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Use of Endosymbionts in Pest Management

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Symbiosis involves close, often long-term associations between different biological species. Endosymbionts live inside host cells or bodies, forming endosymbiosis. In insects, these bacteria are primary (obligate) or secondary (facultative), aiding growth, development, survival, and protection from biotic/abiotic stresses—like defending against pathogens/parasites, influencing plant interactions, environmental adaptation, population dynamics, and pesticide detoxification. Endosymbionts manipulate host reproduction via male-killing, feminization, or cytoplasmic incompatibility. Novel pest control uses include endosymbionts as attractants, paratransgenesis ("Trojan horse"), boosting viral susceptibility, and curbing pesticide resistance—key for integrated pest management. Manipulating symbionts enhances pest control. Trans-infections into major agricultural pests, plus genetically modified endosymbionts, promise new strategies against pests and vector-borne diseases.

Introduction

Symbiosis from "Greek" Word which means together living. The term symbiosis was initially coined by 'Heinrich Anton de Bary' in 1879. A symbiont is an organism that is very closely associated with another, usually larger organism. This larger organism is called a host. These interacting species can affect either in a positive or negative way or sometimes not at all. There are six possible types of symbiotic relationships and are given below in the table.

Categories of endosymbionts

1) Ectosymbiont: An ectosymbiont is the one which lives outside of its host's cells.

Ex: the bacteria living on animal skin and in its digestive tract are ectosymbionts. These bacteria are very helpful in fighting off harmful microorganisms.

2) Endosymbiont: An endosymbiont is the one which lives inside of its host's cells.

Ex: Some plants have endosymbiotic bacteria living inside their root cells which helps the plant to grow in few aspects. Examples include diverse microbiomes .

- Rhizobium, a nitrogen-fixing bacterium living in root nodules of legume roots.
- Actinomycete nitrogen-fixing bacteria, Frankia sps, which lives in alder tree root nodules.
- Single-celled algae in side reef-building corals.
- Bacterial endosymbionts which provides essential nutrients to 10%-15% of insects.

Endosymbionts further divided into two types

1) Primary endosymbionts: They are essential for host growth, development and survival, they provide essential nutrients to its host. They were housed in a specialized structure are called bacteriocytes or mycetocytes. They were obligative in nature. They are transmitting from one generation to another i.e., vertical transmission.

2) Secondary endosymbionts: They are not necessary for its host growth and development but with their presence increases the fitness of the host. They are not enclosed in specialized

structures. They were facultative in nature. They are not transmitting from one generation to another but they may be transmitted through the trans-stadial i.e., horizontal transmission.

Importance of endosymbionts

1) Symbionts can be used for developing management strategies against insect pest populations as alternative to harmful chemical pesticides which leads to

- Environmental pollution.
- Risks to human health and hazards.
- Resistance, resurgence, secondary outbreaks.
- Death of beneficial insects (natural enemies), as well as, rapid loss of biodiversity.

2) Though symbiosis has received lesser attention in the recent past than any other interactions such as predation or competition, it is increasingly recognized at present as an important selective force behind evolution.

3) Focusing on exploiting or manipulation diverse roles played by the endosymbionts in their host species will provide a new vista and will be helpful for effective management of most of the agricultural and horticultural important crop pests and vector borne diseases.

Bacteria as Endosymbionts

INSECT PEST	Aphids	Grassy winged sharpshooter	Tephitid olive Fruit fly	Bark beetles	Drosophilla
ENDO SYMBIONTS	<i>Buchnera aphidicola</i>	<i>Suleria mulleri</i>	<i>Candidatus erwinia dacicola</i>	<i>Enterobacter spp</i>	<i>Spiroplasma</i>
FUNCTIONS	Provides the essential amino acid tryptophan, that is not present in their cell saps.	-Provides vitamins & cofactors of essential amino acids.	-provides essential amino acids to adult flies from nitrogen sources & increase reproductivity	-contributes to host nutrition by fixing atmospheric nitrogen	-protects against parasitoids & parasitic nematodes

While bacteria are the most commonly studied endosymbionts in insect pest systems, recent research highlights that a wide range of microbial taxa—including fungi, viruses, protozoa, and archaea—also play vital roles in influencing insect physiology, development, reproduction, and ecological interactions. For example, *Buchnera aphidicola* is a well-studied primary symbiont in aphids that supplies essential amino acids missing from their phloem-based diet (Gurung *et al.*, 2019). Similarly, *Baumannia cicadellinicola*, found in the glassy-winged sharpshooter, and *Candidatus Erwinia dacicola*, in the olive fruit fly, help their insect hosts by producing essential amino acids and vitamins. In bark beetles, certain *Enterobacter* species contribute to nitrogen fixation, which supports insect growth. In *Drosophila* flies, *Spiroplasma* bacteria provide a form of defense by protecting against parasitic nematodes and parasitoid wasps. Beyond these examples, many insect pests harbor a wide range of bacteria, including groups like *Gammaproteobacteria*, *Alphaproteobacteria*, *Betaproteobacteria*, *Actinobacteria*, *Firmicutes* (such as *Lactobacillus* and *Bacillus*), *Spirochetes*, *Clostridia*, and others. This highlights the remarkable microbial diversity present within insect hosts and the important roles these microbes play in insect biology.

e.g : *Buchnera aphidicola*, a symbiotic bacterium residing within the pea aphid (*Acyrtosiphon pisum*), produces vital amino acids that the aphid cannot obtain from its diet of plant sap.

