

Microbe Microbe Interaction: Types and Its Regulation

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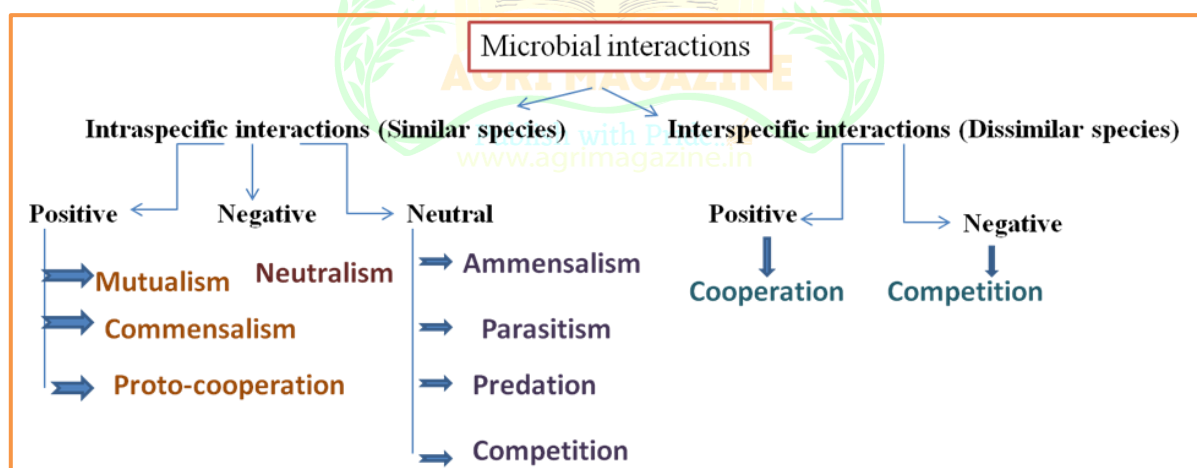
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Microbial interactions are central to ecosystem function, occurring within and across species, genera, and families. These interactions—ranging from mutualism and commensalism to parasitism and competition—are regulated through the exchange of signaling molecules, metabolites, and genetic elements. Gene expression in response to environmental cues drives the production of these exchangeable factors. In soil ecosystems, such interactions critically influence nutrient cycling, plant health, and microbial community structure. Understanding the types and regulation of microbe–microbe interactions is key to advancing applications in agriculture and environmental management

Introduction

Microorganisms such as bacteria, fungi, algae, protists, archaea, and viruses—vary in shape, size, and surface features. Rather than existing in isolation, they often form complex ecological interaction networks. These interactions can occur within the same species, between different species, or across genera and families, playing a vital role in ecosystem function and global biogeochemical cycles. Microbial interactions include mutualism, parasitism, amensalism, commensalism, competition, predation, and protocoperation. They are mediated by molecular and genetic exchanges, such as signaling molecules, secondary metabolites, siderophores, or genetic elements. The core of these interactions lies in gene expression triggered by biotic or abiotic stimuli.



Classes of Microbial Interactions

Mutualism: Mutualism is a relationship where both organisms benefit and are metabolically dependent on each other. It is often obligatory and highly specific, requiring close physical contact, with partners that cannot be substituted. This association enables organisms to thrive in environments they couldn't inhabit alone, effectively functioning as a single unit. Mutualistic microbes often share metabolic products. For example, many bacteria and fungi

produce siderophores—iron-chelating molecules—during such interactions. Since iron is typically scarce in its insoluble Fe(III) form, siderophores help make it bioavailable, supporting microbial growth by sequestering iron from the environment

A classic example of mutualism is seen in sourdough fermentation, where yeasts like *Saccharomyces exiguus* or *Candida humilis* interact with lactic acid bacteria (LAB), especially *Lactobacillus sanfranciscensis*. Yeast amylase breaks down starch, releasing maltose, which is metabolized by *L. sanfranciscensis*, producing glucose as a byproduct. This benefits maltose-negative yeasts, while yeast activity enhances LAB growth by increasing amino acids and peptides. Another example is the microbial consortia in freshwater lakes, such as “*Chlorochromatium aggregatum*”, involving nonmotile, phototrophic green sulfur bacteria and motile, nonphototrophic bacteria. The green sulfur bacteria provide organic matter via photosynthesis, while the motile partners offer mobility. These consortia can dominate microbial biomass in stratified lakes, exemplifying mutual dependence despite not being single organisms.

