Synergism

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1. General aspects

Synergism is when two or more agents or structures (for example, you and your friend) work together in order to accomplish a goal quicker than you would on your own.

It is different from mutualism because it is not an obligatory interaction. This is because each member can produce its own food individually. It is a loose relationship because, one member can be replaced by another microorganism. It allows microbial population to perform such function which it may not be produced individually.

For example, reproducible mixed-species biofilm comprising *Pseudomonas aeruginosa*, *Pseudomonas protegens* and *Klebsiella pneumonia* was more resistant to the antimicrobials sodium dodecyl sulfate and tobramycin than the single-species biofilms.

2. Ecological aspects: diversity

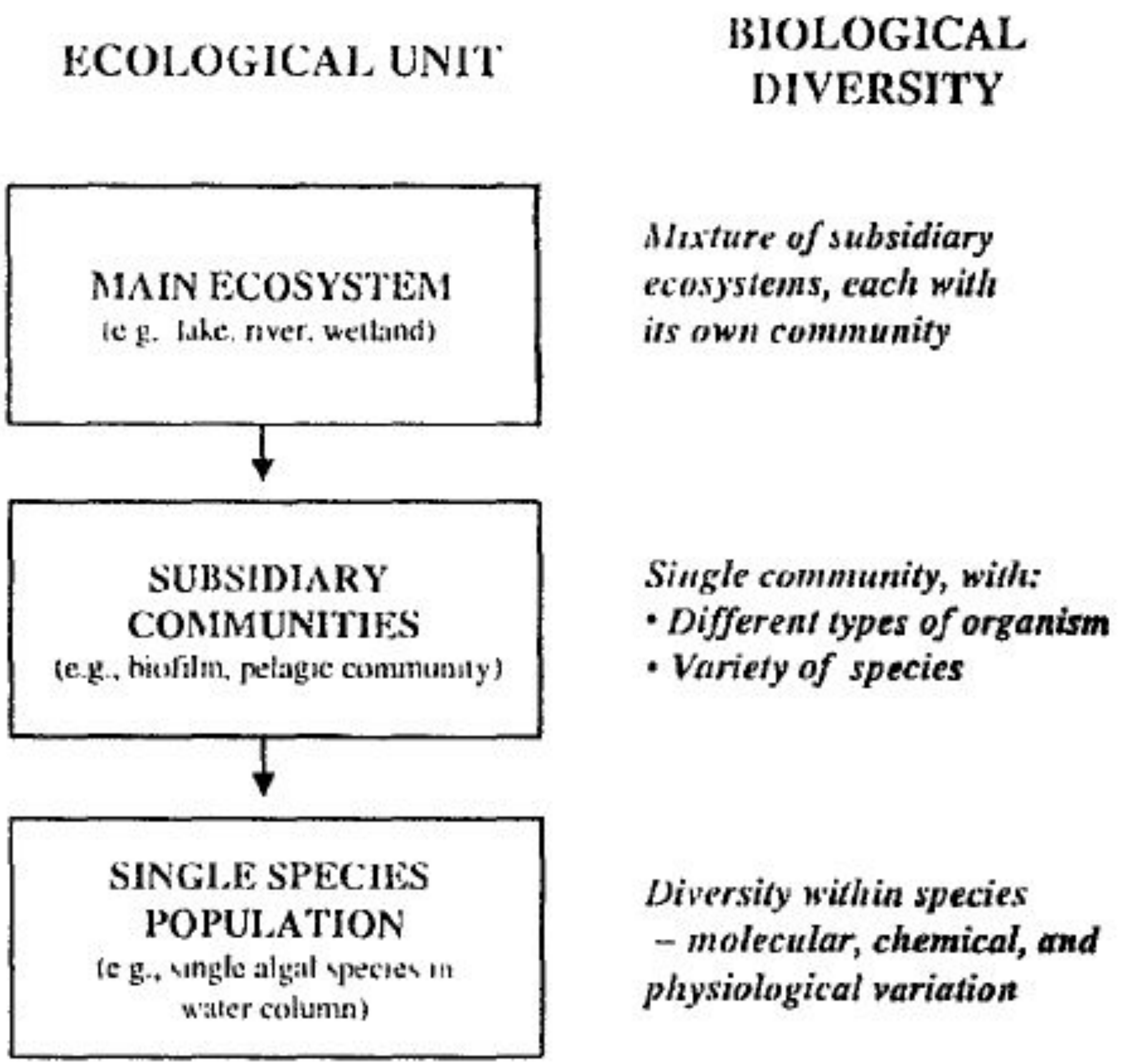


Figure 5.1 Diversity within species, communities, and groups of communities at different levels of organization in freshwater systems.

