Journal of Advances in Biology & Biotechnology

Volume 27, Issue 8, Page 783-801, 2024; Article no.JABB.120309
ISSN: 2394-1081

Beyond Bugs: Exploring Various Role of Insects

Krishna Kumar S [a++], Sreejith Vakayil [b*], S Gopi [c++], Patel Hardikkumar Arvindbhai [d#], Arpitha K C [e++], Devansh Gupta [f†], Surya Kant Ranjan [g++] and Himanshu Sekhar Behera [h‡]

[a] *Department of Agricultural Entomology, University of Agricultural Sciences, GKVK, Bengaluru, India.*
[b] *Department of Sericulture, University of Agricultural Sciences, Bangalore, India.*
[c] *Department of Entomology, College of Horticulture, Bengaluru, University of Horticultural, Sciences, Bagalkot, India.*
[d] *School of Agriculture, PP Savani University, Kosamba, Surat -394 125 (Gujarat), India.*
[e] *Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore, India.*
[f] *College of Horticulture and Forestry, Punjab Agricultural University, Punjab, 141001, India.*
[g] *Department of Biotechnology, School of Bioengineering and Biosciences, Lovely Professional University, Punjab, India.*
[h] *Department of Soil Science and Agricultural Chemistry, Lovely Professional University, Punjab, 144411, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i81197

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/120309

Review Article

Received: 26/05/2024
Accepted: 29/07/2024
Published: 01/08/2024

[++] *Ph.D. Scholar;*
[#] *Assistant Professor;*
[†] *Undergraduate Research Assistant;*
[‡] *Research Scholar;*
**Corresponding author: E-mail: sreejithvakayil94@gmail.com;*

Cite as: *S, Krishna Kumar, Sreejith Vakayil, S Gopi, Patel Hardikkumar Arvindbhai, Arpitha K C, Devansh Gupta, Surya Kant Ranjan, and Himanshu Sekhar Behera. 2024. "Beyond Bugs: Exploring Various Role of Insects". Journal of Advances in Biology & Biotechnology 27 (8):783-801. https://doi.org/10.9734/jabb/2024/v27i81197.*

ABSTRACT

This comprehensive review ventures beyond the conventional realm of insect research, unveiling the potential of insects as catalysts for innovation in medicinal and industrial plant applications. Insects have evolved intricate relationships with plants, fostering the development of unique biomolecules and adaptations. By exploring these interactions, researchers can uncover novel compounds and strategies for drug discovery, crop protection, and sustainable production. From the antimicrobial peptides derived from beetle intestines to the vibrant pigments extracted from butterfly wings, insects offer a vast, uncharted territory for plant-based solutions. The review delves into the realm of entomophagy, where insects are consumed as a source of nutrition, and explores their potential in developing sustainable food systems. Furthermore, the article examines the role of insects in pollination, pest control, and soil health, highlighting their significance in maintaining ecosystem balance. The authors also discuss the challenges and opportunities in harnessing insect-plant interactions, including the development of insect-inspired biomimetic approaches and the need for conservation efforts to protect insect diversity. By bridging the gap between entomology, botany, and biotechnology, this review opens doors to ground breaking advancements in medicine, agriculture, and industry. As the global community seeks sustainable solutions to pressing challenges, "Beyond Bugs" illuminates the vast potential of insects in unlocking innovative plant applications, inspiring future research and collaboration across disciplines.

Keywords: Crop; food; pigments; soil; health; biometric; opportunities.

1. INTRODUCTION

The technique of entomotherapy, which is also known as the utilization of insects and products generated from insects for therapeutic reasons, is one that has been utilized all over the world for the treatment of a variety of health ailments [1]. There are natural substances found in insects that have a wide range of biological capabilities, such as antibacterial, antifungal, antiviral, anticancer, antioxidant, anti-inflammatory, and immunomodulatory properties. These plants can be utilized in a variety of ways, including live, cooked, ground, infusions, plasters, salves, ointments, and even more application methods [2].

Communities all over the world have utilized insects as a means of treating a broad range of problems, including but not limited to renal disease, edema, intestinal disorders, fortified blood, postpartum haemorrhage, lung diseases, liver and stomach ailments, toothaches, rheumatism, and more [3]. Bedbugs are utilized for the treatment of pain and inflammation in the fingers and legs that can be the result of nail insertion or other injuries. On the other hand, mud extracted from termite nests is utilized for the treatment of inflammation throughout the body [4]. There are a number of health ailments that may be treated with honey, honeybee larvae, and honeybee pupae. Some of these conditions include mental anguish, gastrointestinal disorders, stomach difficulties, treatment of external wounds, and maggot therapy respectively [5].

In the seventeenth century, Europeans held the belief that insects have medicinal significance, since they were believed to alleviate a variety of health-related difficulties, including epilepsy, earaches, scrapes, rheumatism, and malnutrition [6]. Recent study on the anticancer potential of the Chartergellus-CP1 peptide, which was discovered in the venom of the *Chartergellus communis* wasp, was conducted on two distinct breast cancer cell lines. The findings of this research were encouraging, as it was able to destroy just cancer cells while leaving healthy cells unaffected. The usage of blister beetles as an aphrodisiac was widespread throughout Europe; however, current research has demonstrated that they can also alleviate the discomfort associated with kidney stones, urinary tract infections, and burns [7].

The purpose of this study is to provide a more fundamental knowledge of the numerous medical uses of insects and the prospective applications of insects in modern medicine. It explores the history, impacts, and potential involved with the usage of numerous insect species all over the world, as well as the influence that these insects have on human health and the necessity of industrial production in order to produce considerable quantities of insect-based therapy [8]. The review provides guidance to researchers who are interested in entomotherapy and makes suggestions for possible future avenues for the development of insects that may be utilized in medicine [9].

As a result of the exponential growth of the world's population, there is a growing demand for meat due to the issues that it presents in terms of nutrition. Strategies such as dietary diversification, biofortification, supplementation, and commercial food fortification are all effective ways that may be utilized in the fight against malnutrition [10]. Every year, thousands of different kinds of insects are consumed, the most of which are consumed in poor countries. In addition, there are 2.5 billion people throughout the world who rely on insects as a source of additional food. It is anticipated that the market of edible insects would be valued more than $3 billion by the year 2030 [11]. Despite this, the majority of western nations continue to adhere to the taboo of eating insects. Consumption of edible insects as snacks or major sources of protein is common in a number of countries across Asia, Africa, Europe, and Latin America worldwide [12].

Edible insects have the potential to address a variety of environmental and health concerns, including climate change, hunger, and environmental degradation brought on by the production of agricultural and industrial goods [13]. A heightened awareness of the difficulties that are associated with global sustainability has been brought about as a result of the expanding population as well as changes in lifestyle, nutritional choice, and income. It is necessary to do research across several disciplines on edible species in order to achieve sustainable development and commercialization. Additionally, the preparation procedure and medicinal properties of these species must be documented [14].

It is necessary to gather further information on the many advantages involved with the cultivation, marketing, and harvesting of edible insects, despite the fact that edible insects have garnered attention for their ability to heal ailments in both animals and humans. The African coconut beetle, the Asiatic rhinoceros beetle, and the African palm weevil are all examples of insects that have the ability to attack and destroy economically significant crops. However, due to the nutritional characteristics of these insects, a significant number of people in Sub-Saharan Africa ingest them [15].

2. EDIBLE INSECTS AND THEIR IMPACT ON ENVIRONMENT

It is essential to have food security in order to ensure that there is adequate food that is not only safe but also healthy and available. At least one billion people are dependent on livestock for their means of subsistence, and seventy percent of the 880 million rural poor people who make less than one dollar per day in the United States rely on livestock for at least some of their income and food security [16,17]. The frequency of undernourishment, on the other hand, has climbed by 1.5% points in recent years, which represents a midpoint of around 720 to 811 million individuals who were suffering from hunger in the first year of the COVID-19 pandemic [18]. It is necessary to make significant dietary adjustments in order to accomplish the aim of global food security. Insects that can be consumed are now regarded as major food sources and have the potential to act as an alternate source of specific nutrients.

There are around 5.5 million different species of insects that may be found across the globe, of which approximately 1 million have been described [19]. It is estimated that around 2,100 of these species are edible. Insects such as beetles, caterpillars, ants, bees, grasshoppers, real bugs, dragonflies, termites, and cockroaches are included in this category of edible insects. Lepidoptera (30.93%), Orthoptera (22.80%), Coleoptera (19.70%), Heteroptera (9.32%), Blattodea (7.40%), Hymenoptera (6.78%), Diptera (1.06%), Dictyoptera (0.85%), Odonata (0.64%), and Ephemenoptera (0.42%) are the orders of insects that are most important for the consumption of edible insects in Africa [20]. It is difficult to assess the nutritional profile of edible insects because of the significant changes that may be found across species, countries, the composition of insect feed, the method of growing insects, and the developmental stage of insects. All of these factors have the potential to influence the nutritional profile [21,22]. Protein is the most important component of the nutritional makeup of edible insects, followed by lipids as the second most important component. Insects belonging to the order Blattodea (termites) and Orthoptera (crickets, grasshoppers, and locusts) have a protein content that ranges from 35.3 to 61.3%, respectively (30). Chitin, which is the primary polysaccharide component of the exoskeleton of insects, serves to shield them from the damaging effects of harmful environmental conditions [23].

