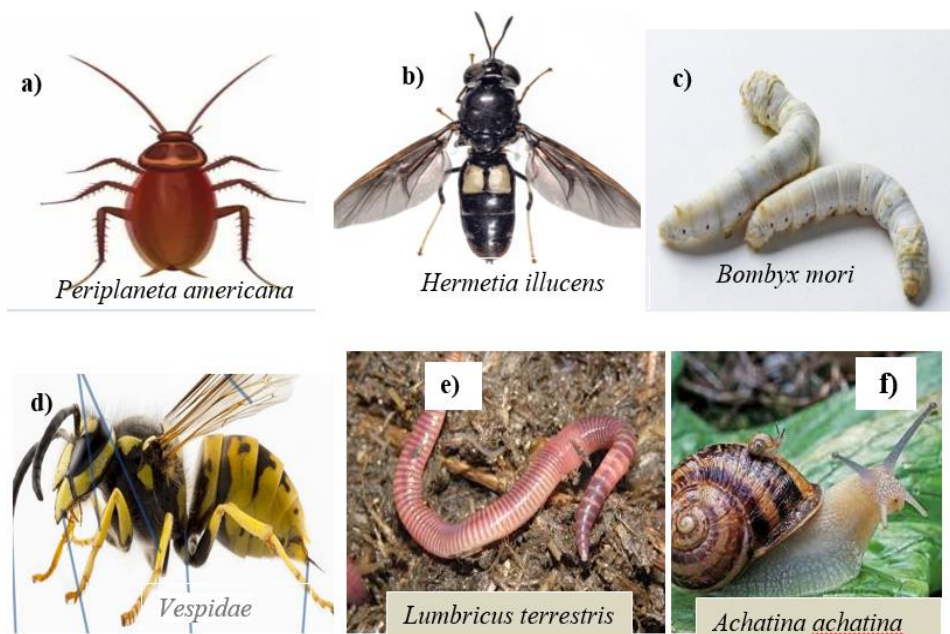


Figure 1: Examples of Insect Reservoir of Antimicrobial Compounds (a) Cockroach (b) Blacksoldier fly (c) Silkworm (d) Wasp (e) Earthworm and (f) Snail

Insect Reservoir of Antimicrobial Compounds

Cockroach

The cockroach *Blattella germanica* is an ancient insect species whose evolutionary origin can be traced to the Upper Carboniferous period. Although the majority of cockroach species inhabit tropical and subtropical regions, more than 4,600 species have been documented worldwide, with only a few closely associated with human dwellings. Among these, *Blattella germanica* and *Periplaneta americana* are the most prevalent, commonly occurring in residential buildings, healthcare facilities, educational institutions, and food-processing environments because of their omnivorous feeding behavior (Guzman *et al.*, 2020). The World Health Organization recognizes cockroaches as important public health pests due to their ability to function as mechanical carriers of numerous pathogens. They can harbor and disseminate bacteria, fungi, protozoa, helminths, and viruses through contamination of food, surfaces, and surrounding environments (Abdolmaleki *et al.*, 2019). Consequently, their presence has been linked to the transmission of diseases such as dysentery, giardiasis, and toxoplasmosis, as well as gastrointestinal

symptoms including diarrhea, vomiting, and abdominal discomfort. Their widespread occurrence in hospital environment further increases the potential risk of infection among patients and healthcare personnel (Adenusi *et al.*, 2018). Antibiotic resistance (AR) has emerged as a critical global health concern, resulting in increased mortality rates, prolonged hospitalization, and escalating healthcare expenditures. It is estimated that by 2050, AR may be responsible for approximately 10 million deaths annually, with the greatest burden occurring in low- and middle-income nations (Guzman *et al.*, 2020). Several clinically important pathogens, such as *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, and *Klebsiella pneumoniae*, have demonstrated increasing levels of resistance and possess the ability to disseminate resistance determinants among bacterial communities (Chehelgerdi *et al.*, 2021). Despite their association with pathogen transmission, cockroaches synthesize antimicrobial peptides (AMPs) within their saliva, hemolymph, and body tissues. These AMPs, including defensins, cecropins, and moricin, possess broad-spectrum antimicrobial

properties. Studies have shown their effectiveness against Gram-positive and Gram-negative bacteria, fungal pathogens such as *Candida albicans* and *Aspergillus fumigatus*, and certain viruses, including HIV-1 and influenza. Therefore, cockroaches possess a dual biological importance. While they contribute to the spread of pathogenic microorganisms, they also represent a valuable reservoir of bioactive molecules.