2. Ecological aspects: diversity

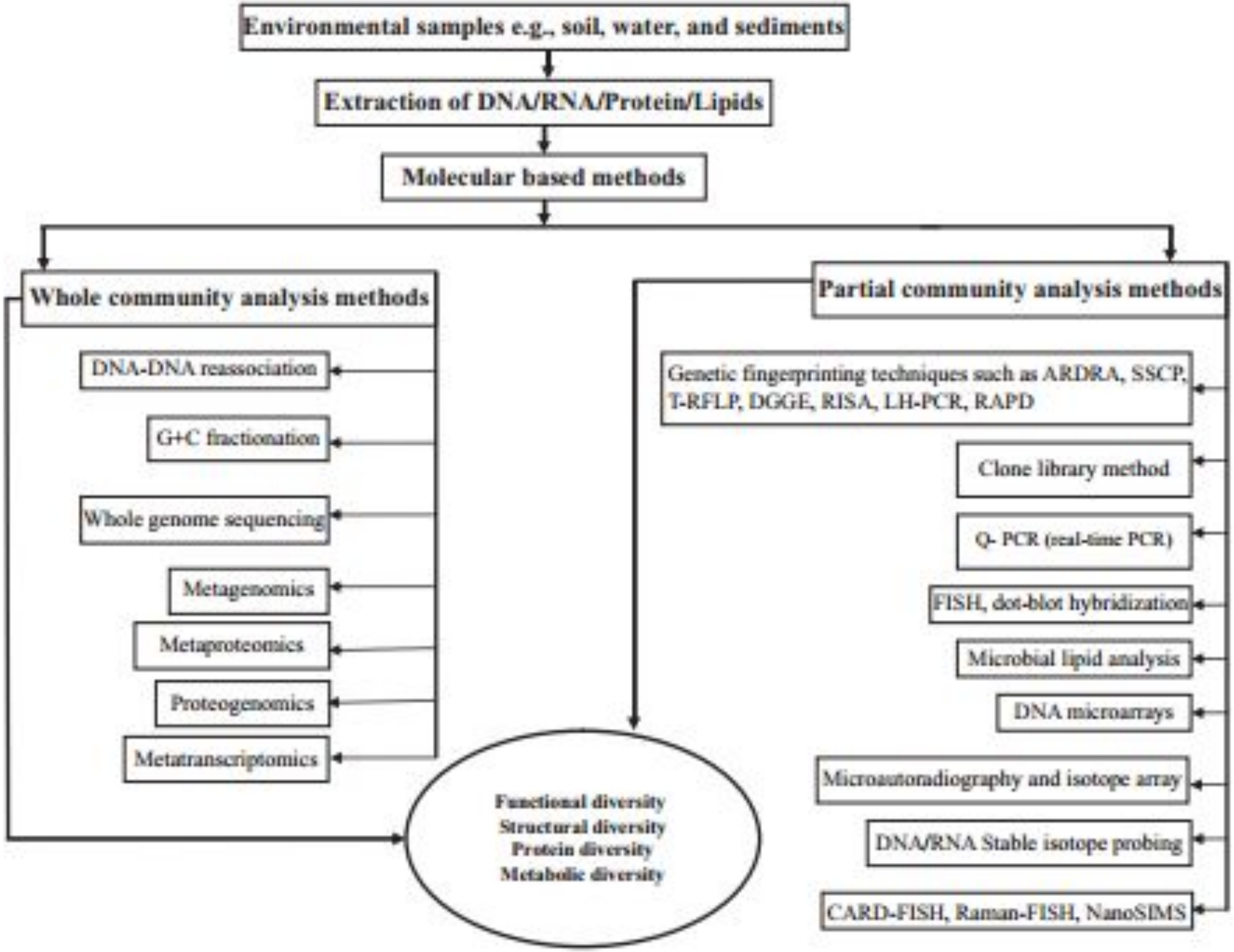
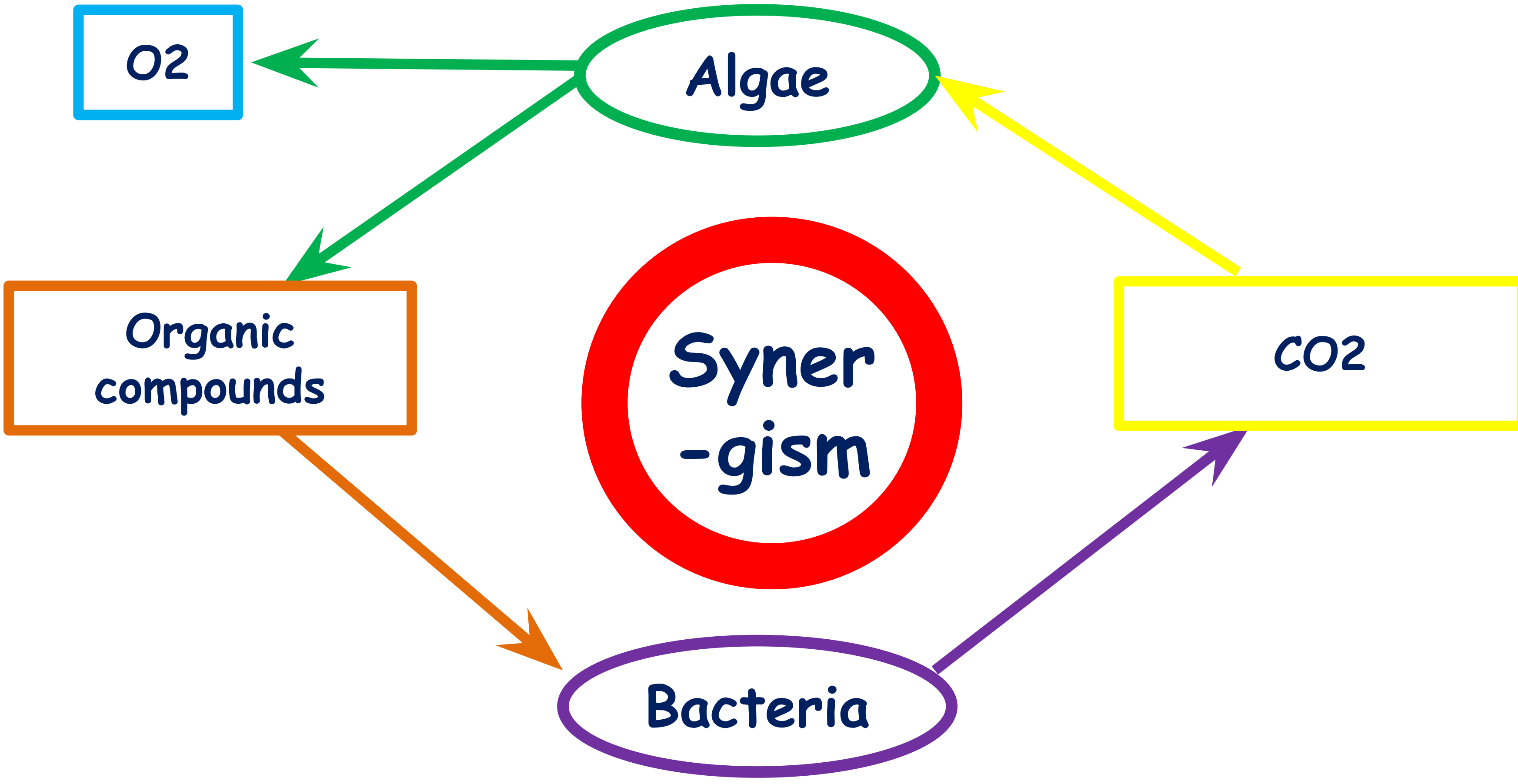


Fig. 2.1 Culture-independent molecular toolbox to characterize the structural and functional diversity of microorganisms in the environment

2. Ecological aspects: Examples



2. Ecological aspects: community structure

Coagregation

In addition, coaggregation confers cross-species protection of anaerobic species from oxygen and of susceptible species from antimicrobials