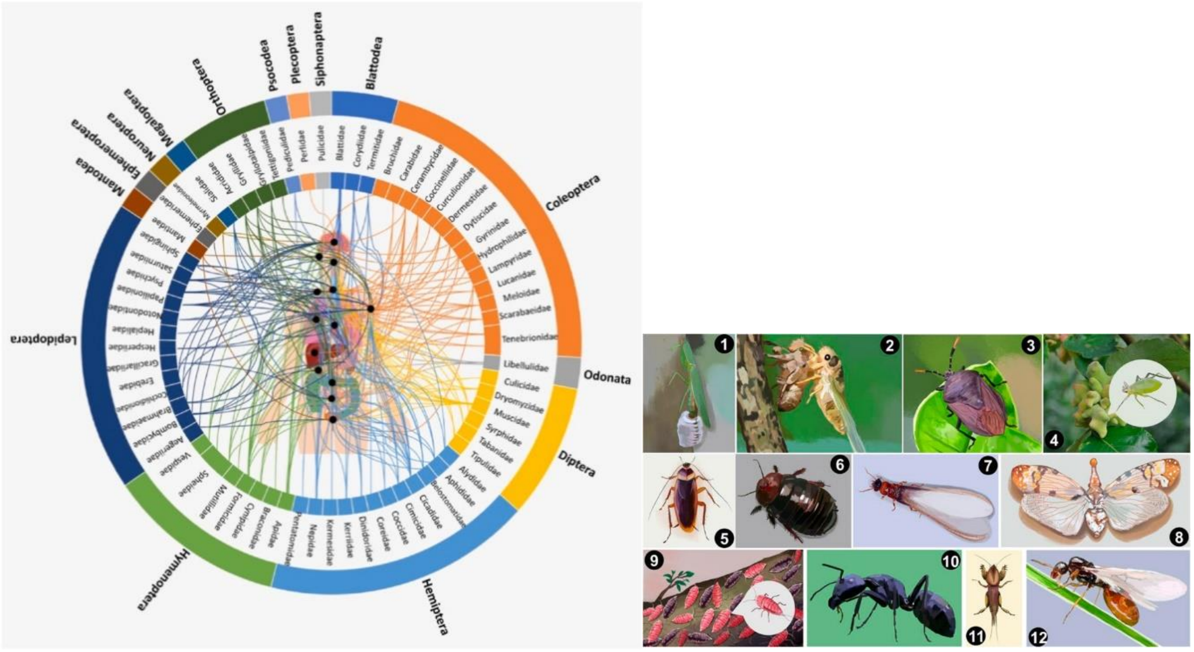

Fig. 1. Insects found across the globe

In general, liquid insects include a relatively high concentration of copper, iron, magnesium, manganese, phosphorous, selenium, and zinc; nevertheless, there is a lack of information on the nutritional profile of vitamins and minerals [24]. The potential contribution that insects might make to the safety of food and nutrition is extremely important on a global scale. On the other hand, a substantial amount of additional information is required for the quantitative nutritional evaluation of insects, particularly with regard to vitamins and minerals [25].

A number of ailments, including stomachaches, respiratory problems, and wound healing, have been treated with edible insects for a considerable amount of time in traditional medicine. The majority of the experiments that have been conducted to investigate the physiological importance of edible insects have focused on their capacity to serve as antioxidants in cell models or in vitro [26]. Only a small amount of study has been conducted on the effects of edible insects on platelet aggregation, anti-inflammatory responses, lipid regulation, and glucose metabolism. Recent years, on the other hand, have seen an increase in the number of studies that investigate the possible health advantages of edible insects from both a theoretical and practical perspective [27].

3. CONTRIBUTION AND IMPACT TO BIODIVERSITY

Biodiversity is the variety of life that exists within an ecosystem. It includes all of the many kinds of plants, animals, and microbes that are able to communicate with one another and provide support for one another. Traditionally, the number of species present in an ecosystem was used to measure the level of biodiversity, with higher numbers being seen as evidence of greater stability and resilience [28]. Nevertheless, biodiversity is not just based on the number of species; it also takes into account the specific characteristics that are supplied by different species. In the context of ecosystems, traits are defined as physical or behavioural features that develop as a result of competitive interactions and abiotic environments. These traits contribute to the health and resilience of the ecosystem being studied [29].

Although species richness is frequently thought to be a straightforward description of community structure, this approach fails to take into account the variety and significance of behavioural or physical characteristics of species that play a role in the provision of ecosystem services [30]. When simply the number of species is taken into consideration, any variation in ecological interactions among species and functional variations within species that might rival differences between species are ignored. When considering how organisms will adapt to changes in the environment, functional diversity is also an important factor to consider. It is vital to take into account the interplay of these functions amongst various species [31].

Another characteristic that plays a significant role in determining biodiversity is size. The size of the body is a significant component that plays a role in defining ecological interactions, and natural communities have size-abundance connections that are consistent. The size of an individual influences the variety of resources that they make use of, and this diversity rises as the individual grows. The research conducted by Volker and colleagues indicated that the identification of species and the size of the body are both significant factors in determining how changes in community structure affect the operation of natural ecosystems [32].

When a species becomes extinct in a particular region, the ecosystem loses the distinctive characteristics that it possessed, which may have an effect on the provision of essential ecosystem services. When trying to determine the level of biodiversity in an ecosystem, it is essential to take into account not only the size and function of the organisms, but also the interactions that occur between the various species [33].

According to estimates, insects are responsible for around 66% of all known species and constitute more than three quarters of the world's biodiversity at the present time. Insects have achieved a great deal of success in terms of both the richness and number of their species. There are a total of 39 orders of insects, with the beetles (Order: Coleoptera) being the most diverse group of insects. There are over 1.5 million different species of beetles, which accounts for approximately forty percent of all arthropod species that have been described [34].

4. THE IMPORTANCE OF INSECTS TO ECOSYSTEMS

Due to the fact that they occupy a variety of trophic niches and carry out a wide range of ecological tasks within their natural habitats, insects play a significant part in the provision of ecological functions and ecosystem services. They may be found in significant numbers in all terrestrial environments and exhibit a vast range of diversity across species in virtually every element of their ecological makeup [35]. There is a tremendous amount of functional relevance associated with insects, and the ecological services that they provide are quite important. Furthermore, insects have a significant part in the operation of ecosystem processes, making them essential components in a wide variety of habitats [36].

There is a possibility that insect herbivores will have a significant impact on the cycle of ecosystems because they alter the quality, amount, and timing of plant detrital inputs. Through the transformation of live plant biomass into frass, greenfall, and throughfall, they play a vital role in the drivers of ecosystem processes. They are responsible for a large portion of the above-ground to below-ground nitrogen and phosphorus fluxes that occur across whole ecosystems [37]. More than three fourth of the wild blooming plant species that are found in temperate climates require pollination in order to thrive, and around two thirds of all plant species are dependent on insects for pollination needs. Flies, bees, and butterflies are the most significant pollinators [38].

When the number of main consumers or phytophagous creatures is below a certain threshold, the function that predation and parasitism play in limiting the population rise is substantial. Herbivorous insects that have the potential to become a nuisance are often controlled by natural predators and parasitoids that are found in the insect kingdom [39]. Predators include insects belonging to the orders Odonata (dragon flies) and Neuroptera (lacewings and ant lions). On the other hand, a significant number of species belonging to the orders Hemiptera (bugs), Coleoptera (beetles), Diptera (flies), and Hymenoptera (wasps, bees, and ants) are also predators [40].

Decomposition is an essential ecosystem activity that is mostly provided by insects, such as species of dung beetles. These insects serve a significant role in the preservation of the health of pastures by burying dung and recycling nutrients that may be utilized by plants since they recycle nutrients [41]. As a result of their ability to increase the amount of nitrogen, phosphorous, potassium, calcium, magnesium, or total proteins in the soil, dung beetles contribute to the health of the soil and reduce greenhouse gas emissions by between 7 and 12 percent [42]. When it comes to raising the amount of mineral nitrogen in the soil, ants and termites, which are macrofauna that live in arid and hot climates, play a significant role.