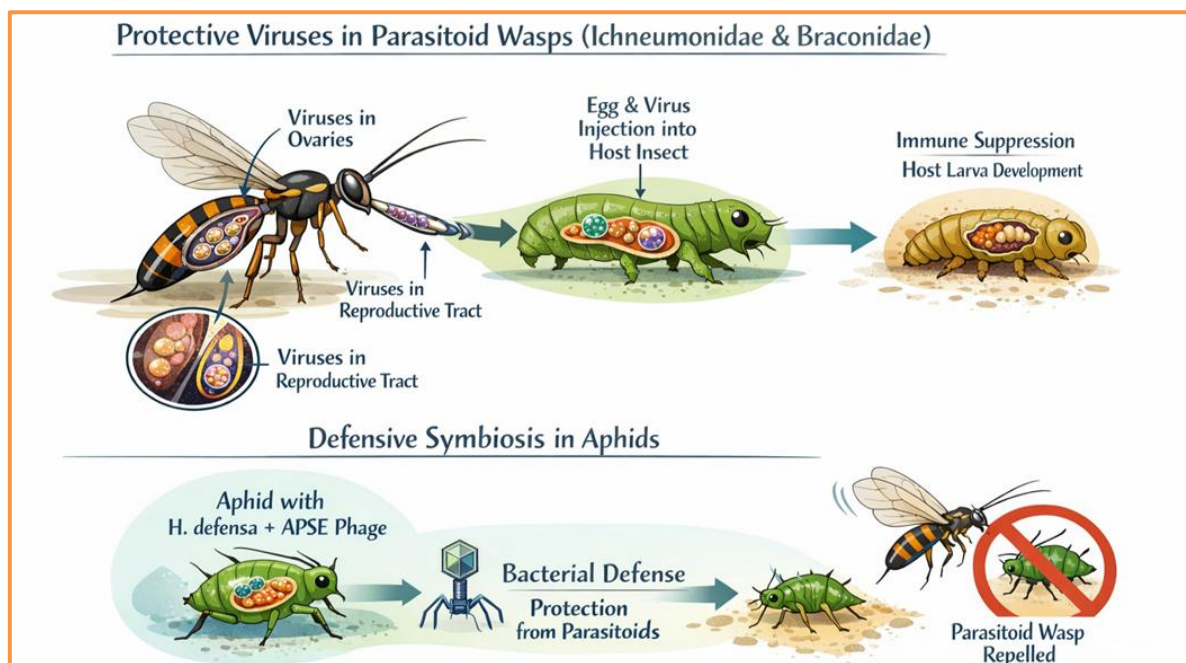
Fungi as endosymbionts

Fungal endosymbionts play a vital role in the biology of many insects. For example, bark beetles rely on *Ophiostoma* fungi to help overcome plant defenses, while various yeasts assist these beetles by aiding in the absorption of essential vitamins. In the brown planthopper (*Nilaparvata lugens*), yeast-like fungi help recycle nitrogen-rich waste like uric acid, making nutrient use more efficient. Similarly, in *Drosophila melanogaster*, yeast symbionts contribute to sterol metabolism, which is essential for maintaining cell membranes and supporting development. In several planthopper species—including *N. lugens*, *Laodelphax striatellus*, and *Sogatella furcifera*—these fungal partners are passed directly from the fat body of adult insects to their eggs, ensuring that each new generation inherits the symbionts. Vega and Dowd (2005) showed that reducing yeast populations through heat treatment leads to serious consequences for these insects. Symptoms such as slower growth, problems with molting, fewer viable eggs, disrupted protein production, and an overall drop in fitness clearly demonstrate how crucial these fungal symbionts are for insect health and survival.

