

# Insects as Medicine: Rediscovering a Sustainable Solution for Global Health

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**Abstract:** *As global healthcare systems face mounting challenges—rising antimicrobial resistance, unequal access to medicine, and the need for sustainable therapeutic resources—there is renewed scientific interest in entomotherapy, the use of insects and their derivatives for medicinal purposes. This paper explores the historical roots, biochemical potential, clinical applications, and future prospects of insect-based medicine. Drawing from ethnopharmacological evidence and contemporary biomedical research, the review identifies key therapeutic compounds such as antimicrobial peptides (AMPs), enzymes, and immunomodulators found in species like *Lucilia sericata*, *Apis mellifera*, and *Tenebrio molitor*. The ecological efficiency of insects, coupled with their capacity to provide cost-effective and locally producible therapeutics, positions them as a viable alternative to conventional pharmaceuticals, especially in resource-limited settings. However, cultural stigma, regulatory gaps, and ethical concerns about bioprospecting and standardization continue to hinder mainstream integration. The paper concludes by proposing strategic directions for bridging traditional knowledge with molecular science, enhancing policy frameworks, and promoting equitable, sustainable innovation in global health. Insects, long seen as nuisances or novelties, may now hold the key to some of the 21st century's most urgent medical challenges.*

**Keywords:** entomotherapy

## I. INTRODUCTION

Throughout human history, insects have played a remarkable, albeit underappreciated, role in health and healing practices. In ancient medical systems across Asia, Africa, and the Americas, insects and their derivatives have been used to treat infections, wounds, and even chronic ailments. Yet, in the contemporary biomedical landscape, the therapeutic potential of insects has largely remained at the periphery, overshadowed by the rise of synthetic pharmaceuticals and a bias toward plant-based remedies. However, faced with 21st-century global health challenges—ranging from antibiotic resistance to unequal access to medicine—there is renewed scientific and ethical interest in rediscovering insect-derived medicine as a sustainable, effective, and culturally relevant alternative (Ratcliffe et al., 2011; Alves & Alves, 2011).

The conventional biomedical model is increasingly strained. The overuse and misuse of antibiotics have led to the proliferation of drug-resistant pathogens, while pharmaceutical innovation is slowing and skewed toward profitable, noncommunicable disease markets. Simultaneously, large portions of the global population, particularly in rural and resource-limited settings, continue to rely on traditional medicine as their primary or only source of healthcare (Ferreira et al., 2009; Syampungani et al., 2009). In this context, insects are emerging as a compelling solution, both from an ecological and a pharmacological standpoint.

Insects exhibit extraordinary biochemical diversity. They produce a wide array of bioactive compounds—antimicrobial peptides (AMPs), enzymes, alkaloids, steroids, and fatty acids—that have shown therapeutic effects against bacteria, fungi, and cancer cells (Ratcliffe et al., 2014). For example, defensins and cecropins isolated from insect hemolymph are potent against multidrug-resistant strains of *Staphylococcus aureus* and *Escherichia coli* (Berasategui et al., 2016). In maggot therapy, fly larvae of *Lucilia sericata* are clinically used for debridement and healing of chronic wounds, especially in cases where antibiotics are ineffective (Sherman & Pechter, 1988). This biomedical application, now FDA-approved, illustrates that even the most unconventional insect therapies can gain scientific validation when approached rigorously.

Moreover, insects are an ecologically sustainable source of medicine. They reproduce rapidly, require minimal land and water resources, and can be cultivated in controlled environments using organic waste as feed (Dossey et al., 2014). This contrasts starkly with the ecological toll of harvesting wild medicinal plants and animals, many of which are endangered. The inclusion of insects in pharmacological bioprospecting thus supports biodiversity conservation and aligns with the United Nations' Sustainable Development Goals (Schowalter et al., 2018).

Culturally, insects have already earned a place in the pharmacopeias of many indigenous and traditional medical systems. From the use of termites to treat asthma in Africa to the application of crushed beetles for rheumatism in South America, zotherapy involving insects is deeply embedded in ethnomedical knowledge (Alves & Alves, 2011; Ferreira et al., 2009). Bridging this knowledge with modern pharmacology offers not only scientific innovation but also epistemological inclusivity—valuing local traditions and empowering communities.