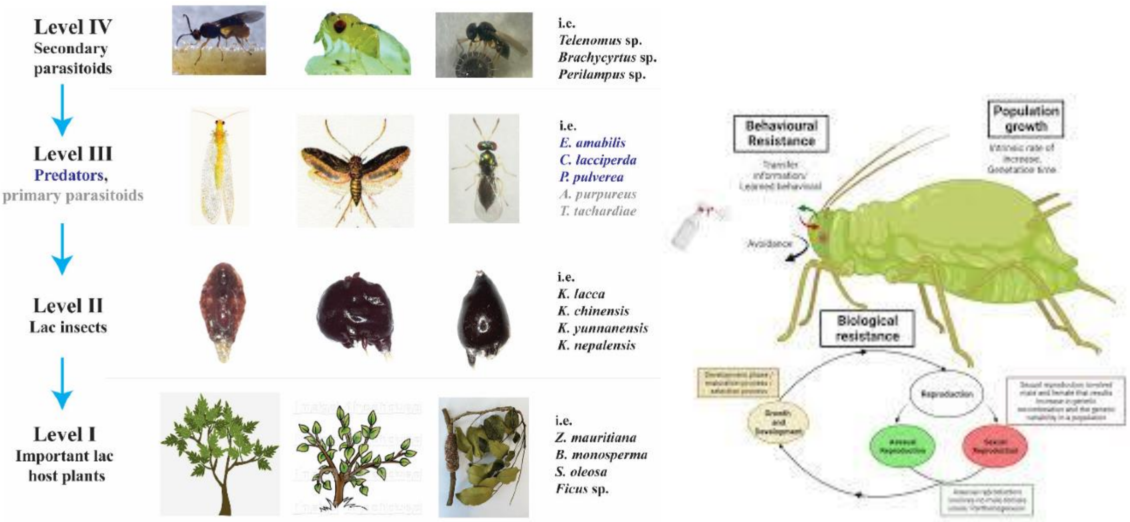

Fig. 2. Contribution and impact to biodiversity

Species of insects that are not native to an area play an important part in ecosystems by supplying native species with habitats and services that are of great value. Providing native species with habitat, food, or trophic subsidies, acting as catalysts for the restoration of those species, and functioning as substitutes for ecosystem engineers that have been extinct are all ways in which they can contribute to the long-term maintenance of ecosystem resilience.

Due to the fact that insects are considered to be rivals in the battle for existence, they have been utilized in agriculture for ages [43,44]. The interaction between insects and plants is the most important one, with around fifty percent of insect species being herbivorous. 18% of the world's agricultural productivity is harmed by herbivorous insects, which are mostly managed via the use of chemical techniques. Insects that are deemed to be a nuisance account for fewer than half of the total number of bug species that are known to exist [45].

It is critical for human life that insects exist because they provide essential ecological services that are necessary for agricultural production. Insects are responsible for pollination of around 72 percent of the world's crop species, which results in an increase or maintenance of production for approximately 75 percent of all crop kinds worldwide [46]. There are hundreds of different types of insects that are called pollinators. Some of these insects include solitary bees, bumblebees, flies, beetles, and butterflies. Pollination is performed by wild bee species, which are more essential than honeybees, and they contribute 9.5% to the overall output of agricultural production [47].

The management of pests is an unavoidable aspect of agricultural production. Predatory insects play a crucial role in the functioning of ecosystems by preventing pest insects from infesting crops that have been planted. Aphids, slugs, root-feeding flies, and phytophagous beetles are some of the economically significant agricultural pests that ground beetles are able to efficiently reduce population levels of Ground beetles are the major generalist predators in arable fields [48]. In addition, insects have a key role in the enhancement of agricultural soil. This is because the activity of insects raises the levels of nitrogen, phosphorous, potassium, calcium, magnesium, or total proteins in the soil. This, in turn, greatly enhances the yields of wheat plants in comparison to the yields of chemical fertilizers [49].

5. DIFFERENT INSECT'S UTILIZATION IN MEDICINAL FIELD

Insects, rats, and other animals that have become a nuisance to people are some of the things that are managed or eliminated through the process of pest control. Insects were utilized as a kind of medicine in ancient societies, and in the present day, researchers are investigating and attempting to rediscover a wide variety of natural compounds derived from insects [50]. Insects and items produced from insects have been utilized as therapeutic agents in several regions of the world since ancient times. Burns may be treated with honey, and a mixture of honey and beeswax is used to treat a variety of dermatological conditions, such as psoriasis, tinea, pityriasis versicolor, atopic dermatitis, and diaper dermatitis [51]. Patients with rheumatoid arthritis have seen a reduction in the number of swollen joints as a result of the usage of royal jelly, which is used to treat postmenopausal symptoms, as well as bee and ant venom [52]. The hive sealant known as propolis, which is produced by bees, has been used as a treatment for aphthous stomatitis. It has been demonstrated that cantharidin, which is derived from the bodies of blister beetles, is effective in treating warts as well as molluscum contagiosum. The utilization of insects in conjunction with traditional therapies could result in additional benefits [53].

Honey venom therapy is one of the honey bee products that is used in medicine. It is comprised of peptides like melittin, apamin, and ado lapin, as well as the mast cell degranulation peptide, enzymes (phospolipase-A2), and amines like histamine and epinephrine, as well as nonpeptide components that have a wide range of pharmaceutical properties [54]. All types of cancer cells, including those found in the kidneys, lungs, liver, prostate, mammary glands, and leukemia, are susceptible to apoptosis when exposed to bee venom. Bee venom has been shown to trigger apoptosis in cancer cells, namely in human leukemic U937 cells [55].

Maggot treatment is a sort of biotherapy that involves the injection of live, disinfected maggots (fly larvae) into the no healing skin and soft tissue wound(s) of a human or animal for the aim of clearing out the necrotic (dead) tissue that is contained inside a wound. Maggots are flying larvae that are able to feed on dead tissue [56]. There is evidence to suggest that maggot treatment may assist in the healing process of wounds. The treatment of wounds using maggots is comprised of three distinct processes: debridement of wounds, wound healing, and disinfection of wounds [57].

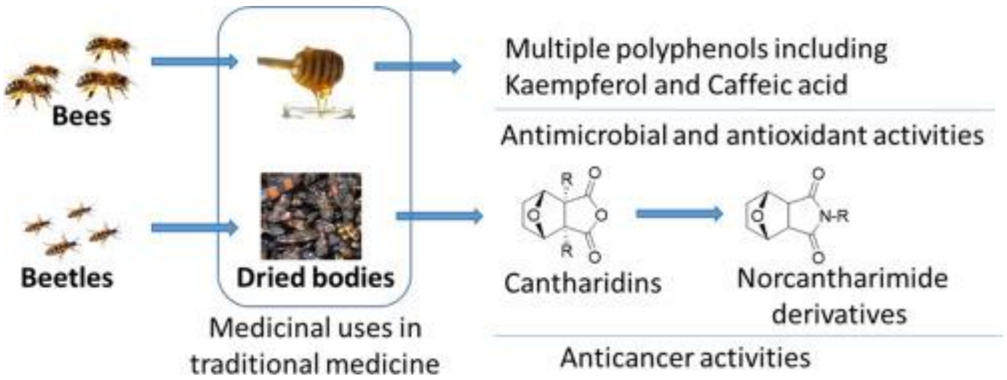

Fig. 3. Importance of insects to ecosystems

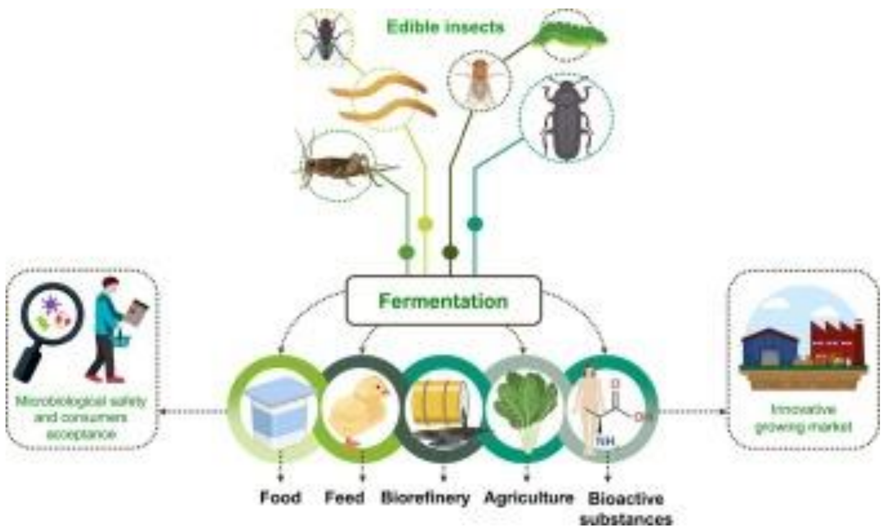

Fig. 4. Different insect's utilization in in medicinal field

Fig. 5. Pollination

There is a species of insect known as the fruit fly that is capable of detecting cancer, which is one of the risky diseases. Cancer cells have a metabolism that is fundamentally different from that of normal cells. This difference in metabolism leads to alterations in the microenvironment of the tumour, lipid peroxidation activity, and putative cancer-specific indicators that are found both inside and outside of the tumour [58]. Certain species of ants, such as the South American tree ant Pseudomyrmex sp., which is more generally referred to as the samsum ant, produce venom that possesses several pharmacological benefits. These effects include the reduction of inflammation, the alleviation of pain, the suppression of tumour growth, the treatment of hepatitis, and the protection of the liver [59]. It has been demonstrated that the medicinal ant known as *Polyrachisla melliden*, which is utilized in Chinese medicine, possesses powerful analgesic and anti-inflammatory properties.

