The Scoop on Poop: Insects' Evolutionary Hacks for Hygiene

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Abstract

Insects have evolved various strategies to manage their feces, crucial for disease prevention and maintaining hygiene in their habitats. This article explores diverse behaviours, from honey bee cleansing flights to caterpillar frass ejection, demonstrating how fecal distancing reduces pathogen transmission. In social insects like ants, bees, and termites, collective behaviours such as grooming, waste removal, and coprophagy contribute to social immunity, minimizing disease spread within colonies. Some insects even leverage their feces for protection and nutrition, while others exhibit antimicrobial properties in their excrement, like termites inhibiting fungal spore growth. Additionally, insects such as beetles harness fecal microbiomes rich in actinobacteria to combat pathogens. These evolutionary adaptations highlight the complex relationship between insects and their waste, revealing feces as a tool for survival rather than a hazard. Studying these behaviours and fecal microbiomes offers promising insights for biotechnology and disease control strategies.

Introduction

Fecal Distancing and Disease Prevention

Insects, through evolutionary adaptations, have developed various strategies to manage and distance themselves from their feces, which can act as a reservoir for disease due to its high organic matter content. This is especially important for species that have high site fidelity or live in close quarters with others. For example, honey bees engage in “cleansing flights,” a behaviour where they leave the hive specifically to defecate, keeping their living space clean and minimizing the risk of disease spread. Similarly, some caterpillar species, which remain stationary in leaf shelters, employ a remarkable method called “ballistic frass ejection,” where they shoot fecal pellets far from their shelters to avoid accumulation of waste. This behaviour not only prevents the need for fecal removal but also significantly reduces the risk of disease transmission.

The importance of feces distancing is not solely about avoiding disease. For instance, predatory and parasitic wasps use chemicals emitted by feces to locate their hosts. In some beetles and lepidopteran species, females avoid laying eggs in areas tainted by fecal matter, as this helps their offspring avoid future competition. Such sophisticated behaviors demonstrate how insects have evolved to deal with the challenges posed by fecal material, turning it from a potential hazard into an evolutionary advantage.

Hygienic Behaviors and Social Immunity in Social Insects

As insects transitioned towards sociality, especially in eusocial species like ants, bees, and termites, living in large groups created increased exposure to pathogens due to the proximity of waste. In response, social insects developed a range of collective hygienic behaviors known as “social immunity.” These behaviors include grooming, waste removal, and even cannibalism of diseased individuals, which help reduce the spread of disease within the colony. Latrines are often designated for waste disposal, minimizing contact with fecal material.

A fascinating example of social immunity is seen in the *Myrmica rubra* worker ants. When they detect pathogenic fungal conidia on feces, these ants become more vigilant and remove waste more actively, particularly when vulnerable brood is present. This demonstrates how such hygienic behaviours are context-dependent, with the presence of young prompting more diligent feces removal. The evolution of these collective practices highlights how sociality demands more advanced hygiene solutions.

Staying Close to Feces: Shelters, Nutrition, and Protection

While many insects work to distance themselves from their feces, some species have evolved to stay in close proximity to it for various advantages. For instance, pyralid moth larvae and bark beetles use their frass (insect excrement) to build their shelters, providing them with a protective barrier. In ants, certain species create "kitchen middens" near their nests where waste is deposited. These middens, rather than being removed, are managed to limit microbial growth, potentially offering a nutritional or chemical benefit to the colony.

Ambrosia beetles, known for their unique farming of fungi, offer another intriguing example of how insects benefit from fecal proximity. These beetles cultivate fungi that thrive on decaying wood, and their feces are thought to recycle essential nutrients back into their environment. The more social the beetle species, the higher the concentration of these essential elements, suggesting that living in close quarters with fecal matter can offer nutritional advantages in some cases.

Some species even use their feces for protection. Leaf beetles, for example, construct "fecal shields" around their larvae. These shields not only provide physical protection from predators but are fortified with chemical compounds derived from plants that the beetles consume, such as alkaloids and saponins. These substances have antimicrobial properties, which may help protect against both predators and pathogens.

Antimicrobial Properties of Feces in Social Insects

One of the most fascinating aspects of insect fecal management is the antimicrobial properties found in their excrement. Termites are an excellent example: studies have shown that feces from the termite *Zootermopsis angusticollis* can inhibit the germination of spores from the fungal pathogen *Metarhizium anisopliae*. This suggests that termites use feces to maintain nest hygiene and protect themselves from potentially harmful microbes.

In addition to termites, earwigs and passalid beetles also exhibit antimicrobial properties in their feces. These findings suggest that many social insects may rely on their gut microbiomes to produce fecal material that helps protect the colony from infections. The microbial origin of these antifungal properties' points to a symbiotic relationship between the insect and its gut bacteria, which produce compounds that suppress harmful pathogens.

The Role of Coprophagy and Microbiome Sharing

In many social insects, behaviors like coprophagy (the consumption of feces) and trophallaxis (the exchange of gut fluids) play key roles in maintaining colony health. These behaviours enable insects to share beneficial microbiomes and metabolites among colony members, potentially aiding in disease prevention. In bumblebees, for instance, the consumption of feces from healthy individuals has been shown to reduce parasite loads. This suggests that coprophagy may serve not only a nutritional role but also a hygienic one, helping to inoculate colony members with beneficial microbes.

Coprophagy in social insects may have evolved as a way to "treat" feces by passing it through the gut again, neutralizing any harmful pathogens. In termites and locusts, the gut microbiome appears to play a significant role in preventing fungal spores from germinating, further supporting the idea that coprophagy helps regulate pathogens. The fecal microbiome's role in social immunity highlights a complex evolutionary strategy where waste is not merely discarded but recycled and used to protect the colony from disease.

Weaponized Poop: Actinobacteria and Disease Prevention

Some insects take feces management to a new level by actively using it as a weapon against disease. Wood-feeding insects like the beetle *Odontotaenius disjunctus* have developed fecal microbiomes rich in actinobacteria, which produce antimicrobial compounds. These actinobacteria are especially effective against fungal pathogens like *Metarhizium anisopliae*, which pose a significant threat to insects living in damp, decaying environments.

The microbiome in these beetles' guts, and subsequently in their feces, harbors strains of bacteria that produce a wide array of antimicrobial compounds. In the case of the longhorn beetle *Cerambyx welensii*, fecal actinobacteria have been shown to produce broad-spectrum antimicrobial compounds, providing the beetles with significant protection against pathogens. Similarly, termites in the genus *Reticulitermes* are known to cultivate actinobacteria in their feces-lined galleries, further suggesting that feces serve as a reservoir for protective microbes.

Future Directions

The study of fecal microbiomes in social insects is still in its early stages, but it holds considerable promise for expanding our understanding of insect biology and immunity. The antimicrobial properties of feces could offer insights into novel microbial strains that have potential applications in medicine and biotechnology. Future research should explore how diet and sociality influence the development of fecal microbiomes and their antimicrobial properties. Additionally, studying the ecological and evolutionary patterns of intestinal and fecal microbiomes across insect lineages may uncover new strategies that insects use to protect themselves from disease.

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