However, the integration of insect-based medicine into mainstream healthcare is not without challenges. There remains considerable skepticism in Western medical systems due to unfamiliarity, aesthetic aversion, and a lack of standardized processing techniques. Regulatory frameworks for entomotherapy are underdeveloped, and only a few countries have policies for approving insect-derived compounds for human use (Halloran et al., 2015). Ethical bioprospecting and equitable benefit-sharing with indigenous communities also remain areas needing urgent attention.

Despite these hurdles, the scientific community is beginning to embrace insects not only as vectors of disease but also as reservoirs of healing. Emerging research in molecular biology, immunology, and biotechnology is unlocking new ways to harness insect-derived compounds, from antimicrobial peptides to immune modulators and enzymes with anticancer potential (Ratcliffe et al., 2014; Berasategui et al., 2016). These findings point toward a transformative shift in how we define and source medicine.

This paper aims to synthesize historical, ethnomedical, and biomedical perspectives on the use of insects as medicine. It explores the bioactive compounds derived from insects, their traditional uses, and modern pharmaceutical applications. Furthermore, it advocates for the incorporation of insect-based therapeutics into sustainable healthcare strategies, particularly for underserved populations and emerging global health threats such as antimicrobial resistance. In doing so, it calls for a paradigmatic shift that not only broadens the horizon of modern medicine but also reinforces ecological and cultural sustainability.

## II. LITERATURE REVIEW: HISTORICAL AND CONTEMPORARY USES OF INSECTS IN MEDICINE

### 2.1 Historical Roots of Insect-Based Medicine

Insects have long been integral to the pharmacopeias of indigenous and traditional healing systems across the globe. Historical accounts from Traditional Chinese Medicine (TCM), Ayurveda, and Amazonian ethnopharmacology illustrate the use of insects in remedies for fever, infections, pain, and even spiritual ailments. For example, silkworm (*Bombyx mori*) powder has been used in TCM for treating convulsions and respiratory disorders, while beetles and ants have been used in tribal South American and African medicine to treat inflammation and wounds (Alves & Alves, 2011; Ferreira et al., 2009).

Traditional uses have often involved not just insect bodies, but also secretions, cocoons, and by-products. In some African societies, termites are consumed to treat bronchitis, while honeybee products—such as royal jelly and propolis—have been extensively used for wound healing and antimicrobial purposes (Ratcliffe et al., 2011). These ancient applications underscore a deep ethnomedical knowledge base that predates modern pharmaceutical science but aligns with many of its current goals.

### 2.2 Ethnopharmacological Evidence and Regional Practices

A comprehensive ethnobiological survey by Ferreira et al. (2009) in Brazil documented the use of over seven insect species for therapeutic purposes, especially among rural populations with limited access to conventional healthcare. Similar studies in Latin America and sub-Saharan Africa reveal the use of insect-derived therapies in treating infections, gastrointestinal issues, and skin disorders (Alves & Alves, 2011). These practices not only persist but are expanding in recognition due to growing interest in ethnopharmacology and biocultural conservation.

Despite historical richness, much of this knowledge remains undocumented or scientifically unvalidated. Yet the rising recognition of these therapies has spurred targeted research on specific species and compounds, especially in the context of antimicrobial resistance.

### 2.3 Bioactive Compounds in Medicinal Insects

Numerous insects have been shown to produce potent bioactive molecules, particularly antimicrobial peptides (AMPs), enzymes, and immune modulators. These include:

- Defensins and Cecropins: Found in insect hemolymph (insect "blood"), these AMPs are effective against Gram-positive and Gram-negative bacteria (Berasategui et al., 2016; Ratcliffe et al., 2014).
- Lucifensin: A peptide secreted by *Lucilia sericata* maggots during wound debridement therapy, with broad-spectrum antimicrobial effects (Sherman & Pechter, 1988).
- Propolis and Melittin: Derived from bees, these compounds exhibit antibacterial, antifungal, and even anticancer activities (Ratcliffe et al., 2011).
- Chitosan and chitin derivatives: Extracted from beetles and crickets, these polysaccharides show promise in drug delivery and as wound-healing agents.

Studies have revealed that these molecules often have mechanisms of action distinct from conventional antibiotics, which makes them especially valuable in the fight against drug-resistant pathogens (Dossey et al., 2014).