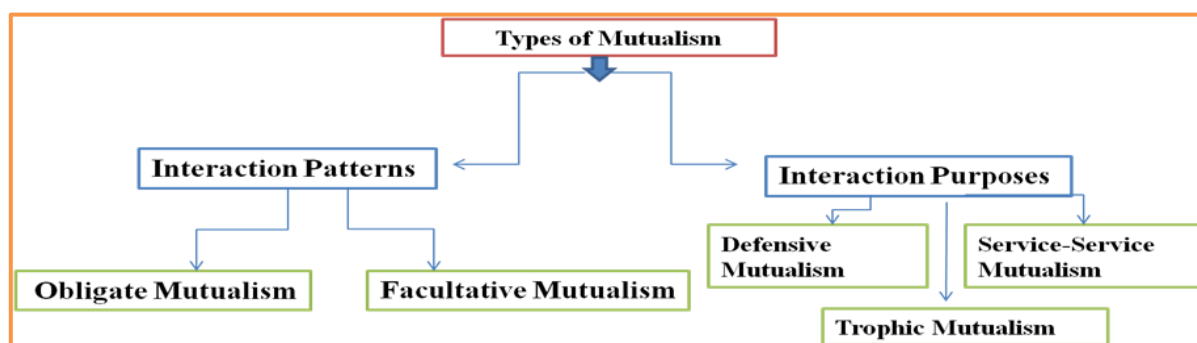


Fig. Showing type of mutualism

Protocooperation: Protocooperation is a non-obligatory, mutually beneficial interaction where both partners can survive independently but perform better together. Examples include: Syntrophy – Metabolic pathway completion by cooperative populations, Chemotactic attraction – Bacteria colonizing algal surfaces due to mutual chemical signaling, Toxic metabolite use – Some microbes utilize harmful by-products of others for growth, Enzyme synergy – *Arthrobacter* and *Streptomyces* degrade xenobiotics like diazinon together, Yoghurt fermentation – *S. thermophilus* and *L. bulgaricus* exchange metabolites (e.g., acids, peptides) that enhance each other's growth., Soil enrichment – *Thiobacillus* (CO₂-fixer) and *Beijerinckia* (N₂-fixer) support each other's nutritional needs, improving soil fertility and plant health.

Syntrophism

Syntrophism: Syntrophism is a mutualistic interaction where one organism's growth depends on or is enhanced by nutrients or substrates provided by a nearby organism. Also known as cross-feeding, it is prominent in anaerobic methanogenic environments like sludge digesters and flooded soils. Fermentative bacteria (e.g., *Syntrophobacter*) degrade fatty acids (e.g., propionic acid → acetate), producing H₂, methanogenic archaea (e.g., *Methanospirillum*) use H₂ and CO₂ to produce methane: $4\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$, rapid consumption of H₂ by methanogens maintains low H₂ levels, enabling continued fermentation by *Syntrophobacter*. This interspecies hydrogen transfer is essential, as it supports the energy metabolism and growth of both organisms, making syntrophism crucial for methane production and organic matter degradation in anaerobic ecosystems.

Commensalism: Commensalism is a unidirectional relationship where one organism (the commensal) benefits, while the other (the host) remains unaffected. The commensal may gain nutrients, shelter, or a favorable environment without harming or depending metabolically on the host. Examples include: *E. coli* in the human gut reduces O₂ levels, aiding obligate anaerobes like *Bacteroides*, without being affected itself, *Flavobacterium* excretes cystine, supporting *Legionella pneumophila* in aquatic environments, *Nitrobacter* benefits from

nitrites produced by *Nitrosomonas* during nitrification, soil fungi degrade complex molecules (e.g., cellulose, lignin), enabling other microbes to utilize the simpler by-products and facultative anaerobes consume oxygen, creating an anaerobic environment favorable for obligate anaerobes in soil.

Amensalism: Amensalism is a unidirectional interaction where one organism negatively affects another without being harmed itself. This often occurs through the production of inhibitory compounds, a process known as antibiosis. The antagonistic organism produces substances like antibiotics, toxins, organic acids, alcohols, HCN, sulfides, or lytic enzymes, which inhibit or kill other organisms. The affected organism suffers reduced growth or viability, while the producer gains competitive advantage.