In particular, their antimicrobial peptides hold significant potential for the development of novel therapeutic agents aimed at addressing the growing challenge of antibiotic-resistant pathogens. The systematic approach for identification and characterization of bioactive peptides from insect against pathogens is shown in Figure 2.

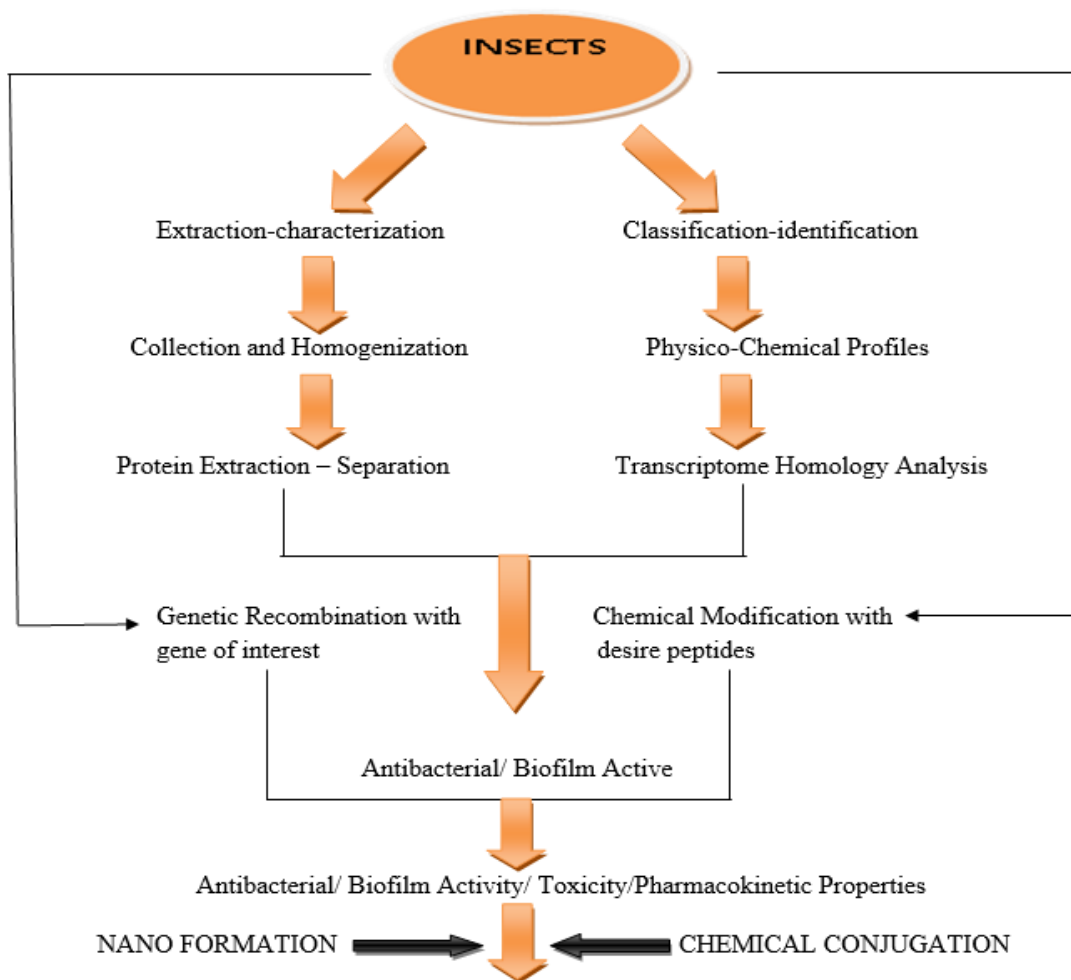


Figure 2: A flowchart showing an approach to identifying and characterizing bioactive peptides from insect