### 2.4 Modern Clinical and Biotechnological Applications

Contemporary medicine has begun to integrate certain insect-based treatments into approved clinical settings. The most notable is maggot debridement therapy (MDT), where sterilized fly larvae are applied to necrotic wounds. These maggots not only digest dead tissue but secrete enzymes and peptides that promote healing and sterilize wounds (Sherman & Pechter, 1988).

In biotechnology, insect-derived enzymes are being explored for use in proteolytic treatments, immunomodulation, and nanoparticle synthesis (Berasategui et al., 2016). The field of insect biotechnology has also extended to symbiotic microbiota of insects, where bacterial symbionts are harvested for novel antibiotics, antifungals, and antivirals.

Moreover, entomotherapy is gaining interest in global health policy dialogues, particularly as a sustainable medical resource for low-income populations. The mass production of medicinal insects offers a low-cost, high-yield model for decentralized pharmaceutical production (Halloran et al., 2015).

### 2.5 Sustainability and Ecological Considerations

Insects offer a remarkable ecological advantage as a source of medical resources. Unlike traditional livestock or endangered medicinal plants, insects can be farmed sustainably on agricultural waste, require little water, and emit far fewer greenhouse gases (Schowalter et al., 2018). This makes insect-based medicine not only a biomedical innovation but an ecological imperative in the Anthropocene.

Moreover, utilizing insects in pharmacology contributes to biodiversity valuation and conservation. It supports arguments for preserving insect habitats as reservoirs of potentially life-saving bioresources (Dossey et al., 2014; Berasategui et al., 2016).

## III. THERAPEUTIC APPLICATIONS OF INSECTS: CASE STUDIES AND EVIDENCE-BASED INSIGHTS

The medicinal potential of insects extends beyond theory and traditional knowledge—numerous empirical studies and clinical trials have validated the therapeutic efficacy of insect-derived compounds. This section explores selected insect species whose bioactive components have led to innovative treatments for microbial infections, chronic wounds, autoimmune conditions, and even cancers.

### 3.1 Maggot Debridement Therapy: The Fly as a Surgeon

One of the most scientifically validated insect-based medical practices is Maggot Debridement Therapy (MDT). The larvae of the green bottle fly (*Lucilia sericata*) are used to clean necrotic wounds by secreting proteolytic enzymes that

liquefy dead tissue while leaving healthy tissue unharmed. These enzymes include serine proteases and chymotrypsin-like enzymes, which also reduce bacterial load through antimicrobial secretion (Sherman & Pechter, 1988). Numerous clinical trials and case reports have demonstrated that MDT accelerates healing in diabetic foot ulcers, pressure sores, and post-surgical wounds—especially when standard antibiotic treatments fail. The therapy is now approved by regulatory bodies like the U.S. FDA and the UK's NICE (National Institute for Health and Care Excellence), signifying a formal integration of insect-derived solutions into modern medical protocols.

### 3.2 Antimicrobial Peptides (AMPs) from Insect Hemolymph

Insects possess an evolutionarily refined immune system that produces antimicrobial peptides (AMPs) in response to microbial threats. These AMPs are effective against a wide spectrum of pathogens including multidrug-resistant bacteria. Notable examples include:

- Defensins, isolated from beetles and flies, active against *Staphylococcus aureus* and *Pseudomonas aeruginosa*
- Cecropins, found in moths, effective against Gram-negative bacteria
- Thanatin, from the spined soldier bug (*Podisus maculiventris*), which disrupts bacterial membranes

These peptides show rapid action, low toxicity to mammalian cells, and reduced likelihood of resistance development—making them promising antibiotic alternatives (Ratcliffe et al., 2011; Berasategui et al., 2016).

### 3.3 Honeybee Products: Natural Pharmacy of the Hive

Honeybees (*Apis mellifera*) are a rich source of medicinal products widely used in both folk medicine and modern pharmacology. Their therapeutic arsenal includes:

- Propolis: A resinous mixture used for its antibacterial and anti-inflammatory properties. It contains flavonoids and phenolics that inhibit *Helicobacter pylori*, oral pathogens, and MRSA.
- Royal Jelly: Known for immunomodulatory effects, it enhances wound healing and shows cytoprotective properties in vitro.
- Melittin: The main peptide in bee venom, which has demonstrated cytolytic effects on cancer cells and modulates immune responses in autoimmune diseases like rheumatoid arthritis.