E.coli 0157:H7 ->
Pseudomonas aeruginosa
(persist in capillary flow cell which requires the colonizing partner P.aeruginosa)

2. Ecological aspects: community structure

Cross species protection

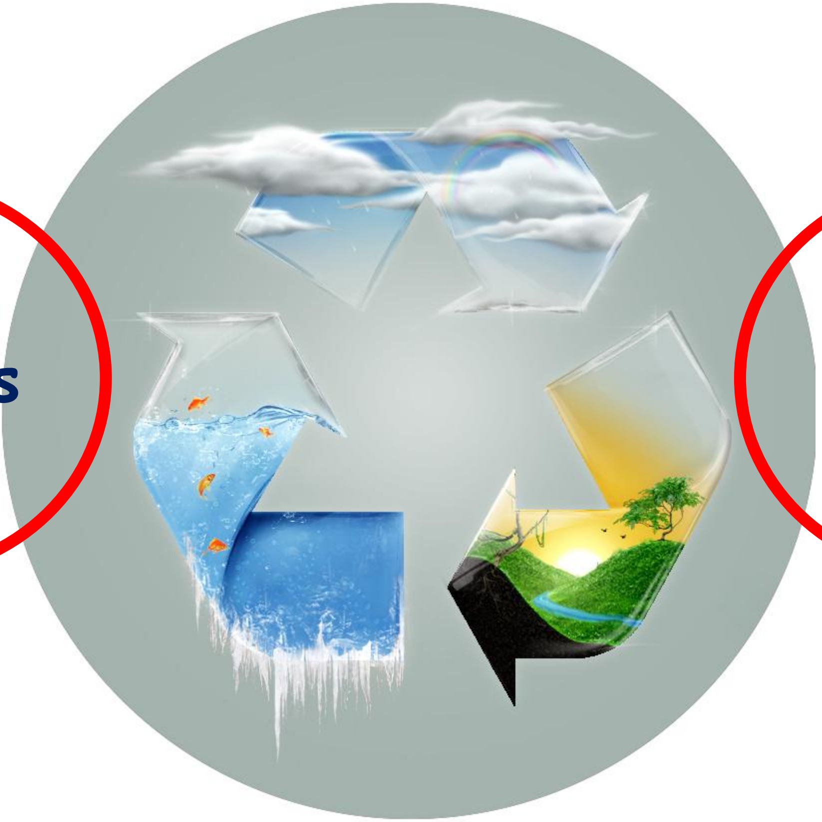
Staphylococcus epidermidis RP62A could inhibit fluconazole penetration and conversely, the presence of Candida albicans in this biofilm appeared to protect the slime-negative Staphylococcus against vancomycin

2. Ecological aspects: community structure

Co-metabolism

One of them is the metabolic interaction through arginine between two oral bacteria *Actinomyces naeslundii* and *Streptococcus gordonii*, where *S. gordonii* genes involved in arginine biosynthesis and transport were induced when coaggregated with *A. naeslundii,* otherwise *S. gordonii* could not grow without sufficient arginine

2. Ecological aspects: environmental conditions



Barriers

Coopera
tion
factor

2. Ecological aspects: abiotic impact

Habitat: soil-> abiotic factor- water desiccation

Chang et al. provided the direct evidence that alginate production by *Pseudomonas putida* contributed to a hydrated microenvironment which protected residents from water-limiting stresses . Moreover, biofilm has a great capacity for heavy metal biosorption and toxic compound degradation which has a significant impact on bioremediation. Additionally, the widespread exposure to antibiotics makes biofilm formation more favorable in soil.

Walker et al. suggested that upon root colonization, *Pseudomonas aeruginosa* gained resistance against root-secreted antibiotics by forming a biofilm.