Termites are insects that are frequently utilized in traditional and popular medicine. There are 45 species of termites belonging to four families that are utilized by human civilizations [60]. Asthma, bronchitis, influenza, whooping cough, influenza, and nasalitis are only some of the disorders that may be treated with termites. Other diseases that can be treated with termites include whooping cough, influenza, and nasalitis. There is a possibility that combining insects with conventional therapies will result in additional advantages [61].

6. INSECT UTILIZATION FOR NUTRITION GAIN AND BIOLOGICAL INDICATORS

Population expansion and urbanization have both contributed to an increase in the demand for food across the world, particularly supplies of protein derived from animals. Honey is the only food that has been consumed by people in Western countries, despite the fact that insects have been consumed for a very long time in a number of countries throughout the world. When it comes to animal hunting, insects have been seen as a crucial element. They have the potential to be a viable solution to meet global concerns like as climate change, population expansion, sustainability, and growing zoonosis [62]. Because of the high nutritional content of insects and the fact that their production is environmentally friendly, there has been an increasing interest in using insects as a source of food in recent decades.

It is possible that insects might be a beneficial alternative to meat and fish in terms of fulfilling the rising demand for food due to the fact that they have a high nutritional content and can be produced in a sustainable manner [63]. The conventional production of animal feed, which includes fishmeal, soy, and grains, has to be further increased in terms of resource efficiency and expanded by making use of alternate sources. More than nine billion humans will require food by the year 2030, in addition to the billions of animals that are farmed annually for the purpose of providing food, for recreational reasons, and as pets. It is theoretically possible to utilize insects as a feed element on a big scale, and it is anticipated that the use of insects as feedstock for aquaculture and poultry feed will become more widespread over the next ten years [64].

There are a number of microbiological and chemical risks that have been linked to insects, and these hazards need to be addressed in accordance with the particulars of the supply chain for insects [65]. The generation of naturally occurring poisons by the insects themselves and the consumption of pollutants from farming substrates are the two primary channels through which chemically dangerous chemicals are introduced into the insect population [66]. The presence of mycotoxins, heavy metals, polychlorinated biphenyls (PCBs), dioxins, pesticides, persistent organic pollutants, plasticizers, and flame retardants has been the subject of research that has been conducted in recent times [67]. In spite of this, the levels of contamination that were discovered for pesticides, PCBs, flame retardants, plasticizers, and dioxins were rather low. The concentration values displayed were comparable to or lower than those that were detected in meat, fish, and eggs, and they did not surpass the legal limits that are now in place for items that are extremely similar [68].

When it comes to heavy metals, the level of possible bioaccumulation along the food chain from polluted soil, plants, or water varies substantially depending on the insect species and the heavy metal that is being researched [69]. This was discovered via the collection of data by research studies that involved a variety of insect species. It is essential to keep in mind that the chemical safety of the final product can be significantly impacted by the type of insects, the habitat in which they are bred, and the modification that occurs throughout the processing and packing stages [70].

There is a danger associated with the possibility of allergic responses being generated by the intake of insects, despite the fact that there are several benefits associated with utilizing insects as food owing to the fact that they contain a number of bioactive substances. Individuals who are allergic to seafood may be at danger while ingesting insects due to the possibility of cross-reactivity with the tropomyosin and arginine kinase of the insects. Several proteins found in insects have been identified as allergens [71]. Despite the fact that insects are not included on the list of allergenic substances in the EU's current legislation, rules that authorize the use of some insect-based products as food require manufacturers to include labels that contain particular warnings for consumers regarding the potential for allergic reactions [72].

The authorities in charge of public health should play a significant part in ensuring that the commercial production of insects for food and feed is carried out in a hygienic and sustainable manner. The process by which they enter the food systems necessitates regulatory risk assessment, which enables competent national or international authorities to evaluate the safety of these substances and implement particular rules that ensure public health [73]. The producers and the consumers need to be provided with clear guidelines, and the experts who are involved in activities related to food safety need to be provided with information and expertise. This applies to both the commercial and public sectors [74].

These specialists in the field of public health, particularly those who are involved in the regulation of the food chain, find insects to be an extremely useful source of food and feed. Taxonomical distance, variances in upbringing, dimensions, and poikilothermy are some of the distinctive qualities that set them apart from goods derived from animals that are typically consumed [75]. Public health specialists who are involved in the management of food and feed have issues due to the absence of a true slaughtering phase and the potential of relatively simple and small facilities controlling production from the farm to the final goods.

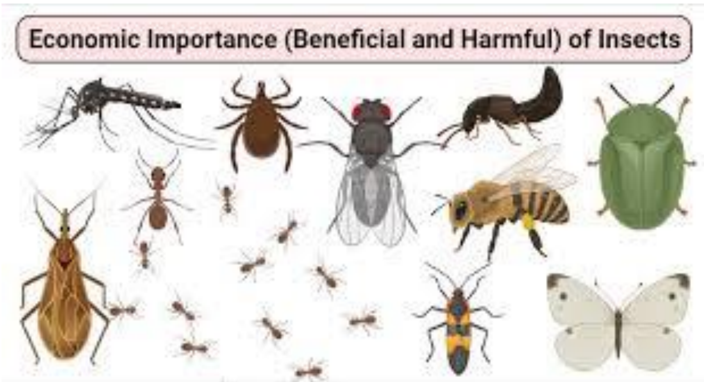

Fig. 6. Economic importance of insects

Due to the fact that insects are used as both food and feed, further research efforts are required in order to evaluate the possible dangers that might arise from this supply chain and to provide solutions for the management of these risks [76]. The dangers posed by probable zoonosis, infections, poisons, and heavy metals (via bio-waste streams) should be the primary emphasis of these. In addition, the function that insects play in giving bioactive chemicals to human nutrition ought to be a study objective due to the fact that they contribute to human nutrition [77].

The scientific evaluation of environmental and human exposure to natural or manmade pollutants is referred to as biomonitoring. This evaluation is based on the sampling and chemical analysis of live organisms within the environment. The use of insects as bioindicators for the purpose of evaluating pollution levels in both aquatic and terrestrial environments has been demonstrated to be an effective method for determining the overall health of ecosystems [78]. Honeybees are an example of insects that are capable of acting as active samplers and detectors of environmental pollution. This is because honeybees are able to fly up to 10 to 12 kilometres away from their hive, acquire electric charge as a result of friction with the air, and trap chemicals that are suspended in the air, including toxins [79].

When it comes to honeybees and their products, biomonitoring programs that evaluate the presence of pesticides and other dangerous compounds might be of great assistance in gaining a better knowledge of the possible hazards that are induced by direct and indirect exposure to certain pollutants [80]. These programs could also serve as an early warning system for public health measures. The use of honeybees as a natural and cost-effective monitoring system that is able to identify potentially hazardous circumstances for public health is an excellent example of the usage of insects as a monitoring system [81].

As a result of their widespread distribution and the relevance they hold for the environment, as well as the fact that they have preserved their signalling pathways, energy metabolism, and structural components, insects have also been utilized as model organisms in a number of different fields of study within the fields of life science and medicine [82]. There is a significant degree of structural and functional homology between the innate immune system of insects and the innate immune system of mammals. As a result, insects are good bioindicators for a variety of contaminants because of this similarity [83].

In addition, insects have been utilized as in vivo alternative models for the purpose of analyzing the processes involved in the development of diseases, determining the virulence of microorganisms, determining the level of host resistance, and determining the effectiveness and toxicity of antibiotics, fungicides, and other biologically active chemicals [84,85].

Insects are capable of producing a wide range of antimicrobial peptides and proteins (AMPs), which are substances that have the ability to work against cancer cells, bacteria, fungus, parasites, and viruses [86]. The mechanism of action of these AMPs is one of a kind, and they serve as great templates for the creation of novel antimicrobial medications. Additionally, they may be added to food and feed as preservatives and additives when they are used. It is necessary to do more research in order to examine the structure-activity connections, activity mechanisms, bioavailability, and synergistic effects with antibiotics [87,88,89].

7. INSECT FARMING AND THEIR IMPLICATION IN HUMAN HEALTH

For the sake of the insects' continued existence, the production systems for insects need to put the health and wellbeing of the insects first. Agricultural insects have the potential to house a wide range of bacteria, which can be classified as either non-pathogenic, pathogenic, or harmful to vertebrates of the animal kingdom [90]. The introduction of these microorganisms can occur through the consumption of contaminated food, the disposal of waste and debris, the dispersion of aerosols, the presence of workers or visitors, as well as the entrance of newly fished specimens or undesired animal species. Insect health and agricultural productivity can be negatively impacted by hidden infection, which can be triggered by stress circumstances or other causes [91].

Insect farmers must design and maintain a health management strategy in order to prevent disease outbreaks and lower yields. This plan must be implemented by continual monitoring of insects in order to recognize indicators of disease and to take prompt action to prevent the spread of infections. In order to design recommendations for the prevention and control of illnesses on farms, including surveillance, sanitation methods, and effective diagnostic screening protocols, it is vital to have a greater understanding of the vulnerability of insects and the biology of pathogens [92].