Bee-derived products are extensively studied in pharmacognosy and are being developed into topical creams, mouthwashes, and dietary supplements (Ratcliffe et al., 2014).

### 3.4 Termites and Ants in Respiratory and Anti-Inflammatory Therapies

In African traditional medicine, termites are used to treat bronchial conditions and asthma. Recent studies have validated the presence of bioactive lignocellulolytic enzymes and phenolic compounds in termite gut extracts that possess anti-inflammatory and antioxidant properties (Alves & Alves, 2011).

Similarly, ants such as *Pseudomyrmex* have been reported in Amazonian ethnomedicine for reducing swelling and pain. Their stings contain alkaloids and small peptides with localized anesthetic and vasodilatory effects—now being studied for pharmaceutical applications in pain relief and vascular therapy.

### 3.5 Cancer and Autoimmune Disease Research

Insects have also shown promise in oncological and immunological applications. Recent studies have demonstrated that bee venom and wasp venom peptides, particularly melittin and mastoparan, induce apoptosis in cancer cells by targeting mitochondrial membranes and disrupting cell signaling pathways.

Research by Ratcliffe et al. (2011) also notes the potential of insect-derived immune modulators in the treatment of autoimmune diseases, including inflammatory bowel disease and lupus, although most of this work remains in the experimental stage.

### 3.6 Insect Symbionts: A Hidden Frontier

Beyond the insects themselves, their microbial symbionts also contribute to medicinal possibilities. For example, symbiotic bacteria from ants and wasps have yielded novel antibiotics, such as *streptomycin*-like molecules, which are

structurally different from known human antibiotics and thus bypass existing resistance mechanisms (Berasategui et al., 2016).

This opens up an exciting new domain in bioprospecting—the insect microbiome—as a treasure trove for pharmaceutical innovation.

Summary Table: Notable Insect-Derived Therapeutics

Insect Species	Medicinal Product	Therapeutic Use	Validation Level
<i>Lucilia sericata</i>	Proteolytic enzymes	Wound debridement	Clinical trials/FDA
<i>Apis mellifera</i>	Propolis, melittin	Antibacterial, anticancer, anti-arthritis	Experimental/OTC
<i>Bombyx mori</i>	Silkworm powder	Respiratory disorders	Traditional use
<i>Tenebrio molitor</i>	Hemolymph peptides	Antimicrobial (MRSA)	Lab/animal studies
<i>Termitidae</i> spp.	Gut extracts	Anti-inflammatory	Ethnomedicine/Lab
<i>Podisus maculiventris</i>	Thanatin (AMP)	Antibacterial (Gram-negative)	Preclinical studies

#### IV. BARRIERS, ETHICAL CHALLENGES, AND REGULATORY FRAMEWORKS IN ENTOMOTHERAPY

Despite the growing scientific evidence supporting the use of insects in medicine, multiple systemic, ethical, and socio-cultural barriers hinder their widespread adoption. These challenges span from regulatory hesitancy and consumer perception to sustainability governance and the ethical treatment of indigenous knowledge systems.

##### 4.1 Regulatory Ambiguity and Fragmented Legal Frameworks

One of the foremost challenges in advancing entomotherapy is the absence of clear, harmonized regulations for insect-derived pharmaceuticals and medical devices. While some applications—such as maggot therapy—have gained regulatory approval in countries like the United States and the United Kingdom, most insect-based medicines remain in legal limbo. For example:

- Maggot Therapy is regulated as a “medical device” in the U.S. by the FDA, but similar standardization does not exist globally.
- Bee-derived products such as propolis or venom are typically sold as nutraceuticals or traditional remedies without stringent quality controls or dosage guidelines.

Lack of consensus on how to classify and evaluate insect-based products delays their market entry and restricts international collaboration in research and development (Halloran et al., 2015).

##### 4.2 Public Perception and Cultural Resistance

The general perception of insects in many societies—particularly in the West—is deeply negative. They are often viewed as unhygienic, dangerous, or disgusting. This “yuck factor” presents a major barrier to consumer acceptance of insect-derived therapies, especially in clinical settings.

Surveys show that even when scientific evidence is presented, patients tend to express skepticism or outright refusal to engage with entomotherapeutics unless alternatives have failed (Yates-Doerr, 2015). Overcoming this cultural resistance will require robust educational campaigns and transparent communication about safety, efficacy, and sustainability.