Black soldier fly

The Black Soldier Fly (*Hermetia illucens*) is recognized as a significant source of antimicrobial compounds due to its ability to flourish in environments heavily populated by microorganisms. Its larvae consume decomposing organic materials and transform them into nutrient-rich biomass containing proteins and lipids that are useful in agriculture, bioenergy production, cosmetics, and biomedical applications (Franco *et al.*, 2022). Continuous exposure to diverse bacterial and fungal communities within these substrates has contributed to the evolution of a highly

efficient immune defense system in the larvae. To withstand these microbe-dense conditions, *H. illucens* larvae synthesize a diverse array of antimicrobial peptides (AMPs), either constitutively or following stimulation by microbial exposure and dietary factors (Vogel *et al.*, 2018). Transcriptomic analyses have revealed several AMP families in this species, including defensins, cecropins, attacins, dipterocins, and lysozymes, which collectively enhance its antimicrobial defense mechanisms (Moretta *et al.*, 2020). These bioactive molecules

exert their effects by disrupting microbial cell membranes or hydrolyzing cell wall components. The antimicrobial properties of black soldier fly larvae are extensive and potent. Larval extracts have shown inhibitory activity against bacterial pathogens such as *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella enterica*, as well as antifungal activity against organisms including *Candida albicans* and *Aspergillus niger*. Additionally, some studies have indicated possible antiviral effects, although further investigations are required to validate these findings. Recent research on *H. illucens* revealed AMPs to be concentrated on assessing their efficacy against pathogenic microorganisms. In an investigation, a synthetic peptide library was evaluated against Gram-positive bacteria, Gram-negative bacteria, and fungal species. Members of the cecropin family exhibited the strongest antimicrobial activity, with several peptides effectively inhibiting *Escherichia coli* and *Pseudomonas aeruginosa* at remarkably low concentrations, highlighting their considerable therapeutic potential (Wu *et al.*, 2018; Manniello *et al.*, 2021). The black soldier fly represents a sustainable and valuable reservoir of bioactive compounds. Its antimicrobial peptides, particularly cecropins, demonstrate considerable promise as candidates for the development of novel therapeutic agents aimed at addressing the growing challenge of antibiotic-resistant pathogens.

Silkworm

The Silkworm (*Bombyx mori*) has gained considerable attention as a valuable model for the discovery of novel antimicrobial agents, particularly in response to the decline in antibiotic innovation since the mid-twentieth century. Although certain pathogens possess mechanisms to evade insect immune defenses, insects generally exhibit effective protection against infections through a sophisticated innate immune system (Elias *et al.*, 2020). This immune system comprises both cellular responses mediated by immune cells and humoral defenses involving soluble molecules released into the hemolymph to recognize and neutralize invading microorganisms. Insects are regarded as rich sources of antimicrobial peptides (AMPs), with more than 150 AMPs identified since the 1970s. While many of these peptides possess similar structural characteristics, they often display selective activity against different categories of microorganisms (Zhang and Gallo, 2021). The cooperative and synergistic interactions among these peptides significantly strengthen the

insect's defense against bacteria, fungi, and protozoan pathogens.

In *Bombyx mori*, over 30 antimicrobial peptides have been characterized, including cecropins, attacins, moricins, gloverins, lebecins, enbocins, and defensins. These AMPs exhibit broad-spectrum antimicrobial properties and are effective against a wide range of Gram-positive and Gram-negative bacteria, as well as other pathogenic microorganisms (Dijksteelt *et al.*, 2021). The antimicrobial activity observed in silkworms is primarily associated with the presence of these peptides in their hemolymph. Research has demonstrated that silkworm-derived AMPs can suppress the growth of several bacterial species, including *Escherichia coli*, *Enterobacter cloacae*, *Micrococcus luteus*, *Bacillus subtilis*, and *Staphylococcus aureus*. AMPs derived from *Bombyx mori* represent promising candidates for alternative antimicrobial therapies. Their broad-spectrum efficacy and activity against diverse bacterial pathogens underscore their potential for the development of innovative treatments aimed at combating infectious diseases, particularly in the context of escalating antibiotic resistance.