For the purpose of defining and operating health management systems in insect farms, controlling live insect markets, and preventing the spread of infections, professionals who have knowledge in insect health are required [93]. The significance of these operations will grow in tandem with the expansion of the number of insect farms and the market share of feed and food. When it comes to monitoring the health condition of farms and certifying live insects during commercial exchanges, standardization and the availability of diagnostic procedures that are able to identify insect infections are also key components [94].

When it comes to farmed vertebrates, animal welfare is described in terms of the "Five Freedoms," which include freedom from hunger, thirst, discomfort, pain, injury, fear, distress, and the ability to express natural behaviour [95]. Within the context of a unified legislative framework, the European Commission has set basic criteria for animal welfare in cattle; however, the scope of applicability does not include invertebrates. A type of invertebrates known as cephalopods is included in the European Union Directive on the protection of animals used for scientific reasons [96]. In the future, animal experiments might serve as a starting point for further examination of the welfare needs of all invertebrates, including insects. It is possible that the ethical issues of utilizing invertebrates in scientific study might extend to other elements of relationships with these species, notably with regard to the methods of pest control and intensive insect farming [97].

The consumption of edible insects is becoming increasingly significant for people as a novel source of food and feed for animals that are raised in intensive systems. Concerns have been raised by agencies in charge of veterinary public health over the identification of welfare criteria and recommended husbandry techniques [98]. Insects have been shown to have complex reactions, which suggests that they should be regarded as "precautionary as sentient beings." Recent research on pain perception, cognitive ability, and pessimistic bias has revealed these responses [99]. Because of the significant evolutionary distance between species and the heterogeneity that exists between them, there is a lack of information about the practical welfare needs of farmed insects. These requirements may be different from those for vertebrates [100].

For reasons related to trade secrets, prominent insect farmers have provided an outline of acceptable agricultural methods for their specific niche markets. These practices have not been made available to the general public. By applying the Five Freedoms to insect farming, the Finnish Food Safety Authority (Evira) and the International Pesticide Innovation Forum (IPIFF) have worked to improve the welfare of insects [101]. These freedoms include taking into account the physiological and ethological requirements of individual species, providing an adequate environment, preventing injuries and cannibalism, and ensuring a speedy death through the use of euthanasia that is both effective and appropriate. In recent times, several techniques of death have been documented, including the use of boiling vapour, freezing, mincing, and hot water [102].

The welfare of animals, economic productivity, the safety of food and feed, and public health in the event of zoonotic infections are all significant reasons why biosecurity is so important. Within the context of an insect farm, prevention encompasses all elements of preventing dangerous agents from entering and spreading within the farm as well as insects from fleeing from the farm [103]. Important factors that contribute to the long-term viability and health of insect farming include the provision of assured feed, water, and raising substrates, as well as the maintenance of an acceptable environment and sanitary parameters, as well as cleaning operations, binding access procedures, and quarantine as considered necessary [104].

At the moment, there are no special biosecurity instructions for insect farming; rather, the International Platform of Insects for Food and Feed (IPIFF) has only issued general guidance on proper hygiene standards for insect farmers. Other than that, there are no specific instructions for insect farming [105]. Public health authorities continue to face difficulties in putting into practice and continuously improving biosecurity policies for insects that are raised in an agricultural setting. The installation of dedicated management systems should be a prerequisite for a successful biosecurity system. These management systems should include excellent breeding techniques, good hygiene standards, good farming practices, and effective pest management and pest control programs [106].

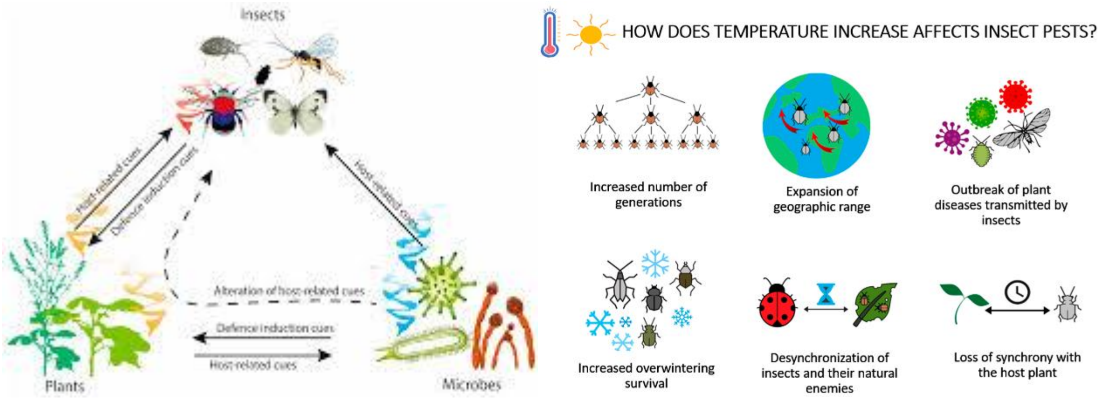

Fig. 7. Effect of temperature on insect population

Biosecurity measures for this new industry need to be developed as quickly as possible by public health authorities. These measures need to be novel, particular, comprehensive, and adaptive (that is, regarding insect species and infrastructural capabilities). For the purpose of maintaining the raising process, insect farming necessitates a high degree of insect health status, which is determined by daily inspections [107]. This need is accompanied by an adequate set of analyses, which includes both visual inspection and molecular testing. It is important to determine and achieve the appropriate level of biosecurity in an insect farming system based on the purpose for which the insects are intended to be used. There is a significant amount of allergens that are found in insects, and it is possible for people to be exposed to insect particles in both indoor and outdoor environments during the course of their daily lives, both in non-occupational and occupational settings [108]. Having to handle edible insects on a daily basis can be a contributing factor in the development of allergies; thus, public health authorities should prescribe certain behaviours and insect farmers should follow them [109].

8. CONCLUSION

In conclusion, the exploration of insects in medicinal and industrial plant applications reveals a wealth of untapped potential that could revolutionize various sectors. Insects, often overlooked, play crucial roles in enhancing the medicinal properties of plants. For instance, their interactions with plants, such as pollination and the secretion of bioactive compounds, can boost the production of essential medicinal metabolites. These metabolites have significant therapeutic potential, ranging from anti-inflammatory and antimicrobial to anticancer properties. By understanding and harnessing these interactions, we can develop more effective natural remedies and pharmaceuticals. On the industrial front, insects contribute to sustainable practices through bioconversion and waste management. Insects such as black soldier flies are efficient decomposers, capable of converting organic waste into valuable by-products like high-quality protein and bio-fertilizers. This not only reduces waste but also provides a sustainable source of animal feed and soil enhancers, aligning with circular economy principles. Additionally, insects' ability to degrade and recycle plant materials can lead to the development of innovative bioprocessing technologies, further enhancing industrial efficiency and reducing environmental impact. The integration of insects into agricultural and industrial systems offers multifaceted benefits. It promotes biodiversity, enhances ecosystem resilience, and supports sustainable agriculture practices. Furthermore, the study of insect-plant interactions can lead to breakthroughs in pest management, reducing reliance on chemical pesticides and fostering organic farming practices. Overall, the synergy between insects and plants opens new frontiers in both medicinal and industrial applications. By embracing this synergy, we can create a future where biological resources are utilized more efficiently and sustainably. This holistic approach not only addresses contemporary challenges such as food security and environmental sustainability but also paves the way for innovative solutions that harness the full potential of nature's ingenuity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Li D, Li W, Chen Y, Liu L, Ma D, Wang H, Zhang L, Zhao S, Peng Q. Anti-fibrotic role and mechanism of *Periplaneta americana* extracts in CCl4-induced hepatic fibrosis in rats. Acta Biochim. Biophys. Sin. 2018;50:491–498.
DOI: 10.1093/abbs/gmy024
2. Tian M, Dong J, Wang Z, Lu S, Geng F. The effects and mechanism of Kangfuxin on improving healing quality and preventing recurrence of gastric ulcer. Biomed. Pharmacother. 2021;138.
DOI: 10.1016/j.biopha.2021.111513
3. Yoon IN, Lu LF, Hong J, Zhang P, Kim DH, Kang JK, Hwang JS, Kim H. The American cockroach peptide periplanetasin-4 inhibits Clostridium difficile toxin A-induced cell toxicities and inflammatory responses in the mouse gut. J. Pept. Sci. 2017;23:833–839.
DOI: 10.1002/psc.3046
4. Lin Q, Fu Q, Su G, Chen D, Yu B, Luo Y, Zheng P, Mao X, Huang Z, Yu J, Luo J, Yan H, He J. Protective effect of Bombyx mori gloverin on intestinal epithelial cells exposure to enterotoxigenic E. coli. Braz. J. Microbiol. 2021;52:1235–1245.
DOI: 10.1007/s42770-021-00532-0
5. Shen Y, Sun J, Niu C, Yu D, Chen Z, Cong W, Geng F. Mechanistic evaluation of gastroprotective effects of Kangfuxin on ethanol-induced gastric ulcer in mice. Chem. Biol. Interact. 2017;273: 115–124.
DOI: 10.1016/j.cbi.2017.06.007
6. Lu K, Zhou J, Deng J, Li Y, Wu C, Bao J. Periplaneta americana oligosaccharides exert anti-inflammatory activity through immunoregulation and modulation of gut microbiota in acute colitis mice model. Molecules. 2021;26:1718.
DOI: 10.3390/molecules26061718
7. Ma X, Hu Y, Li X, Zheng X, Wang Y, Zhang J, Fu C, Geng F. *Periplaneta americana* ameliorates dextran sulfate sodium-induced ulcerative colitis in rats by Keap1/Nrf-2 activation, intestinal barrier function, and gut microbiota regulation. Front. Pharmacol. 2018;9.
DOI: 10.3389/fphar.2018.00944
8. Peng S, Ling X, Rui W, Jin X, Chu F. LMWP (S3-3) from the larvae of Musca domestica Alleviate D-IBS by adjusting the gut microbiota. Molecules. 2022;27:4517.
DOI: 10.3390/molecules27144517.
9. Wang SP. Effect of active peptides of Eupolyphaga on intestinal flora in rats with hyperlipemia. Chin. Pharmacol. Bull. 2020;621–626:621–626.
10. Kim HJ, Kim KY, Ji SD, Lee HT. Anti-melanogenic activity of steamed and freeze-dried mature silkworm powder. J. Asia Pac. Entomol. 2017;20:1001–1006.
DOI: 10.1016/j.aspen.2017.07.013.
11. Im AR, Ji KY, Park I, Lee JY, Kim KM, Na M, Chae S. Anti-photoaging effects of four insect extracts by downregulating matrix metalloproteinase expression via mitogen-activated protein kinase-dependent signaling. Nutrients. 2019;11:1159.
DOI: 10.3390/nu11051159
12. Zhang N, Zhao Y, Shi Y, Chen R, Fu X, Zhao Y. Polypeptides extracted from Eupolyphaga sinensis Walker via enzymic digestion alleviate UV radiation-induced skin photoaging. Biomed. Pharmacother. 2019;112.
DOI: 10.1016/j.biopha.2019.108636.
13. Rujimongkon K, Ampawong S, Reamtong O, Buaban T, Aramwit P. The therapeutic effects of Bombyx mori sericin on rat skin psoriasis through modulated epidermal immunity and attenuated cell proliferation. J. Tradit. Complement. Med. 2021;11:587–597.
DOI: 10.1016/j.jtcme.2021.06.007
14. Kahl M, Gökçen A, Fischer S, Bäumer M, Wiesner J, Lochnit G, Wygrecka M, Vilcinskas A, Preissner K. Maggot excretion products from the blowfly Lucilia sericata contain contact phase/intrinsic pathway-like proteases with procoagulant functions. Thromb. Haemostasis. 2015; 114:277–288.
DOI: 10.1160/TH14-06-0499
15. De Masiero FS, Nassu MP, Soares MP, Thyssen PJ. Histological patterns in healing chronic wounds using Cochliomyia macellaria (Diptera: Calliphoridae) larvae and other therapeutic measures. Parasitol. Res. 2015;114:2865–2872.
DOI: 10.1007/s00436-015-4487-y