##### 4.3 Ethical Considerations and Indigenous Knowledge

A significant ethical issue surrounding insect-based medicine is the appropriation of traditional knowledge without proper acknowledgment or compensation. Many of the modern discoveries about medicinal insects are rooted in ethnobiological practices of Indigenous and rural communities, particularly in Africa, South America, and Southeast Asia.

The Nagoya Protocol on Access and Benefit-Sharing (ABS) aims to address this issue by mandating equitable sharing of benefits derived from biological resources. However, its implementation remains inconsistent, and many

pharmaceutical and biotech firms continue to extract bioresources with minimal local engagement (Ferreira et al., 2009; Alves & Alves, 2011).

#### 4.4 Challenges in Standardization and Quality Control

Unlike synthetic pharmaceuticals, insect-derived substances can exhibit high variability due to:

- Species diversity and strain-specific properties
- Diet, life stage, and habitat conditions
- Extraction and processing methods

This variability complicates efforts to ensure batch-to-batch consistency, dosage control, and shelf life. The lack of pharmacopeial standards for most insect-derived bioactives limits their integration into formal medical systems. Advanced biotechnological methods such as peptide synthesis, genomic editing, and cell culture expression systems are being explored to standardize production, but these remain costly and largely experimental (Berasategui et al., 2016).

#### 4.5 Environmental and Animal Welfare Concerns

While insects are often lauded for their ecological efficiency, large-scale farming raises concerns over:

- Genetic homogenization of insect stocks
- Ethical issues related to invertebrate suffering
- Biosafety risks associated with releasing laboratory-reared insects

There is currently no universally accepted welfare protocol for insects in farming or research settings. As public awareness of animal ethics grows, similar concerns are likely to emerge in the context of entomopharmacology.

#### 4.6 Limited Research Funding and Institutional Support

Finally, one of the most pervasive barriers is the lack of targeted funding and institutional incentives for research into insect-based medicine. Compared to synthetic drug development or even plant-based pharmacognosy, insect medicine remains underfunded and underrepresented in university curricula, public health programs, and pharmaceutical innovation pipelines.

This neglect is compounded by limited interdisciplinary collaboration between entomologists, pharmacologists, and clinicians—a gap that needs bridging to unlock the full potential of entomotherapy.

Table: Antimicrobial Activity of Selected Insect-Derived Compounds

No.	Insect Species	Active Compound	Target Pathogen(s)	Therapeutic Effect	Validation Stage
1	<i>Lucilia sericata</i>	Lucifensin	<i>Staphylococcus aureus</i> , <i>Pseudomonas spp.</i>	Wound healing, antimicrobial	Clinical Trials
2	<i>Apis mellifera</i>	Propolis	<i>Helicobacter pylori</i> , MRSA	Antibacterial, anti-inflammatory	In Vitro + Clinical
3	<i>Tenebrio molitor</i>	Defensins	<i>E. coli</i> , <i>Bacillus subtilis</i>	Broad-spectrum antimicrobial	Preclinical Studies
4	<i>Bombyx mori</i>	Sericin	<i>Staphylococcus epidermidis</i>	Antioxidant, cell proliferation	In Vitro Studies
5	<i>Podisus maculiventris</i>	Thanatin	<i>E. coli</i> , <i>Klebsiella pneumoniae</i>	Membrane disruption of Gram-negatives	Experimental Models

**Source :** Compiled from multiple peer-reviewed studies including: Ratcliffe et al. (2011, 2014), Berasategui et al. (2016), and Sherman & Pechter (1988), which detail the bioactive compounds of medicinal insects and their antimicrobial properties.

## V. STRATEGIC DIRECTIONS AND FUTURE PROSPECTS FOR INSECTS IN GLOBAL HEALTH

In light of increasing scientific validation and mounting global health pressures, insect-derived medicine is positioned to evolve from an ethnomedical niche to a mainstream biomedical resource. This section outlines strategic priorities for research, innovation, integration, and governance that will enable entomotherapy to scale effectively and ethically.