Wasp

The Wasp, a member of the order Hymenoptera, possesses a sophisticated venom system that plays an essential role in both defense and prey capture. Wasp venom is composed of a complex mixture of bioactive substances, including amino acids, peptides, biogenic amines, and phospholipids, which collectively contribute to its biological activity (Yacoub *et al.*, 2020). This rich chemical composition has contributed to the evolutionary success of these insects and has attracted considerable attention in biomedical and pharmaceutical research. Wasp venom has emerged as a promising source of novel antimicrobial agents. Antimicrobial peptides (AMPs) isolated from wasp venom display potent bactericidal properties and exert their effects through various mechanisms, including disruption of microbial cell membranes, modification of cellular metabolic processes, and interference with intracellular signaling pathways (Parish, 2019). Their broad mode of action and comparatively low likelihood of promoting microbial resistance make them attractive candidates for therapeutic applications (Mahlapuu *et al.*, 2020). Research has demonstrated that wasp-derived bioactive compounds exhibit broad-spectrum antimicrobial activity. These compounds are effective against bacterial pathogens such as *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, as well as fungal species including

Candida albicans and *Aspergillus niger* (da Silva *et al.*, 2018). It has been reported by Owolabi *et al.*, (2024) that many insect-based bacteria are capable of producing small molecules with activity against bacterial pathogens which are eminent and therefore, a source of novel antimicrobial agents. Wasp venom represents an important natural reservoir of antimicrobial molecules. The potent activity of its bioactive peptides underscores their potential in the development of innovative therapeutic strategies for combating drug-resistant microbial infections.

Snail (*Cornu aspersum*)

The snail has attracted increasing scientific interest because of the therapeutic properties of its mucus, particularly its applications in wound healing and antimicrobial therapy. Research has shown that land snail mucus exhibits antibacterial, antioxidant, and regenerative activities that support tissue repair processes (Dolashki *et al.*, 2020; Kirilova *et al.*, 2024). These biological effects are primarily associated with the presence of antimicrobial peptides (AMPs), along with various bioactive proteins and glycoproteins contained within the mucus (Deng *et al.*, 2023). Comparable antimicrobial activities have been documented in other snail species, where these bioactive molecules play an important role in their protective and therapeutic functions (Cerullo *et al.*, 2023).

Snail mucus and tissue extracts demonstrate broad-spectrum antimicrobial activity against a variety of pathogenic microorganisms. Studies have reported inhibitory effects against bacterial species such as *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, as well as fungal pathogens including *Candida albicans* and *Aspergillus niger* (Dolashki *et al.*, 2020). In addition, preliminary evidence suggests that snail-derived compounds may possess antiviral properties, although further studies are necessary to establish their efficacy and mechanisms of action. The antimicrobial activity of snail mucus is closely linked to its complex biochemical composition. Bioactive constituents such as glycoproteins and glycolipids contribute to microbial inhibition by disrupting cellular integrity, while enzymes such as lysozyme enhance antimicrobial defense through the degradation of bacterial cell walls. Snail-derived bioactive compounds constitute a promising natural source of antimicrobial agents. Their diverse biological activities, including antimicrobial and wound-healing properties, underscore their potential for the

development of alternative therapeutic approaches for infection control and tissue regeneration.

Earthworm

The earthworm is widely recognized for its essential role in maintaining soil ecosystems and is frequently referred to as an “ecological engineer” because of its capacity to decompose organic materials, recycle nutrients, and enhance soil fertility (Jones *et al.*, 1994). In addition to their ecological significance, earthworms have been utilized in traditional medicine for centuries to manage ailments such as fever, jaundice, and infectious diseases. Their biological systems contain numerous natural compounds with antioxidant and antimicrobial properties, making them important in both environmental sustainability and biomedical research. Earthworms possess a highly developed innate immune system and synthesize a wide range of bioactive molecules. These compounds exhibit diverse biological activities, including fibrinolytic, anticoagulant, anticancer, and antibacterial effects, which have generated considerable interest for potential therapeutic applications. Their medicinal value has been documented in ancient traditional Chinese medical literature and continues to be recognized in contemporary pharmacopoeias (Sun and Jiang, 2017; Cooper, 2012).

