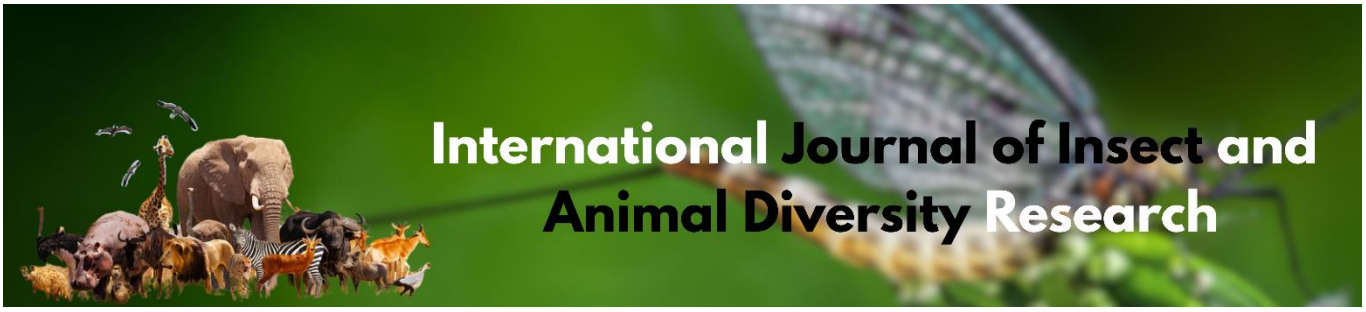

Biological Applications of Insects

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Abstract
Insects are one of the largest and most diverse groups of animals in phylum Arthropod, and are an important component of the earth's biodiversity, and represent several ecosystems on land and water. Increasing scientific interest in insects has emerged as an important position that they play in the delivery of ecosystem services essential to the sustainability of natural and agricultural systems. Insects play a significant role in both active pollination, decomposition of organic material, recycling of plant nutrients and organic materials, soil structure and soil fertility and biological pest control and control of other organisms in food webs. They also help in maintaining the diversity of microbes in the soil as well as increasing the effectiveness of biogeochemical processes. Insects are vital elements of an ecosystem and as a result of their high distribution and functional diversity have been used as an important indicator. Thus, ecological functions of insects and their interrelation with other ecosystem elements is a scientific basis on which the biodiversity preservation and viability of the natural resources can be secured in the conditions of the rapid environmental changes.

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Introduction

Insects are the most abundant and diverse group of animals, with it estimated that they make up about 70-80% of all the described animal species on earth and there are millions of other species yet to be described (Cardoso; Stork, 2020 *et al*.) [2]. The most important characteristics of insects are their great adaptability to all kinds of environments and the development of intricate ecological relationships with plants, microorganisms and other animals. They have an important structural and functional role in natural and agricultural ecosystems (Seibold *et al*. 2020). In the past few years, scientists and researchers have focused more on the examination of the ecosystem services of insects, particularly because of reports of their decline in some regions of the world. It can have broad environmental and economic implications (Wagner *et al*. 2021) [22], because it promotes the sustainability of ecosystems by providing support and regulation for pollination processes, decomposition of organic matter, nutrient recycling, regulation of pest populations and supporting and stabilizing food webs (Noriega *et al*. 2020) [14]. Although insects are known to provide a wide range of ecosystem and economic services, the extent and quality of these services are largely a subject for science research and development, especially in determining the value of insects and their long-term impacts on the sustainability of natural resources. For this reason, this introduction will attempt to constitute a modern conceptual framework that can explain the role of insects in given ecosystem services, such as helping plants to reproduce by pollination, increasing soil fertility by decomposing organic wastes, or natural biological control of agricultural pests.

The Role of Insects in the Ecosystem

Insects are the most numerous and varied life forms found on Earth, with more than a million described; there are probably millions of species yet to be discovered (Stork, 2020). Insects are a large portion of animal biodiversity. They grow in a wide

range of habitats, including tropical forests, urban agricultural systems, etc. This is part of the ecosystem services provided by insects, not just in natural environments, but also in anthropogenic landscapes and semi-natural habitats; insects play a pivotal role in this context in supporting agricultural production and resource sustainability (Mansour *et al*., 2024) [13].

First: Pollination Services and Support for Plant Production

The insects, particularly bees, butterflies, and beetles are important pollinators of wild plants as well as crops. It has been estimated that a large percentage of food crops are partially or completely reliant on biological pollination and that insects play an important role in food security. International food security (Raven & Wagner, 2021) [17, 22]. Pollinator diversity also helps to stabilize and improve agriculture, especially in mixed and semi-natural agriculture.

Second: Recycling elements and improving soil fertility

Saprophytic insects e.g. dung beetles and the larvae of certain flies are important in decomposition and breaking down of organic matter so as to enhance recycling of nutrients within the soil. The practice has a positive effect on the soil structure, aeration, microorganism's activity, which are good for the fertility and productivity of the soils (Noriega *et al*., 2020) [14]. These processes which maintain continuity of biogeochemical cycles also involve the support services.

Third: Biological control and regulation of biological communities

Predatory insects and parasites are an important part of the control of agricultural pests. This decreases the use of chemical pesticides and minimizes their effects on the environment This service is one of the most noticeable environmental regulation services.