### 5.1 Bridging Traditional Knowledge and Modern Science

Traditional medicinal systems offer an invaluable reservoir of information about insect uses in healing. However, these systems often lack biochemical validation, standardized dosage, and clinical testing. Future research must prioritize:

1. Ethnopharmacological mapping: Conducting cross-cultural surveys and systematizing insect-based remedies across continents.
2. Bioactivity-guided fractionation: Identifying and isolating the active compounds responsible for therapeutic effects in traditional formulations.
3. Participatory research models: Involving indigenous communities in co-designing protocols and benefit-sharing mechanisms.

Combining modern pharmacological tools with community-led ethnoscience offers a synergistic model of innovation rooted in cultural respect and scientific rigor.

### 5.2 Investment in Molecular and Synthetic Biology

Scaling entomotherapy for global health will require precision, consistency, and industrial scalability—qualities that can be delivered through biotechnology. Strategic investments should focus on:

1. Genetic engineering: Using CRISPR and transgenic models to produce specific peptides or compounds in scalable insect bioreactors.
2. Synthetic peptide production: Replicating insect-derived AMPs like cecropins and defensins using recombinant DNA technologies.
3. Microbial symbiont mining: Exploring the microbiota of insects to identify symbiotic organisms that produce novel antibiotics or immune modulators (Berasategui et al., 2016).

These directions promise safer, cleaner, and more consistent production pipelines while minimizing the environmental load of insect harvesting.

### 5.3 Development of Global Regulatory Standards

Global harmonization is crucial for legitimizing insect-based medicines. Future frameworks must address:

1. Quality control protocols: Defining international guidelines for purity, safety, and efficacy testing of insect products.
2. Classification systems: Determining whether insect-based products are drugs, nutraceuticals, or medical devices depending on their formulation and use.
3. Ethical certifications: Incorporating environmental and bioethical certifications to ensure compliance with conservation and animal welfare standards.

Agencies like the WHO, FAO, and national pharmacopeias must work collaboratively to integrate insects into official health policies and essential medicines lists.

### 5.4 Incorporation into Sustainable Health Systems

Insect-based medicine aligns with principles of sustainable development, circular economy, and decentralized health equity. Specific opportunities include:

1. Community-based production: Training rural communities to safely cultivate medicinal insects like *Lucilia sericata* or *Tenebrio molitor*, generating both healthcare and livelihoods.
2. Decentralized pharma models: Establishing localized processing units where insect compounds can be extracted, tested, and formulated into traditional or modern therapeutics.
3. Climate-resilient health strategies: Leveraging insects as low-resource, high-yield medicinal resources in drought-prone or biodiverse regions.

These models are especially relevant for the Global South, where access to synthetic drugs is limited and ecological resources are abundant.

### 5.5 Public Education and Medical Curriculum Integration

To overcome the cultural stigma surrounding insects, long-term shifts must occur in public perception and professional training:

1. Medical education reform: Including entomotherapy modules in pharmacology, public health, and medical anthropology curricula.
2. Public awareness campaigns: Communicating the science, history, and sustainability of insect-based medicine through media and outreach.
3. Patient engagement programs: Involving patients in trials, feedback sessions, and culturally sensitive discussions to enhance acceptability.

Such initiatives would normalize entomotherapy and encourage its use alongside existing medical systems.

## VI. RESULTS AND DISCUSSION

### 6.1 Synthesis of Therapeutic Outcomes Across Case Studies

The review of entomotherapeutic literature reveals a consistent trend: insects offer bioactive compounds with potent therapeutic activity across a range of medical domains. Specifically:

- Maggot Therapy (*Lucilia sericata*) demonstrated consistent wound debridement efficiency, reduction in bacterial load, and accelerated healing in chronic wounds such as diabetic ulcers (Sherman & Pechter, 1988).
- Propolis and bee venom therapies have shown anti-inflammatory and antimicrobial effects, with melittin demonstrating apoptotic action against cancer cells in vitro and in some animal models (Ratcliffe et al., 2011).
- Insect antimicrobial peptides (AMPs) like defensins and thanatin are effective against both Gram-positive and Gram-negative bacteria, including multi-drug-resistant strains, with lower potential for resistance development (Berasategui et al., 2016).
- Ethnopharmacological evidence supported the use of termites, ants, and beetles for conditions ranging from asthma and inflammation to rheumatism and gastrointestinal infections (Alves & Alves, 2011; Ferreira et al., 2009).

These outcomes validate the biomedical value of insects and highlight their therapeutic potential across multiple pharmacological classes—antibacterial, antifungal, immunomodulatory, and anticancer.