INSECT PEST	Bark beetles	Brown Plant hopper	Many bark beetles	<i>Drosophila melanogaster</i>
ENDO SYMBIONTS	<i>ophiostoma spp</i>	yeast like symbionts	yeast	Yeast
FUNCTIONS	Helps in defeating the host defence (resin flow & Toxins)	- When nitrogen is limited , symbionts reuse the plant hopper's uric acid & convert into useful compounds.	- Vitamin assimilation	- Sterol

Virus as Endosymbionts

Viruses, especially those belonging to the Polydnviridae family, have developed unique symbiotic relationships with certain parasitoid wasps, including species in the Ichneumonidae and Braconidae families. These viruses are located primarily in the reproductive tissues of the wasps, particularly within the ovaries, and are introduced into host insects during egg-laying. Once inside the host, the viruses play a crucial role by weakening the host's immune defenses, which allows the wasp larvae to develop successfully. This intricate three-way relationship—between the parasitoid wasp, the virus, and the host insect—illustrates how viral endosymbionts can contribute indirectly to controlling pest populations (Drezen *et al.*, 2014). Aphids offer an intriguing example of virus-bacteria-insect symbiosis. The protective capacity of *Hamiltonella defensa* in aphids is enhanced by bacteriophages such as *Acyrtosiphon pisum* secondary endosymbiont (APSE) phages. These phages carry toxin genes that help the host defend against parasitoid wasps. Aphids infected with *H. defensa* harboring APSE exhibit higher resistance to parasitoid attacks compared to those lacking the phage, demonstrating a unique case where the endosymbiont's defensive function depends on viral elements (Ayoubi *et al.*, 2025).



Protozoan as Endosymbionts

Protozoan endosymbionts also play important roles, especially in wood-feeding insects like termites. These protozoa assist in digesting complex plant materials by producing hydrolytic enzymes, enabling termites to thrive on nutritionally poor substrates such as decaying wood. Additionally, archaea—especially methanogenic and nonmethanogenic members of the phylum *Euryarchaeota*—have been identified in the guts of beetles, cockroaches, termites, and millipedes (Protasov *et al.*, 2023). These archaea contribute to metabolic processes like hydrogen removal and methane production, which can influence gut microbial dynamics and host digestion. Together, these diverse endosymbionts—including bacteria, fungi, viruses, protozoa, and archaea form complex, often species-specific associations with insect pests, significantly influencing their survival, adaptability, and ecological fitness. Recognizing and understanding this microbial diversity is crucial for the development of novel and targeted pest management strategies that exploit the functional roles of non-bacterial symbionts in conjunction with bacterial ones.

Transmission of symbionts

- A. **Transovarial Transmission:** Vertical, or transovarial, transmission is the most widespread and evolutionarily stable way that insects pass endosymbionts to their offspring. In this process, the symbionts are inherited directly through the mother's ovaries, ensuring that each new generation carries them. This method is especially common among primary endosymbionts microbes that are vital for the insect's survival and development. Well-known examples include *Buchnera aphidicola* and *Serratia symbiotica* in aphids, along with *Wolbachia*, *Rickettsia* and *Spiroplasma*, which are found in a range of insect species (Romanov *et al.*, 2020) [. These symbionts are often localized within the reproductive tissues and are packaged into the developing oocytes during oogenesis, guaranteeing their stable inheritance.
- B. **Capsule Transmission:** Capsule transmission represents a more specialized form of symbiont transfer observed in certain Hemipteran insects such as stinkbugs. A well-documented case is that of *Megacopta punctatissima*, which produces small, brownish capsules during oviposition. These "symbiont capsules" contain high densities of the beneficial bacterium *Ishikawaella capsulate* (Fukatsu and Hosokawa, 2002) After hatching, the nymphs actively probe and ingest the contents of these capsules, thereby acquiring their essential gut symbionts. This mechanism ensures that symbionts are transmitted externally but remain closely associated with the egg mass, allowing for effective host-symbiont continuity.

c) Egg smearing: In *Acanthosomatidae* and some lepidopterans like cabbage butterfly lays eggs that are superficially contaminated with the symbiotic bacterium during oviposition, and the newborn nymphs acquire the symbiont by scratching egg surfaces as soon as they hatch. In addition to the midgut crypts, female acanthosomatids develop a pair of symbiotic organs, called “lubricating organs” in the abdominal tip are specialized for smearing the symbiont on egg surfaces.

d) Environmental acquisition: In contrast to vertical transmission methods, some insect hosts acquire their symbionts afresh from the environment with each generation, a process known as environmental acquisition or horizontal transmission. This strategy is prominent in insect families such as Alydidae and Coreidae. For example, the bean bug *Riptortus pedestris* acquires its beneficial *Burkholderia* symbionts from the surrounding soil during the early nymphal stages. The bacteria colonize specific gut regions, such as the midgut crypts, and contribute to host fitness by enhancing growth and resistance to environmental stressors (Takeshita et al., 2018). Environmental acquisition allows insects to select symbionts from a diverse microbial pool, potentially enhancing adaptability under varying ecological conditions.

e) Coprophagy: In some bugs, cockroaches and termites symbiont acquisition by symbiont-free individuals requires direct contact or ingestion of faeces after excretion.

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