16. Borkataki S, Katoch R, Goswani P, Bhat A, Chakrabotty D. Acceleration of cutaneous wound healing by Lucilia sericata maggots in diabetic Wistar rats. Trop. Biomed. 2021;38:86–93.
DOI: 10.47665/tb.38.1.015
17. Szczepanowski Z, Grabarek BO, Boroń D, Tukiendorf A, Kulik-Parobczy I, Miszczyk L. Microbiological effects in patients with leg ulcers and diabetic foot treated with Lucilia sericata larvae. Int. Wound J. 2022;19:135–143.
DOI: 10.1111/iwj.13605
18. Han S, Park K, Nicholls Y, Macfarlane N, Duncan G. Effects of honeybee (Apis mellifera) venom on keratinocyte migration *In vitro*. Phcog. Mag. 2013;9:220.
DOI: 10.4103/0973-1296.113271
19. Martinotti S, Pellavio G, Laforenza U, Ranzato E. Propolis induces AQP3 expression: a possible way of action in wound healing. Molecules. 2019;24:1544.
DOI: 10.3390/molecules24081544
20. Chen Z, Hu Y, Li J, Zhang C, Gao F, Ma X, Zhang J, Fu C, Geng F. A feasible biocompatible hydrogel film embedding *Periplaneta americana* extract for acute wound healing. Int. J. Pharm. 2019;571.
DOI: 10.1016/j.ijpharm.2019.118707
21. Góngora J, Díaz-Roa A, Ramírez-Hernández A, Cortés-Vecino JA, Gaona MA, Patarroyo MA, Bello F. Evaluating the effect of *Sarconesiopsis magellanica* (Diptera: Calliphoridae) larvae-derived haemolymph and fat body extracts on chronic wounds in diabetic rabbits. J. Diabetes Res. 2015;2015:1–10.
DOI: 10.1155/2015/270253
22. Zou Y, Zhang M, Zeng D, Ruan Y, Shen L, Mu Z, Zou J, Xie C, Yang Z, Qian Z, Xu R, Li S, Kang Q, Zou H, Zhao S, Liu L, Wang K, Wang X, Zhang X. *Periplaneta americana* extracts accelerate liver regeneration via a complex network of pathways. Front. Pharmacol. 2020;11:1–12.
DOI: 10.3389/fphar.2020.01174
23. Li X, Liu N, Xia X, Zhang S, Bai J, Wang J. The effects of maggot secretions on the inflammatory cytokines in serum of traumatic rats. Afr. J. Tradit., Complementary Altern. Med. 2013;10.
DOI: 10.4314/ajtcam.v10i4.24
24. Telford G, Brown AP, Rich A, English JSC, Pritchard DI. Wound debridement potential of glycosidases of the wound-healing maggot, *Lucilia sericata*. Med. Vet. Entomol. 2012;26:291–299.
DOI: 10.1111/j.1365-2915.2011.01000.x
25. Kui W, Ying F, Long SUN, Zhao HE, Zhi-yong C. Isolation of ethyl acetate extract from *Periplaneta americana* and its antimicrobial activity. For. Res. 2013;26: 163–166.
Available:http://www.lykxyj.com//article/id/20130206
26. Amer A, Hamdy B, Mahmoud D, Elanany M, Rady M, Alahmadi T, Alharbi S, AlAshaal S. Antagonistic activity of bacteria isolated from the *Periplaneta americana L*. gut against some multidrug-resistant human pathogens. Antibiotics. 2021;10:294.
DOI: 10.3390/antibiotics10030294
27. Long Y, Zhang Y, Huang F, Liu S, Gao T, Zhang Y. Diversity and antimicrobial activities of culturable actinomycetes from Odontotermes formosanus (Blattaria: Termitidae) BMC Microbiol. 2022;22:80.
DOI: 10.1186/s12866-022-02501-5
28. Maroufi Y, Ghaffarifar F, Dalimi A, Sharifi Z. Interferon-Gamma and Interlukin-4 patterns in BALB/c mice suffering from cutaneous leishmaniasis treated with cantharidin. Jundishapur J. Microbiol. 2014;7.
DOI: 10.5812/jjm.10907
29. Lee J, Lee D, Choi H, Kim HH, Kim H, Hwang JS, Lee DG, Il Kim J. Synthesis and antimicrobial activity of cysteine-free coprisin nonapeptides. Biochem. Biophys. Res. Commun. 2014; 443:483–488.
DOI: 10.1016/j.bbrc.2013.11.125
30. Xu C, Cao X, Wang Y, Wang Q, Sun R. Purification of a galactose-specific lectin with antibacterial and mitogenic activity from Musca domestica pupae. J. Pure Appl. Microbiol. 2013;7:494–503.
31. Ahn MY, Han JW, Hwang JS, Yun EY, Lee BM. Anti-inflammatory effect of glycosaminoglycan derived from *Gryllus bimaculatus* (a type of cricket, insect) on adjuvant-treated chronic arthritis rat model. J. Toxicol. Environ. Health, Part A. 2014;77:1332–1345.
DOI: 10.1080/15287394.2014.951591.
32. Dutta P, Dey T, Manna P, Kalita J. Antioxidant potential of *Vespa affinis L*., a traditional edible insect species of North East India. Plos One. 2016;11.
DOI: 10.1371/journal.pone.0156107

