Fungi as Insect Symbiont

Introduction

- Symbiosis can be defined as the association between dissimilar organisms in which benefit may accrue to both at least for a period during the association
- Associations need not be static
- In a few cases, the symbiotic phase may continue to a parasitic or commensal phase
- The following are examples where symbiosis appears to continue for much of the life cycle of both organisms, and where the functional integration between partners is highly evolved

Scale Insects and Fungi: Mechanism

- Mutually beneficial interactions between insect and fungus can be viewed from the point of view of the partners or humans
- A case of the former involves Septobasidial fungi (Basidiomycota) and scale insects
- They form an association in which the insect relies on the fungus to provide protection from predators, parasites and pathogens
- The fungus gains nutrients and a means of dispersal, and appears to rely on the insect absolutely
- The fungus grows a tough cover over the colony of scale insects
- The fungus also penetrates insects through natural openings forming haustoria LINK in the haemocoele of individuals
- Insects continue to feed, providing a flow of nutrients to the fungus directly from the plant

- **The fungus releases a chemical attractant**
- **Once detected, the insect associates with the fungus forming a colony**
- **Some members of the colony become parasitized**
- **Once the fungus has access to nutrients it spreads over the colony**
- **The insect provides chemical signals that appear to modify the structure of the fungal covering**
- **The fungal shield consists of a series of tunnels, apparently developed in response to the insects**
- **In addition, the fungus is dispersed by scale insects carrying basidiospores from infested trees to uninfested trees**

- **The fungus forms the majority of the nutrient for larvae, but is relatively unimportant for the adult**
- **However, enzymes in the fungus may play a part in detoxifying or digesting the plant material obtained by the adult**
- **Establishment of new colonies requires transport of mycelium by the queen (vertical transmission) as the fungus is thought to lack sporulation, though occasional basidiocarps may be seen associated with abandoned ant colonies**

- **Interestingly, weeding and grooming are processes that require recognition of 'foreign" and useful symbionts**
- **The recognition molecules or cues are unknown**
- **It might be assumed that the cue is odorous as ants use olfactory cues for recognition**
- **Fungi can produce various odours, and each species might have specific cues**
- **However, any "foreign" organism able to mimic a useful symbiont would then be able to benefit from the cleansing and feeding provided to the fungus garden**
- **Production of odoriferous cues remains to be examined in most fungi**

Leaf Cutter Ants, Termites and Fungi

- Fungus-growing ants (Tribe Attini in the family Formicidae) obligately depend on the cultivation of a fungal mutualist for their nutrition
- The tribe Attini has been divided into higher and lower groups
- The higher Attine ants (the genera Atta and Acromyrmex) cultivate fungal gardens in their colony, using leaf material harvested from adjacent living plants
- The fungus found in colonies of higher Attine ants is of the tribe Leucocoprinae in the family Lepiotiaceae

- **The symbiosis has been well studied because of the damage ants can do to crops and forests**
- **Found in the tropics of the Americas, Attine ants harvest leaf material from many different plant species, shred the material and feed it to their fungus garden in the ant colony**
- **Each leaf fragment is inoculated with a fragment of fungus and then placed in the fungal garden**
- **The garden consists of chewed leaf surrounded by a dense mycelium**
- **The mycelium is characterised by formation of hyphae with swollen tips called staphylae**
- **The staphylae are harvested by worker ants, held in the gut and subsequently fed to larvae or digested by the adult**

- **The lower Attine ants have smaller colonies, commonly among leaf litter**
- **They feed their fungi on leaves, insects and other organic matter**
- **The fungi of the lower ants appear to be polyphyletic**
- **Interestingly, sequence analysis suggests that the more stable association between the higher group and Leucocoprinae is also the most ancient**

Termites and Fungi

- The fungus *Termitomyces* (Tricholomataceae, Basidiomycota) forms similar, specific symbioses with termites in the Macrotermitinae, enabling the establishment of huge colonies in tropical Africa and Asia
- In the "higher" termites, the fungus is carried by the queen (vertical transmission) of two species of termite to form new colonies
- In the lower termites, horizontal transmission is most likely
- Members of*Termitomyces* form basidiocarps and disperse spores horizontally
- Thus termites may initiate colonies after selecting fungi from the environment
- The fungus is maintained in a fungal comb within the colony

