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Symbiotic Fungi

Principles and Practice

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Chapter 1
Symbiosis: The Art of Living

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1.1 Introduction

The term symbiosis (from the Greek: sym, "with"; and biosis, "living") commonly describes close and mostly long-term interactions between different biological species. The term was first used in 1879 by the German mycologist, Heinrich Anton de Bary, who defined it as "the living together of unlike organisms".

In symbiosis, at least one member of the pair benefits from the relationship. The other member may be injured, i.e., have the parasitism association, or be relatively unaffected, i.e., have the commensalism association. Another type of relationship is mutualism; in this type both the partners get benefit from the associationship (Fig. 1.1). In this current chapter, we will discuss the term symbiosis only in relationship to these mutually beneficial interactions.

Endosymbiosis is any symbiotic relationship in which the symbionts lives within the tissues of the host, either in the intracellular space or extracellularly. Examples are nitrogen-fixing bacteria (called rhizobia) which live in root nodules on legume roots, Actinomycete nitrogen-bacteria called *Frankia* which live in alder tree root nodules, single-celled algae inside reef-building corals, and bacterial endosymbionts that provide essential nutrients to about 10–15% of insects.

Ectosymbiosis, also referred to as exosymbiosis, is any symbiotic relationship in which the symbiont lives on the body surface of the host, including the inner surface of the digestive tract or the ducts of exocrine glands. Examples of this include ectoparasites such as lice, commensal ectosymbionts, such as the barnacles that attach themselves to the jaw of baleen whales, and mutualist ectosymbionts such as cleaner fish.

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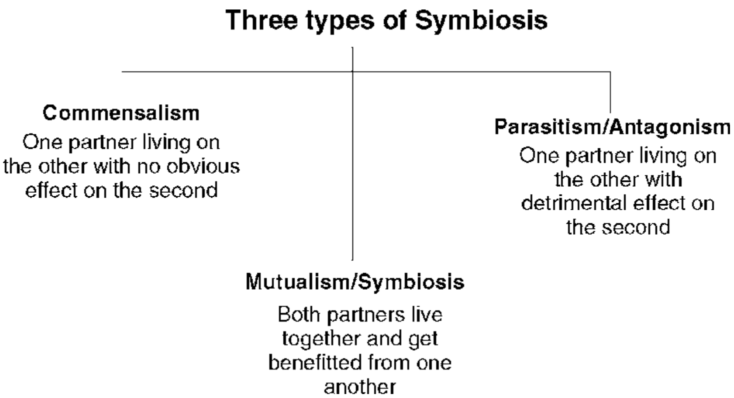

Fig. 1.1 Types of symbiosis

All the divisions of the plant kingdom, namely bryophytes, pteridophytes, gymnosperms, and angiosperms, form symbiotic relationships with bacteria, cyanobacteria, actinomycetes, and fungi.

1.2 History of Symbiosis

Plants are the very foundations of life on the earth. A large proportion of the microbial population are present in the region immediately around plant roots, the rhizosphere. The surface and immediate neighborhood of a root provides a specialized environment for microorganisms where the microbial population is enhanced because of the root exudates. Almost 90% of all vascular plant families enjoy symbiotic relationships with microorganisms. Most symbiotic relationships probably started out as facultative. Over many generations, the organisms came to depend more on the symbiosis because natural selection favored those traits and not others. Eventually, the symbiosis became the sole source of the food, shelter, enzyme, or whatever else the symbionts derived from one another (http://science howstuffworks.com/symbiosis.htm).

Symbiotic relationships in which both the species of the association benefits are mutualistic. Mutualistic relations between plants and fungi are very common. The fungus helps the host plant absorb inorganic nitrogen and phosphorus from the soil. Some mycorrhizal fungi also secrete antibiotics which may help protect their host from invasion by parasitic fungi and bacteria. One of the most important examples of mutualism in the overall economy of the biosphere is the symbiotic relationship between certain nitrogen-fixing bacteria and their legume hosts. About 80% of all land plants have a symbiotic relationship with fungi of the phylum Glomeromycota. The fungus penetrates cells in the plant's roots, and provides the plant with phosphates and other nutrients from the soil. This kind of symbiosis is called an arbuscular mycorrhiza. Fossil evidence (Remy et al. 1994) and DNA sequence analysis (Simon et al. 1993) have suggested that arbuscular mycorrhiza had appeared 400–460 million years ago, when the first plants were colonizing land. Remy et al. (1994) have reported the existence of arbuscules in the Early Devonian, which indicates that nutrient-transfer mutualism may have been in existence when plants invaded the land. The discovery of arbuscules in *Aglaophyton major*, an Early Devonian land plant, provides unequivocal evidence that mycorrhizae were established >400 million years ago. Nonseptate hyphae and arbuscules occur in a specialized meristematic region of the cortex that continually provided new cells for fungal infection. Arbuscules are morphologically identical to those of living arbuscular mycorrhizae, in consisting of a basal trunk and repeatedly branched bush-like tufts within the plant cell.

The arbuscular mycorrhiza play an important role in nature. Beneficial plant–microbe interactions in the rhizosphere are primary determinants of plant health and soil fertility. The carbohydrates produced by plants are translocated from their source location (usually leaves) to the root tissues and then to the fungal partners. In return, the plant gains the use of the mycelium's very large surface area to absorb water and mineral nutrients from the soil, thus improving the mineral absorption capabilities of the plant roots. Plant roots alone may be incapable of taking up phosphate ions that are immobilized, for example, in soils with basic pH. The mycelium of the mycorrhizal fungus can, however, access these phosphorus sources, and make them available to the plants they colonize. The mechanisms of increased absorption are both physical and chemical. Mycorrhizal mycelia are much smaller in diameter than the smallest root, and can explore a greater volume of soil, providing a larger surface area for absorption. Also, the cell membrane chemistry of fungi is different from that of plants. Mycorrhizae are especially beneficial for the plant partner in nutrient-poor soils. Arbuscular mycorrhizae are the most important microbial symbioses for the majority of plants and, under conditions of P-limitation, influence plant community development, nutrient uptake, water relations and above-ground productivity. They also act as bioprotectants against pathogens and toxic stresses. Other valuable effects of mycorrhiza in ecosystems are biological nitrogen fixation by *Rhizobium* in legume hosts, which can also be enhanced through co-infection with AMF (Xavier and Germida 2002).

A.B. Frank's observations and hypotheses about mycorrhizae in 1885 flew in the face of conventional thinking of the time. He reported that what we now term ectomycorrhizae were widespread on root systems of many woody plant species in a great diversity of habitats and soils. He hypothesized that mycorrhizae represent an all-encompassing mutualistic symbiosis in which fungus and host nutritionally rely on each other. He explained that the fungus extracts nutrients from both mineral soil and humus and translocates them to the tree host; and the host tree, in turn, nourishes the fungus. Today, with the help of modern scientific tools, it has been possible to achieve conclusive evidence to nearly Frank's entire hypothesis. Nonetheless, the revolution in thinking about plant and fungal evolution, ecology and physiology generated by Frank is still in the process of acceptance by much of

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