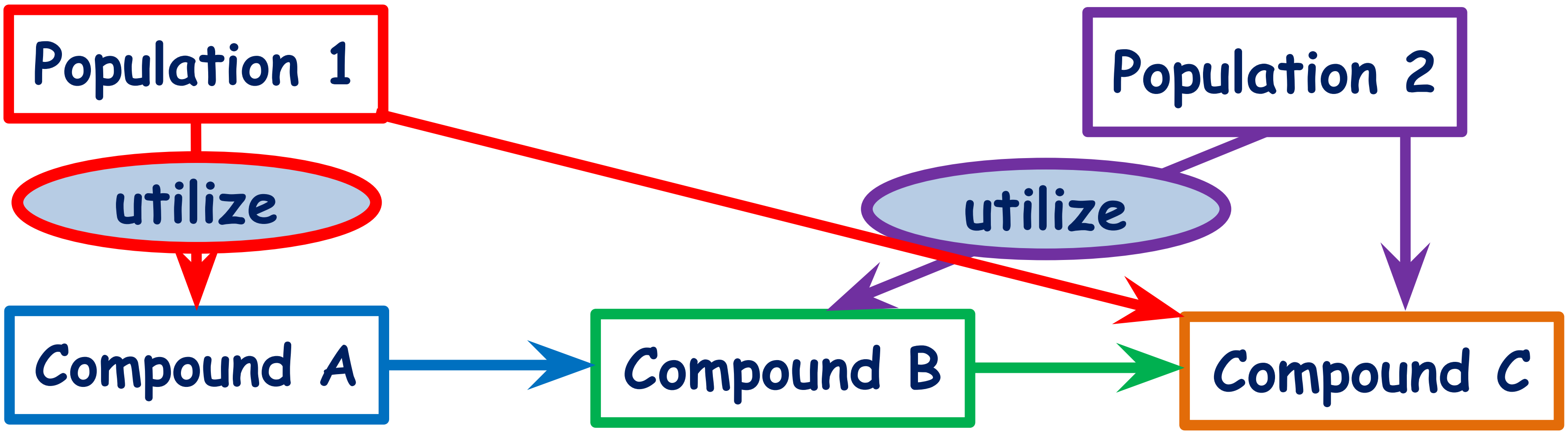
2. Ecological aspects: evolutionary strategies

Microbes have developed strategies which enable them to survive:

- Survival and growth by structural adaptation. eg alkaline soda lakes, saline lakes, hot springs, desert soils.
- Nutrient adaptation in case of r strategists & k strategists

r-strategists	k-strategists
High reproduction rate allows survival	Low reproduction rates
High nutrients enables rapid growth to outcompete other cells	Low nutrients available ie nutrient limiting conditions.
Crowded conditions exist	Less crowded
Subject to extreme population fluctuations when nutrients are depleted	More permenant and stable members of the community
Ex: Cyanobacterial blooms due to PO_4, *Pseudomonas* responds to increased carbon source	Ex: Spirilla and vibrios in marine environments, prostecate bacteria in oligotrophic lakes

3. Metabolic aspects: mechanism of metabolic interaction



For example the relationship between Enterococcus faecalis and Lactobacillus arabinosus. E. faecalis requires folic acid for growth whereas L. arabinosus requires phenyl-alanine for good growth. When grown in medium that does not have any of the required nutrient E. faecalis supplies phenyl-alanine while L. arabinosus supplies folic acid required. Hence they have cooperated to produce their required nutrients which encourage their rapid growth rate.

3. Metabolic aspects

LIGNOCELLULOSE AS CARBON SOURCE PROMOTES BACTERIAL SYNERGISM AND REDUCES ANTAGONISM

by Yijie Deng

May 2016

3. Metabolic aspects

1. Bacterial synergism occurred frequently in lignocellulose medium but never in glucose medium, suggesting that bacterial synergistic growth was dependent on the structural complexity of the carbon source.

2. When glucose is the only carbon source and in a limited amount, bacteria compete for the labile substrate resulting in the predominance of antagonistic interactions.

4. Physiological aspects: regulation of growth

These improved biofilm-associated fitnesses mentioned above suggest that the preferred mode of bacterial growth is in a biofilm. By being encased in the recalcitrant matrix, the bacteria grow in a relatively stable environment called microbial homeostasis, reflected not by the characteristics of resident individuals but by the balance imposed by the numerous microbial interactions, including examples of quorum sensing (QS) and horizontal gene transfer (HGT). By means of quorum sensing, the sessile cells in the biofilms can "talk" to each other. Due to the increased population density and constrained diffusion, the quorum sensing molecules are concentrated. Once reaching a threshold level, these quorum sensing molecules modulate the transcription of certain genes and trigger phenotypic changes, including swarming motility, biofilm formation and the production of virulence factors.