- **Premasticated plant material is added to the young comb, and termites feed from the older parts of the comb**
- **Establishment of symbiosis with fungi by these social insects have enabled the insects to establish large, long-lived and complex colonies**
- **With the symbiosis, the insects are able to occupy niches with abundant resources**
- **The fungi have gained access to the resources and environments where they are artificially maintained**

Endosymbionts of Arthropods

- Microbes in their gastro intestinal tract (GIT) of many organisms aid in digestion
- The microbes are referred to as endosymbionts to distinguish them from symbionts that lack a tight association
- Apart from the commensal fungi of the Trichomycetes, microbes including fungi are found in the GIT of a wide range of arthropods
- The microbes are held in various ways. Some are a component of the fluid moving through the GIT
- They may have some activity but this is difficult to determine

- **Others are held in specialised structures within the body indicating the coevolution of the association**
- **The structures include specialised fermentation chambers, and ducts of gastric glands**
- **Endosymbionts may also be held within cells of the epithelium of the gut, Malphigian tubules, or fat bodies**
- **As these different associations are found across a wide range of insect taxa, it might be argued that the association is of considerable benefit to both partners**

Ambrosia Beetles, Bark Beetles and the Sirex Wood Wasp

- A range of insects that are found in living trees utilize fungi they carry with them to partially digest the timber thus nourishing the larvae. The associations are symbiotic, in that the insect carries the fungus from tree to tree in specific pouches called mycangia, and the fungus digests the food for the insect.
- Wood rot fungi may be carried by tunneling insects
- Ambrosia Beetles (sub-family Platypodinae) and other related weevils have a highly developed association with a group of ascomycetous yeasts, including Ambrosiella, Ascoidea, Cephaloascus and Dipodascus

- **The adult insect carries fungi in mycangia, deep pockets in the outer cuticle of the body**
- **The eggs are deposited along with fungi into holes bored into the timber**
- **The fungus germinates and colonises the tunnels bored by the insect**
- **When hatched, larvae feed from the fungus**
- **This association is interesting because the fungi form ambrosia along the walls of the tunnel**
- **Ambrosia are thin walled cells that sprout as a continuous layer from underlying continuous hyphae within the timber**
- **A range of insects feed from the ambrosia, including the insects that inoculated the timber**

- **Bark beetles excavate tunnels through the inner bark. Adults and larvae feed on the phloem, and incidentally, any fungi that may be present**
- **The fungi may be carried with the insects from tree to tree**
- **Two pathogens are carried in this way**
- **Both *Ceratocystis* and *Ophiostoma* form long-necked perithecia that exude sticky spores above the bark**
- **These spores are collected accidentally and dispersed to other trees**

- **When the wood wasp *Sirex noctilio* arrived in Australia, it caused great concern**
- **The insect is known to cause shoot deformation in *Pinus radiata***
- **Females bore into shoots and deposits eggs and the fungus *Amylostereum areolatum***
- **The fungus causes a white rot of the timber, and the rot spreads rapidly**
- **The fungus digests cellulose and oxidises lignin**
- **Newly hatched larvae feed on the fungus, and also utilise fungal cellulases to digest components of timber**
- **As with Ambrosia weevils, spores of the fungus are carried by the adult female in mycangia, and they are deposited into timber during oviposition**

- **Ironically, a nematode Deladenus may also be carried with the partners. The nematode also feeds on the fungus**
- **After contacting a larval wasp, the nematode colonises the wasp, in some cases, reducing their fecundity or in extreme cases, sterilising females**
- **When females lay eggs, the fungus and nematode are transferred to the hole**
- **The cycle is thus complete.**

Conclusion

- **A few fungi have evolved close functional and structural associations with insects and other arthropods. The associations are closely integrated and mutually beneficial. In each case, the fungus appears to be gaining access to organic energy, and in a few systems, the animal ensures close association by dispersing with the symbiont attached.**