This is helping to achieve food web balance and increase ecosystem stability (Cardoso *et al*., 2020) [2]. Loss of insect biodiversity has been demonstrated to cause ecological imbalances that can have adverse consequences for agricultural production and ecosystem health.

Fourth: Medical properties

The insect toxins are complex mixture of biologically active peptides, enzymes, biogenic amines and allergens. Melittin, apamin and phospholipase A2 (Wehbe *et al*., 2019) are some significant compounds of the Apis mellifera poison. They are molecules that have been shown to have anti-inflammatory and immunomodulatory effects. It has antimicrobial and antitumor properties (Park *et al*., 2020) [15]. Wasp venom, on the other hand, contains many short, highly potent peptides that have been found to affect microbial and cancer cell membranes, with more interest in studying the structure and function of peptides extracted from insect toxins for therapeutic application to tumors in recent years. The components of bee venom have been studied in one study, which found that melittin, a component of bee venom, might be able to selectively lyse cancer cell membranes and activate apoptosis pathways. Recently, some of the venom peptides from wasps were also found to exhibit cytotoxic activity against cancer cells through disruption of cell membrane integrity and influencing the intracellular signaling pathway, which further extended their potential therapeutic application as a supplement to conventional cancer therapies (Zhang *et al*., 2022) [25].

Fifth: Insects are a food source for animals

One of the most important constituents of poultry feed is protein. Traditional protein sources used in the animal production industry are fishmeal and soybeans. The price and intermittence of such resources have, however, encouraged researchers to seek more environmentally friendly alternatives.

One of the most significant is the insect larvae, which in many studies have proven to be very efficient both in terms of nutrition and productivity (Van Huis, 2020; Makkar *et al*., 2014) [20, 11]. Larvae are also used for animal protein in feed for poultry and are about 30% dry matter of the total mass. The moisture content and proteins content make up around 54% of dry matter and the relative variation is dependent on the species and rearing conditions (Makkar *et al*., 2014) [11].

It features a mix of amino acids, fats and digestible energy, making it a good protein source alternative. Can be eaten fresh, dried or ground depending on what dietary system is being used (Siriwong *et al*., 2009) [19]. Studies conducted in Nigeria and Cameroon revealed that the larval production may be a good source of animal protein for the local poultry farms particularly in low cost rural systems (Ekoue & Hadzi, 2000; 2002; and Teguia *et al*., 2000; 2002) [5].

Sixth: Insects in Industrial Applications

Insects are an important sustainable source of many high value economic and industrial compounds and raw materials, and their applications are growing rapidly as biotechnology and bioengineering innovations rapidly increase.

The most notable of these uses are biotextiles, in which natural silk harvested from the silkworm, Bombyx mori, is used in luxury textiles.

In addition to its advanced medical applications as a component for surgical sutures and tissue engineering scaffolds, owing to its mechanical properties such as strength and flexibility—and high biocompatibility (Kundu *et al*., 2023) [9].

Similarly, insect exoskeletons are a valuable source of natural polymers like chitin and chitosan, which are applied in interactive wound dressings, water treatment membranes and smart food packaging systems, due to their high biodegradability and non-toxicity (Hahn *et al*., 2024) [7]. Regarding environmental management, Black Soldier Fly (*Hermetia illucens*) larvae are an excellent biotechnological platform for bioconversion of organic waste and residues into concentrated proteins for feed production and organic fertilizers (frass), supporting the three pillars of the circular economy and minimizing the environmental pollution footprint (Barragán-Fonseca *et al*., 2022) [1]. The extraction of natural pigments, carmine, and resinous materials, like shellac, used in the food and precision industries as safer substitutes for synthetic materials, complement this ecosystem (FAO, 2023). The modern concept of insects as an important source for sustainable "Bio-industries" and a major factor in achieving the Sustainable Development Goals (SDGs), as renewable and environmentally friendly alternatives is encapsulated in these applications.

Seventh: Challenges and Future Prospects of Insects

The paradigm shift in biological applications of insect systems is being stimulated by the dynamics of the environment. On the other hand, the impacts of climate change on insects include a disruption of geographic range (Deutsch *et al*., 2023) [4], changes to community dynamics and life cycles, and phenological mismatches in their complex ecological interactions, all of which are likely to affect the efficiency of important ecosystem services, including pollination, biological control of pests, and nutrient cycling (Deutsch *et al*., 2023) [4]. At the same time, advanced genomic and metagenomics methods give a deep understanding of the genetic structure of species and their microbiomes, revealing intricate functional relationships in biological surface systems, which can be used as an accurate alternative to field-based techniques to predict and mitigate these impacts (Høye *et al*., 2021; Malacrinò, 2022) [8, 12]. Moreover, remote sensing and Unmanned Aerial Vehicles (UAVs) in combination with Geographic Information Systems (GIS) enable high resolution mapping of vegetation cover and habitats, and monitoring of insect dispersal pathways at large spatial scales (Wagner *et al*., 2021) [22]. The combination of molecular, digital and physical tools is the current approach to the sustainable management of biological systems and the conservation of biodiversity.

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