4. Physiological aspects

In gram-negative bacteria, acylated homoserine lactones (AHLs) are the most intensively investigated signal molecules and have been well described in *Pseudomonas aeruginosa*. There is also report that two different chemical languages: N-acyl homoserine lactones (AHLs) and cis-2-unsaturated fatty acids were utilized to control biofilm formation and virulence in *Burkholderia cepacia* complex.

The signaling communication in multispecies biofilms are mainly mediated by autoinducer 2 (AI-2), which is synthesized by the enzyme LuxS and found in both gram-negative and –positive bacteria. AI-2 has been shown to promote the biofilm formation of two oral bacteria *Actinomyces naeslundii* T14V and *Streptococcus oralis* 34. Whereas, AI-2 of *Fusobacterium nucleatum* was reported to differentially regulate biofilm growth of two oral streptococci by producing a stimulatory effect on *Streptococcus gordonii* and an inhibitory effect on *S. oralis*.

4. Physiological aspects

Another quorum sensing signal-diffusible signal factor (DSF), identified in *Burkholderia cenocepacia* and *Pseudomonas aeruginosa*, was reported recently to be involved in interspecies communications by altering biofilm formation, architecture and resistance to antibiotic.

4. Genetic aspects

Forsberg et al. with the finding that multidrug-resistant soil bacteria, containing resistance cassettes against five classes of antibiotics, have perfect nucleotide identity to genes from diverse human pathogens. Therefore, the enhanced efficiency of gene transfer in biofilms has a profound impact on the pathogenesis, persistence and hence the treatment of human disease.

4. Genetic aspects: mechanism for gene transfer

For example, lateral gene transfer of AHL synthase gene could facilitate cross talk between *Burkholderia spp*. and *Pseudomonas spp*., whereas lateral gene transfer of ring-hydroxylating-dioxygenase (RHD) gene may improve aromatics'degradation by spreading the gene among different species

Burmølle et al. reported a conjugative plasmid pOLA52, which confers resistance to olaquindox and other antimicrobial agents through a multidrug efflux pump, can also promote biofilm formation in Escherichia coli. Also, there is example that transfer efficiency of plasmids in *Pseudomonas putida* biofilm depended on the type of antibiotics, suggesting biofilm bacteria may "sense" antibiotics to which they are resistant and enhance the spread of that resistance. Overall, efficient gene transfer is both the cause and consequence of biofilm development.

4. Practical aspects: practical meaning

Despite of the notorious resistance to various common antibiotics and host defenses, soil biofilms can also be exploited for their diverse application in agriculture. The biofilmed inocula can be used as biofertilisers (BFBF) to promote and stimulate plant growth as well as aid in disease control. Furthermore, in the biofilm formed by bacteria and fungi, another natural inhabitant in soil, there is often generated synergistic interactions with possible consequences of a significant increase in nutrient acquisition and uptake of phosphorus, nitrogen and metal ion.

4. Practical aspects: practical meaning

The fungal-bacterial biofilms (*Penicillium frequentans* and *Bacillus mycoides*) resulted in a 14-fold increase in the biodegradability of degradable polyethylene by *P. frequentans*. A bradyrhizobial-fungal biofilm showed nitrogenase activity, whereas the bradyrhizobial strain alone DID NOT, which improved the shoot and root growth, nodulation and nitrogen accumulation of soybean and directly contributed to soil nitrogen fertility in the long term.

Additionally, anaerobic degradation of complex organic matter into methane and carbon dioxide requires the progressive action of numerous species of microorganisms. Biofilms can provide such an ideal environment for the interaction of these metabolically cooperative organisms, owing to their highly organized structure enhancing the nutrient availability as well as removal of potentially toxic metabolites.

4. Practical aspects: practical meaning

Pseudomonas aeruginosa PAO1 and *Burkholderia sp.* NK8 showed enhanced biofilm formation in a dual-species biofilm, directly benefitting bioremediation potential, as chlorobenzoates were more efficiently degraded and similar biofilm synergies were observed in drinking water systems.

CONCLUSION

Wheeler states in an article on "Social Life Among the Insects" that "Living- beings not only struggle and compete with one another for food, mates and safety, but they also work together to insure to one another these same indispensable conditions for development and survival."

THANKS FOR ATTENTION!