33. El-Ashram S, El-Samad LM, Basha AA, El Wakil A. Naturally-derived targeted therapy for wound healing: Beyond classical strategies. Pharmacol. Res. 2021;170. DOI: 10.1016/j.phrs.2021.105749.
34. Chantawannakul P. From entomophagy to entomotherapy. Front. Biosci. 2020; 25: 4802. DOI: 10.2741/4802
35. Loko LEY, Medegan Fagla S, Orobiyi A, Glinma B, Toffa J, Koukoui O, Djogbenou L, Gbaguidi F. Traditional knowledge of invertebrates used for medicine and magical–religious purposes by traditional healers and indigenous populations in the Plateau Department, Republic of Benin. J. Ethnobiol. Ethnomed. 2019;15:66. DOI: 10.1186/s13002-019-0344-x
36. Alves RRN, Rosa IL, Léo Neto NA, Voeks R. Animals for the gods: Magical and religious faunal use and trade in Brazil. Hum. Ecol. 2012;40:751–780. DOI: 10.1007/s10745-012-9516-1.
37. El Hajj M, Holst L. Herbal medicine use during pregnancy: A review of the literature with a special focus on sub-saharan Africa. Front. Pharmacol. 2020;11. DOI: 10.3389/fphar.2020.00866.
38. James PB, Wardle J, Steel A, Adams J. Traditional, complementary and alternative medicine use in Sub-Saharan Africa: A systematic review. BMJ Glob. Health. 2018;3. DOI: 10.1136/bmjgh-2018-000895.
39. Mudonhi N, Nunu WN. Traditional medicine utilisation among pregnant women in sub-saharan african countries: A systematic review of literature. Inq. J. Heal. Care Organ. Provision, Financ. 2022; 59. DOI: 10.1177/00469580221088618
40. Mwaka AD, Abbo C, Kinengyere AA. Traditional and complementary medicine use among adult cancer patients undergoing conventional treatment in sub-saharan Africa: A scoping review on the use, safety and risks. Cancer Manag. Res. 2020;12:3699–3712. DOI: 10.2147/CMAR.S251975.
41. Meo SA, Al-Asiri SA, Mahesar AL, Ansari MJ. Role of honey in modern medicine. Saudi J. Biol. Sci. 2017;24:975–978. DOI: 10.1016/j.sjbs.2016.12.010
42. Nikhat S, Fazil M. History, phytochemistry, experimental pharmacology and clinical uses of honey: A comprehensive review with special reference to Unani medicine. J. Ethnopharmacol. 2022;282. DOI: 10.1016/j.jep.2021.114614
43. Sforcin JM, Bankova V, Kuropatnicki AK. Medical benefits of honeybee products, Evidence-Based Complement. Alternative Med. 2017;2017:1–2. DOI: 10.1155/2017/2702106
44. Zurier RB, Mitnick H, Bloomgarden D, Weissmann G. Effect of bee venom on experimental arthritis. Ann. Rheum. Dis. 1973;32:466–470. DOI: 10.1136/ard.32.5.466.
45. Kolayli S, Keskin M. Natural bee products and their apitherapeutic applications. Bull. ESA. 2020;66:175–196. DOI: 10.1016/B978-0-12-817907-9.00007-6
46. Donev R. Academic Press. Protein and Peptide Nanoparticles for Drug Delivery; 2015.
47. Gajski G, Garaj-Vrhovac V, Melittin. A lytic peptide with anticancer properties. Environ. Toxicol. Pharmacol. 2013;36:697–705. DOI: 10.1016/j.etap.2013.06.009
48. Jallouk AP, Palekar RU, Pan H, Schlesinger PH, Wickline SA. Modifications of natural peptides for nanoparticle and drug design. Adv. Protein Chem. Struct. Biol. 2015;98:57–91. DOI: 10.1016/bs.apcsb.2014.12.001.
49. Denisow B, Denisow-Pietrzyk M. Biological and therapeutic properties of bee pollen: A review. J. Sci. Food Agric. 2016;96:4303–4309. DOI: 10.1002/jsfa.7729
50. Amr A, Abd El-Wahed A, El-Seedi HR, Khalifa SAM, Augustyniak M, El-Samad LM, Abdel Karim AE, El Wakil A. UPLC-MS/MS analysis of naturally derived Apis mellifera products and their promising effects against cadmium-induced adverse effects in female rats. Nutrients. 2022; 15:119. DOI: 10.3390/nu15010119
51. Yin W, Zhao C, Liao C, Trowell S, Rickards RW. Preparative isolation of novel antimicrobial compounds from Pergidae sp. by reversed-phase high-performance liquid chromatography. Chem. Nat. Compd. 2013;49:41–45. DOI: 10.1007/s10600-013-0501-8

52. Crockett SL, Boevé JL. Flavonoid glycosides and naphthodianthrones in the sawfly Tenthredo zonula and its host-plants. Hypericum perforatum and H. hirsutum, J. Chem. Ecol. 2011;37:943–952.
DOI: 10.1007/s10886-011-0001-x
53. Tang JJ, Fang P, Xia HL, Tu ZC, Hou BY, Yan YM, Di L, Zhang L, Cheng YX. Constituents from the edible Chinese black ants (Polyrhachis dives) showing protective effect on rat mesangial cells and anti-inflammatory activity. Food Res. Int. 2015;67:163–168.
DOI: 10.1016/j.foodres.2014.11.022
54. Narsinghani T, Sharma R. Lead optimization on conventional non-steroidal anti-inflammatory drugs: An approach to reduce gastrointestinal toxicity. Chem. Biol. Drug Des. 2014;84:1–23.
DOI: 10.1111/cbdd.12292
55. Yan YM, Li LJ, Qin XC, Lu Q, Tu ZC, Cheng YX. Compounds from the insect Blaps japanensis with COX-1 and COX-2 inhibitory activities. Bioorg. Med. Chem. Lett. 2015;25:2469–2472.
DOI: 10.1016/j.bmcl.2015.04.085
56. Abd El-Wahed AA, Khalifa SAM, Sheikh BY, Farag MA, Saeed A, Larik FA, Koca-Caliskan U, AlAjmi MF, Hassan M, Wahabi HA, Hegazy MEF, Algethami AF, Büttner S, El-Seedi HR. Bee venom composition: From chemistry to biological activity. 2019;459–484.
57. Munstedt K, Hackethal A, Schmidt K. Bee venom therapy, bee venom acupuncture or apipuncture--what is the evidence behind the various health claims? Am. Bee J. 2005;145:665–668.
58. Oyebode O, Kandala NB, Chilton PJ, Lilford .J. Use of traditional medicine in middle-income countries: A WHO-SAGE study. Health Pol. Plann. 2016;31:984–991.
DOI: 10.1093/heapol/czw022
59. Meyer-Rochow VB, Chakravorty J. Notes on entomophagy and entomotherapy generally and information on the situation in India in particular. Appl. Entomol. Zool. 2013;48:105–112.
DOI: 10.1007/s13355-013-0171-9
60. Chakravorty J, Ghosh S, Meyer-Rochow VB. Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India) J. Ethnobiol. Ethnomed. 2011;7:5.
DOI: 10.1186/1746-4269-7-5
61. Devi WD, Bonysana R, Kapesa K, Mukherjee PK, Rajashekar Y. Edible insects: As traditional medicine for human wellness, Futur. Foods. 2023;7.
DOI: 10.1016/j.fufo.2023.100219
62. Lensvelt EJS, Steenbekkers LPA. Exploring consumer acceptance of entomophagy: A survey and experiment in Australia and The Netherlands, Ecol. Food Nutr. 2014;53:543–561.
DOI: 10.1080/03670244.2013.879865
63. Innocent E. Trends and challenges towards integration of traditional medicine in formal health care system: Historical perspectives and an Appraisal of education curricula in Sub-Sahara Africa. J. Intercult. Ethnopharmacol. 2016;5:312.
DOI: 10.5455/jice.20160421125217.
64. Cherniack EP. Bugs as drugs, Part 1: Insects: The “new” alternative medicine for the 21st century? Alternative Med. Rev. 2010;15:124–135.
65. Shelomi M. Why we still don't eat insects: Assessing entomophagy promotion through a diffusion of innovations framework. Trends Food Sci. Technol. 2015;45:311–318.
DOI: 10.1016/j.tifs.2015.06.008
66. Meyer-Rochow VB. Ethno-entomological observations from North Korea (officially known as the “Democratic People's Republic of Korea”) J. Ethnobiol. Ethnomed. 2013;9:7.
DOI: 10.1186/1746-4269-9-7.
67. Feng Y, Zhao M, He Z, Chen Z, Sun L. Research and utilization of medicinal insects in China. Entomol. Res. 2009;39: 313–316.
DOI: 10.1111/j.1748-5967.2009.00236.x.
68. Cortes Ortiz JA, Ruiz AT, Morales-Ramos JA, Thomas M, Rojas MG, Tomberlin JK, Yi L, Han R, Giroud L, Jullien RL. In: Insects as Sustain. Food Ingredients. Dossey AT, Morales-Ramos JA, Rojas MG, editors. Elsevier. Insect Mass Production Technologies. 2016; 153–201.
69. Feng Y, Chen XM, Zhao M, He Z, Sun L, Wang CY, Ding WF. Edible insects in China: utilization and prospects. Insect Sci. 2018;25:184–198.
DOI: 10.1111/1744-7917.12449.