### 6.2 Thematic Trends Identified

#### 6.2.1 Traditional Knowledge as a Scientific Reservoir

Many validated insect-based treatments have ethnomedical origins, indicating the need to preserve and investigate traditional healing practices. However, only a small fraction of these have been biochemically characterized, signaling an untapped research frontier.

#### 6.2.2 Multi-functionality of Insect Compounds

Unlike many single-target synthetic drugs, insect-derived molecules often show multi-target bioactivity. For instance, bee venom exhibits antimicrobial, anti-inflammatory, and neurotoxic effects depending on the dosage and context (Ratcliffe et al., 2014).

#### 6.2.3 Ecological and Economic Viability

Insects offer high therapeutic yields at low ecological cost. Their scalability through vertical farming or waste-fed systems presents significant advantages for sustainable medical production, especially in resource-limited settings (Schowalter et al., 2018).

### 6.3 Contrasts and Gaps in Current Research

Despite the promising results, the field faces significant gaps:

Gap Area	Description
Clinical Trials	Most compounds remain at preclinical or in vitro stages; human trials are rare.
Mechanistic Understanding	Limited insight into how many insect-derived compounds function at molecular levels.
Standardization	Lack of GMP-grade protocols for insect cultivation, harvesting, and compound isolation.
Cultural Barriers	The “yuck factor” and association of insects with disease hinder public acceptance.

These disparities suggest the field is still emergent and requires systematic investment, interdisciplinary collaboration, and translational pipelines.

#### 6.4 Implications for Global Health

The findings from this review carry significant implications for the global healthcare landscape:

- For Developing Nations: Insect-based therapies could reduce dependence on expensive pharmaceuticals and serve as accessible, culturally familiar treatments.
- For Antimicrobial Resistance: AMPs from insects present promising leads for next-generation antibiotics that circumvent current resistance mechanisms.
- For Healthcare Resilience: Decentralized insect farming and processing can support localized pharmaceutical production in emergencies and pandemics.

These implications are not merely theoretical. Pilot programs, such as community-based maggot therapy centers in India and rural Brazil, have already demonstrated the feasibility of low-cost, high-impact entomotherapy when integrated into primary healthcare systems.

#### 6.5 Integrative Interpretation

Insects as medicine constitute more than a revival of ancient knowledge—they represent a forward-thinking, biologically grounded strategy to address pressing health challenges. The cross-section of sustainability, traditional knowledge, biotechnology, and pharmacology suggests a new paradigm of healthcare: one that is decentralized, ecological, and adaptive.

The discussion makes it clear that while empirical support is growing, institutional, regulatory, and perceptual bottlenecks remain. Bridging the scientific promise with systemic support will be critical to realizing the full potential of insect-based medicine in global health.

### VII. CONCLUSION

As this review has demonstrated, the medicinal potential of insects is neither a relic of the past nor a speculative curiosity—it is a scientifically credible, ecologically sustainable, and socio-culturally rich resource that remains largely untapped. From antimicrobial peptides in beetles and flies to immune-modulating compounds in bee venom, insects offer a diverse pharmacological repertoire with proven applications in wound healing, infectious disease control, and even cancer research.

What makes insects especially compelling for global health is not merely their biochemical potency, but their accessibility and sustainability. They can be farmed with minimal environmental impact, cultivated locally in rural and low-income communities, and used in both traditional and modern therapeutic frameworks. This positions insects as strategic agents in addressing some of the most pressing health challenges of our time—antimicrobial resistance, inequitable drug access, and the need for climate-resilient healthcare systems.

However, realizing this potential requires more than scientific validation. It demands the dismantling of cultural biases, the construction of robust regulatory frameworks, ethical collaboration with Indigenous knowledge holders, and targeted investment in biotechnology and public health education. Without these efforts, insect-based medicine may remain marginalized despite its promise.

Insects can no longer be viewed solely as pests, vectors, or curiosities—they are emerging as allies in the pursuit of equitable and sustainable healthcare. By bridging ethnomedicine and biotechnology, ecology and pharmacology,

tradition and innovation, the field of entomotherapy holds the power to transform both how we heal and how we sustain our health systems.

The path forward lies in rediscovery, refinement, and reintegration—a future where the smallest creatures help solve the largest global health problems.

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