Apart from their contribution to soil improvement, earthworms also play a role in suppressing disease-causing organisms. The application of vermicompost, for instance, has been reported to reduce the incidence of infections associated with soil-borne pathogens (Szczech and Smolińska, 2001) and their coelomic fluid and body extracts contain abundant bioactive substances that strengthen their defense mechanisms against microbial invasion. Research has shown that earthworm-derived compounds possess broad-spectrum antimicrobial activity. These substances are capable of inhibiting the growth of bacterial pathogens such as *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, as well as fungal species including *Candida albicans* and *Aspergillus niger* (Rajesh *et al.*, 2019). In addition, some studies have suggested possible antiviral properties, although further investigations are necessary to confirm these effects. Earthworms constitute a promising natural reservoir of antimicrobial agents. Their diverse array of bioactive compounds, combined with their longstanding history in traditional medicine, underscores their potential for the development of

alternative therapeutic strategies to combat infectious diseases.

Antimicrobial peptides (AMPs) isolated from these organisms (insects, snails and earthworms) have demonstrated broad-spectrum antimicrobial activity and a reduced likelihood of resistance development, making them attractive alternatives to conventional antibiotics (Barra *et al.*, 2020; Manniello *et al.*, 2021). The antimicrobial peptides produced from some

insects, snail and earthworms including sources, name of peptides, mechanism of action and targeted microbes are depicted in Table 1. The bioactive compounds obtained from organisms such as snails and earthworms have exhibited significant therapeutic potential in wound healing, anti-inflammatory therapy, and infection management (Bao *et al.*, 2022; Deng *et al.*, 2023).

Table1: Antimicrobial Peptides of Insects

Source (Species/Organ)	Peptide Name	Mechanism of Action	Target Microbes	References
<i>Blattella germanica</i> and <i>Periplaneta americana</i>	Attacins	Inhibit synthesis of outer membrane proteins and increase membrane permeability	Gram-negative bacteria (<i>Escherichia coli</i> and <i>Pseudomonas aeruginosa</i>)	Benavent <i>et al.</i> , 2020.
<i>Hermetia illucens</i> hemolymph, fat body, immune-induced larvae	Defensin-like Peptides (DLP1–DLP4)	Disrupt bacterial membranes through pore formation; interact with intracellular targets. DLP2 and DLP4 possess a cysteine-stabilized $\alpha\beta$ (CS $\alpha\beta$) structure.	Gram-positive bacteria, (<i>Staphylococcus aureus</i> and MRSA), some activity against Gram-negative bacteria.	Fahmy <i>et al.</i> , 2024.
<i>Bombyx mori</i> hemolymph, fat body	Cecropins (A, B, C, D, E)	Bind to negatively charged microbial membranes and form pores, causing membrane leakage and cell lysis	Gram-positive bacteria (<i>Bacillus subtilis</i>), Gram-negative bacteria (<i>Escherichia coli</i> , <i>Pseudomonas aeruginosa</i>), and some fungi	Nesa <i>et al.</i> , 2020.
<i>Vaspula lewisii</i> and other vespid wasps; venom gland/venom	Mastoparan	Amphipathic α -helical peptide inserts into microbial membranes, causing pore formation, membrane disruption, and cell lysis	Gram-positive bacteria, Gram-negative bacteria, and some fungi (<i>Candida albicans</i>)	da Silva <i>et al.</i> , 2018.
<i>Achatina fulica</i> ; hemocytes and mucus	Mytimacin-AF	Disrupts microbial membranes and interferes with cell metabolism	Gram-positive and Gram-negative bacteria, fungi	Zhong <i>et al.</i> , 2013
<i>Eisenia fetida</i> ; coelomic fluid	Lysenin	Binds membrane sphingomyelin and forms pores, causing cell lysis	Bacteria, protozoa, and some fungi	Venkatachalam <i>et al.</i> , 2025

CHALLENGES

Despite the promising antimicrobial potential of compounds derived from insects, snails, and earthworms, several limitations hinder their practical application. Firstly, most investigations remain confined to *in vitro* studies and experimental models, with only a limited number advancing to clinical evaluation. A factor such as habitat, diet, species, and

environmental conditions can complicate the reproducibility of findings and the development of standardized products.