70. Rumpold BA, Schlüter OK. Potential and challenges of insects as an innovative source for food and feed production. Innovat. Food Sci. Emerg. Technol. 2013; 17:1–11.
DOI: 10.1016/j.ifset.2012.11.005
71. Meyer-Rochow VB, Gahukar RT, Ghosh S, Jung C. Chemical composition, nutrient quality and acceptability of edible insects are affected by species, developmental stage, gender, diet, and processing method. Foods. 2021;10:1036.
DOI: 10.3390/foods10051036
72. Delgado C, Romero R, Vásquez Espinoza R, Trigozo M, Correa R. Rhynchophorus palmarum used in traditional medicine in the Peruvian Amazon. Ethnobiol. Lett. 2019;10:120–128.
DOI: 10.14237/ebl.10.1.2019.1271.
73. Zhou Y, Wang M, Zhang H, Huang Z, Ma J. Comparative study of the composition of cultivated, naturally grown *Cordyceps sinensis*, and stiff worms across different sampling years. Plos One. 2019;14:1–15.
DOI: 10.1371/journal.pone.0225750
74. Chamberlin SR, Blucher A, Wu G, Shinto L, Choonoo G, Kulesz-Martin M, McWeeney S. Natural product target network reveals potential for cancer combination therapies. Front. Pharmacol. 2019;10.
DOI: 10.3389/fphar.2019.00557.
75. Huang X, Yang Z, Xie Q, Zhang Z, Zhang H, Ma J. Natural products for treating colorectal cancer: A mechanistic review. Biomed. Pharmacother. 2019;117.
DOI: 10.1016/j.biopha.2019.109142
76. Razzak MI, Imran M, Xu G. Big data analytics for preventive medicine. Neural Comput. Appl. 2020;32:4417–4451.
DOI: 10.1007/s00521-019-04095-y
77. Medical News Today. Can Food Be Medicine? Pros and Cons; 2022.
Available:https://www.medicalnewstoday.com/articles/can-food-be-medicine-pros-and-cons
78. World Health Organization. WHO Establishes the Global Centre for Traditional Medicine in India; 2022.
Available:https://www.who.int/news/item/25-03-2022-who-establishes-the-global-centre-for-traditional-medicine-in-india
79. Ishara J, Ayagirwe R, Karume K, Mushagalusa GN, Bugeme D, Niassy S, Udomkun P, Kinyuru J. Inventory reveals wide biodiversity of edible insects in the Eastern Democratic Republic of Congo. Sci. Rep. 2022;12:1576.
DOI: 10.1038/s41598-022-05607-y
80. Skotnicka M, Karwowska K, Kłobukowski F, Borkowska A, Pieszko M. Possibilities of the development of edible insect-based foods in Europe. Foods. 2021;10:766.
DOI: 10.3390/foods10040766
81. Hanboonsong Y, Jamjanya T, Durst PB. RAP Publication. Six-legged Livestock: Edible Insect Farming, Collection and Marketing in Thailand; 2013.
82. Mercês MD, Peralta ED, Uetanabaro APT, Lucchese AM. Atividade antimicrobiana de méis de cinco espécies de abelhas brasileiras sem ferrão. Ciência Rural. 2013;43:672–675.
DOI:10.1590/S0103-84782013005000016.
83. Yang X, Tian Y, Liu H, Ren Y, Yang Z, Li X, Du C, Liu C, Wu F. Heavy metal pollution analysis and health risk assessment of two medicinal insects of Mylabris. Biol. Trace Elem. Res. 2022; 200:1892–1901.
DOI: 10.1007/s12011-021-02775-2
84. Ssepuuya G, Wynants E, Verreth C, Crauwels S, Lievens B, Claes J, Nakimbugwe D, Van Campenhout L. Microbial characterisation of the edible grasshopper Ruspolia differens in raw condition after wild-harvesting in Uganda. Food Microbiol. 2019;77:106–117.
DOI: 10.1016/j.fm.2018.09.005.
85. Scott MJ, Concha C, Welch JB, Phillips PL, Skoda SR. Review of research advances in the screwworm eradication program over the past 25 years. Entomol. Exp. Appl. 2017;164:226–236.
DOI: 10.1111/eea.12607
86. Van Huis A, Dicke M, Van Loon JJ. Wageningen Academic Publisher. Insects to Feed the World; 2015.
87. Varelas V. Food wastes as a potential new source for edible insect mass production for food and feed: A review. Fermentation. 2019;5:81.
DOI: 10.3390/fermentation5030081
88. Varelas V, Langton M. Forest biomass waste as a potential innovative source for rearing edible insects for food and feed – a review. Innovat. Food Sci. Emerg. Technol. 2017;41:193–205.
DOI: 10.1016/j.ifset.2017.03.007

89. Kok R. Preliminary project design for insect production: Part 1 – overall mass and energy/heat balances. J. Insects as Food Feed. 2021;7:499–509. DOI: 10.3920/JIFF2020.0055.
90. Kok R. Preliminary project design for insect production: Part 2 – organism kinetics, system dynamics and the role of modelling and simulation. J. Insects as Food Feed. 2021;7:511–523. DOI: 10.3920/JIFF2020.0146
91. Kok R. Preliminary project design for insect production: Part 4 – facility considerations. J. Insects as Food Feed. 2021;7:541–551. DOI: 10.3920/JIFF2020.0164
92. Melgar-Lalanne G, Hernández-Álvarez A, Salinas-Castro A. Edible insects processing: Traditional and innovative technologies. Compr. Rev. Food Sci. Food Saf. 2019;18:1166–1191. DOI: 10.1111/1541-4337.12463
93. Gan J, Zhao M, He Z, Sun L, Li X, Feng Y. The effects of antioxidants and packaging methods on inhibiting lipid oxidation in deep fried crickets (Gryllus bimaculatus) during storage. Foods. 2022;11:326. DOI: 10.3390/foods11030326
94. Eilenberg J, Vlak JM, Nielsen-Le Roux C, Cappellozza S, Jensen AB. Diseases in insects produced for food and feed. J. Insects as Food Feed. 2015;1:87–102. DOI: 10.3920/JIFF2014.0022
95. IPIFF. IPIFF Guide on Good Hygiene Practices for European Union (EU) Producers of Insects as Food and Feed; 2022. Available:https://ipiff.org/good-hygiene-practices/
96. Wilderspin DE, Halloran A. Edible Insects Sustain. Food Syst. Springer International Publishing; Cham. The effects of regulation, legislation and policy on consumption of edible insects in the global south. 2018;443–455.
97. Lähteenmäki-Uutela A, Marimuthu S, Meijer N. Regulations on insects as food and feed: A global comparison. J. Insects as Food Feed. 2021;7: 849–856. DOI: 10.3920/JIFF2020.0066
98. Bindroo BB, Manthira Moorthy S. Genetic divergence, implication of diversity, and conservation of silkworm, Bombyx mori. Int. J. Biodivers. 2014;2014:1–15. DOI: 10.1155/2014/564850
99. Bhattacharyya P, Jha S, Mandal P, Ghosh A. Artificial diet based silkworm rearing system-A review. Int. J. Pure Appl. Biosci. 2016;4:114–122. DOI: 10.18782/2320-7051.2402
100. Smetana S, Spykman R, Heinz V. Environmental aspects of insect mass production. J. Insects as Food Feed. 2021; 7:553–571. DOI: 10.3920/JIFF2020.0116
101. Arévalo Arévalo HA, Menjura Rojas EM, Barragán Fonseca KB, Vásquez Mejía SM. Implementation of the HACCP system for production of Tenebrio molitor larvae meal. Food Control. 2022;138. DOI: 10.1016/j.foodcont.2022.109030
102. Triantafyllou A, Sarigiannidis P, Bibi S. Precision agriculture: A remote sensing monitoring system architecture. Information. 2019;10:348. DOI: 10.3390/info10110348
103. Lee JH, Kim TK, Jeong CH, Yong HI, Cha JY, Kim BK, Choi YS. Biological activity and processing technologies of edible insects: A review. Food Sci. Biotechnol. 2021;30:1003–1023. DOI: 10.1007/s10068-021-00942-8.
104. Castro-López C, Santiago-López L, Vallejo-Cordoba B, González-Córdova AF, Liceaga AM, García HS, Hernández-Mendoza A. An insight to fermented edible insects: a global perspective and prospective. Food Res. Int. 2020;137. DOI: 10.1016/j.foodres.2020.109750
105. Peiyun Xiao YY, Shi G, Li K, Yang M, Zhao Y. The Preparation of Blattaria Anti-hepatic Fibrosis Activity Extract and Detection Method; 2014.
106. Vieira SA, Zhang G, Decker EA. Biological implications of lipid oxidation products. J. Am. Oil Chem. Soc. 2017;94:339–351. DOI: 10.1007/s11746-017-2958-2
107. Kamau E, Mutungi C, Kinyuru J, Imathiu S, Tanga C, Affognon H, Ekesi S, Nakimbugwe D, Fiaboe KKM. Moisture adsorption properties and shelf-life estimation of dried and pulverised edible house cricket *Acheta domesticus (L*.) and black soldier fly larvae Hermetia illucens (L.) Food Res. Int. 2018;106:420–427. DOI: 10.1016/j.foodres.2018.01.012
108. Van Huis A, Tomberlin JK. Wageningen Academic Publisher. Insects as Food and Feed: from Production to Consumption; 2016.

109. Insect Doctor. Educating Insect Pathologists to Prevent Infectious Diseases in Mass-Reared Insects; 2020. Available:https://www.insectdoctors.eu/en/insectdoctors/about.htm

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/120309