Example includes - Food fermentation: Alcohols and carboxylates inhibit spoilage microbes, LAB bacteriocins: *Nisin* (from *Lactococcus lactis*) disrupts cell membranes and inhibits peptidoglycan synthesis, *Plantaricin* and *Pediocin* (from *L. plantarum* and *Pediococcus*) target related Gram-positive bacteria, *Lactococcin A* binds to Man-PTS receptors forming pores in target cells. Fungus-growing ants: Antagonistic *Escovopsis* fungi attack ant-cultivated fungi using toxins like shearinines and diketopiperazines, Defensive Actinobacteria (e.g., *Pseudonocardia*, *Streptomyces*) produce depsipeptides and polyene macrolides like *nystatin P1*, *candididin D*, and *selvamycin*. Soil microbes: *Myxobacteria* and *Streptomyces* secrete lytic enzymes (e.g., glucanase, chitinase, protease) that degrade pathogens by destroying their cell walls or spores.

Predation: Predation is a biological interaction where a predator attacks, engulfs, and consumes a prey organism, typically resulting in the prey's death. The prey can be larger or smaller than the predator. Predation enhances nutrient cycling by mineralizing organic matter before it reaches higher consumers. Returns nutrients to primary producers, boosting soil fertility. Helps control pathogenic populations, particularly plant pathogens, maintaining ecosystem balance.

Examples of Predatory Bacteria: *Bdellovibrio*: Penetrates the prey's periplasmic space, multiplies, and lyses the host to release progeny. *Vampirococcus*: Attaches externally, secretes enzymes to consume cell contents, and replicates until the prey is exhausted. *Daptobacter*: Enters the host and feeds on cytoplasmic contents.

Parasitism: Parasitism is a complex microbial interaction where one organism benefits at the expense of another, usually harming the host. It involves nutrient acquisition and/or physical association, often allowing for coexistence. However, stable parasitism may shift toward pathogenicity, resembling predation.

Some viruses, like bacteriophages, can exist lysogenically within host bacteria, sometimes enhancing host traits—for example, toxin production in *Corynebacterium diphtheriae*. Parasitic fungi like *Rhizophyidium sphaerocarpum* (with *Spyrogyra*) and *Rhizoctonia solani* (on *Mucor* and *Pythium*) play key roles in biocontrol. Parasitism can be beneficial (if targeting plant pathogens) or harmful (if targeting beneficial microbes) to plant health.

Types of Microbe-Microbe Parasitism

1. **Mycoparasitism (Fungus-Fungus Interaction):** *Hyperparasite* infects the *hypoparasite*. *Necrotrophic*: Kills host (e.g., *Trichoderma* via chitinase, antibiotics). *Biotrophic*: Parasite thrives on living host tissue.
2. **Mycophagy (Fungivory):** Bacteria (e.g., *Aeromonas caviae*) and amoebae consume fungi (e.g., *Rhizoctonia solani*, *Fusarium oxysporum*). Antagonistic amoebae include *Arachnula*, *Vampyrella*, etc.
3. **Bacterivores:** Microscopic, heterotrophic organisms (e.g., amoebae, *Vorticella*) feeding on bacteria.
4. **Bacteriophages (Phages):** Viruses that infect bacteria and archaea. Types: dsDNA (e.g., T4, lambda), ssDNA (e.g., M13, Φ X174).

Competition

Competition occurs among different soil microbial populations that depend on the same limited resources such as nutrients, oxygen, water, light, and space. According to Gause's competitive exclusion principle (1934), when two organisms overlap too much in resource use, one is eventually excluded. Microbes with better adaptation or faster growth dominate competitors relying on the same scarce nutrients. For example, *Fusarium*, *Aphanomyces*, and *Verticillium dahliae* spores require external nutrients to germinate. Other soil microbes may deplete these nutrients, delaying germination and reducing pathogen populations. During organic matter decomposition, microbial demand for oxygen and nutrients increases. Weak saprophytes often fail to compete with stronger ones, limiting their survival.

Regulation of Microbial Interactions

1. Physical Regulation: Temperature: Affects microbial enzyme activity (e.g., soy sauce fermentation).

Oxygen: Essential for aerobic growth (e.g., *Gluconacetobacter xylinum* stops cellulose production without O₂).

pH: Determines microbial survival and niche adaptation.

Nutrients: Type and quantity vary by species; vital for metabolic activities.

2. Molecular Regulation: Secondary Metabolites: Non-essential compounds aid in defense, competition, signaling, and interaction (e.g., polyketides, trichothecenes).

3. Cell–Cell Adhesion: Mediated by adhesion molecules (e.g., integrins, selectins), facilitating microbial attachment and communication.

4. Quorum Sensing (QS): Cell-density dependent signaling via autoinducers (AIs) regulates gene expression linked to virulence, biofilm formation, and adaptation.

5. Biofilm Formation: Microbes attach to surfaces, secrete EPS matrix, form structured communities enabling cooperation, signaling, and genetic exchange.

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