Secondly, the extraction and purification of bioactive compounds, including AMPs and glycoproteins, are often technically demanding and costly. The absence of universally accepted protocols for extraction, dosage determination, and antimicrobial testing

further limits the comparability of results across studies.

Another major challenge is the difficulty associated with large-scale production, which restricts the commercialization and pharmaceutical development of these compounds. Regulatory approval for antimicrobial agents derived from unconventional biological sources is also a lengthy and rigorous process that requires extensive safety and efficacy assessments.

Another significant challenge is the variability in antimicrobial activity resulting from differences in species, environmental factors, and extraction methods, which complicates standardization efforts (Vogel *et al.*, 2018).

Moreover, large-scale harvesting of insects and earthworms may raise ecological and ethical concerns by potentially disrupting natural ecosystems. Finally, the substantial financial investment required to translate laboratory discoveries into clinically approved therapeutics remains a significant barrier.

Despite these promising prospects, several important research gaps remain. A major limitation is the incomplete understanding of the molecular mechanisms underlying the antimicrobial action of many AMPs (Manniello *et al.*, 2021). Furthermore, the majority of available studies are restricted to *in vitro* investigations and animal models, while clinical studies evaluating safety and efficacy in humans remain scarce (Dijksteel *et al.*, 2021).

In addition, limited information is available regarding the long-term toxicity, immunogenicity, and allergenic potential of these compounds, creating uncertainty regarding their clinical applicability (di Somma *et al.*, 2022).

Future Prospects and Research Gaps

The investigation of unconventional biological resources, including insects, snails, and earthworms, offers considerable potential for the discovery of novel antimicrobial agents. Advances in biotechnology, particularly genetic engineering and synthetic biology, provide opportunities for the large-scale production of these compounds, thereby addressing the limitations associated with natural extraction processes (Buonocore *et al.*, 2021; Moretta *et al.*, 2020).

The combined use of AMPs with conventional antibiotics may enhance antimicrobial effectiveness while reducing the development of resistant microbial strains (Neshani *et al.*, 2020). Additionally, the incorporation of nanotechnology-based drug delivery systems could improve the stability,

bioavailability, and targeted delivery of these antimicrobial molecules (Dijksteel *et al.*, 2021).

Beyond human healthcare, these bioactive compounds may also find valuable applications in agriculture and veterinary medicine as environmentally friendly alternatives to synthetic antimicrobial agents, thereby promoting sustainable practices (Franco *et al.*, 2022).

CONCLUSION

The increasing prevalence of antimicrobial resistance has created an urgent demand for innovative therapeutic alternatives. Unconventional biological sources, including insects, snails, and earthworms, constitute valuable reservoirs of bioactive compounds, particularly antimicrobial peptides, which exhibit promising antibacterial, antifungal, and antiviral activities. These naturally derived compounds offer substantial potential for the development of effective, sustainable, and next-generation antimicrobial therapies. Nevertheless, the successful integration of these bioactive molecules into clinical and industrial applications requires the resolution of several challenges, including issues related to safety, standardization, stability, and large-scale production. Continued scientific investigation, coupled with advances in biotechnology and pharmaceutical development, would be essential for fully exploiting the therapeutic potential of these natural resources in the global effort to combat antimicrobial resistant pathogens.

Authors Contribution

COE conceptualized and supervised, OOO wrote the first draft of manuscript. TOA reviewed and wrote the final draft of manuscript. All authors contributed to the article and approved the final and submitted version.

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