Plant Biostimulants for Use in Agriculture

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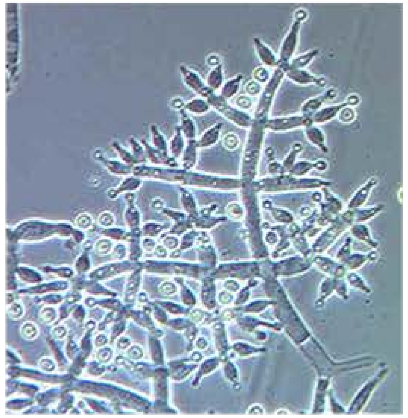
UF | IFAS Extension
UNIVERSITY of FLORIDA

What are plant biostimulants?

Mycorrhizae

Beneficial bacteria



Trichoderma

Seaweed extracts

Protein hydrolysates

Chitosan

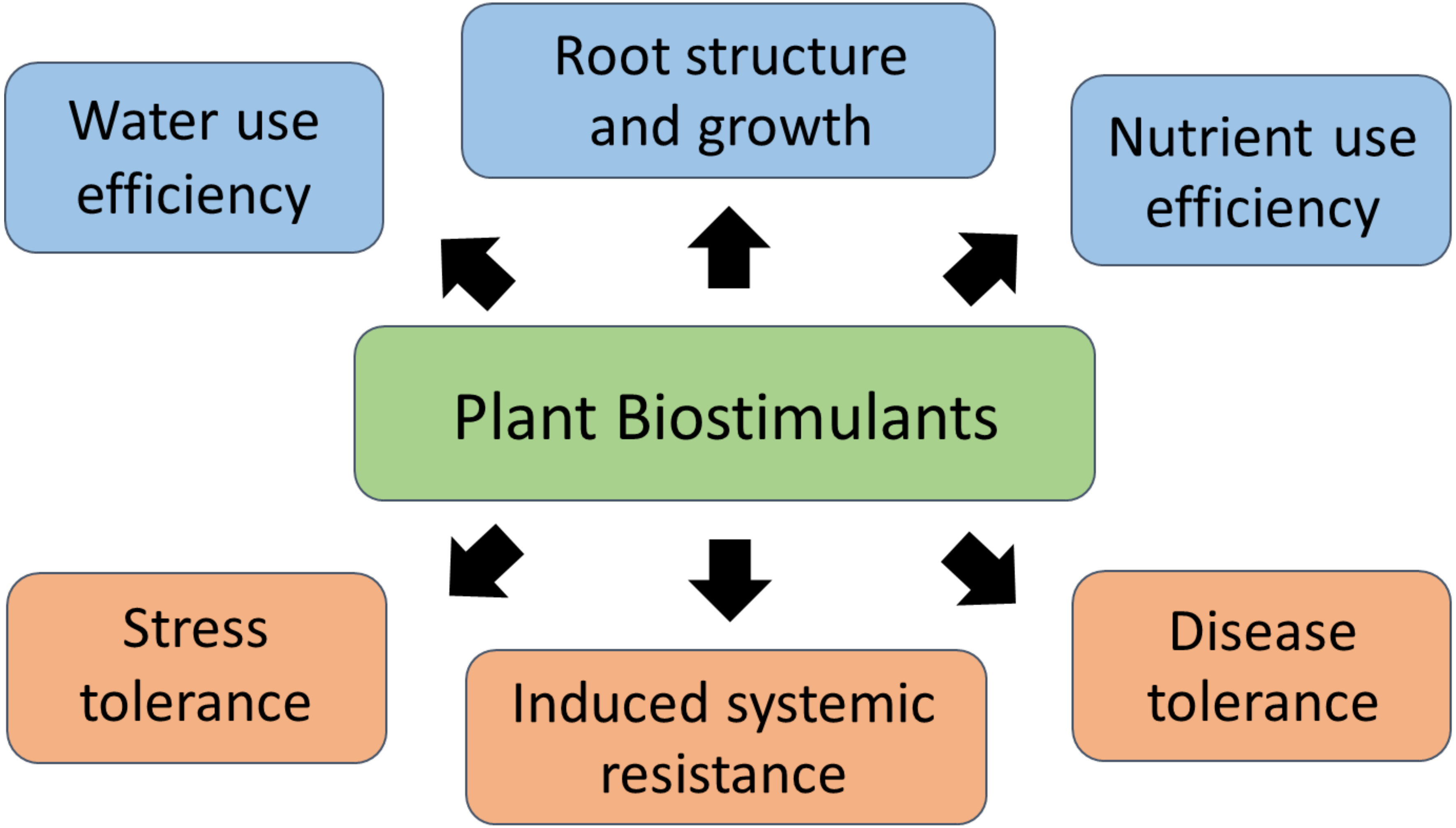
Humic acids

Silicon

Snake oils or beneficial products?

Many scientific publications report beneficial effects of biostimulants on a wide range of different crops

Plant biostimulant effects



https://edis.ifas.ufl.edu/publication/HS1330

Definition

"A substance or micro-organism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield."

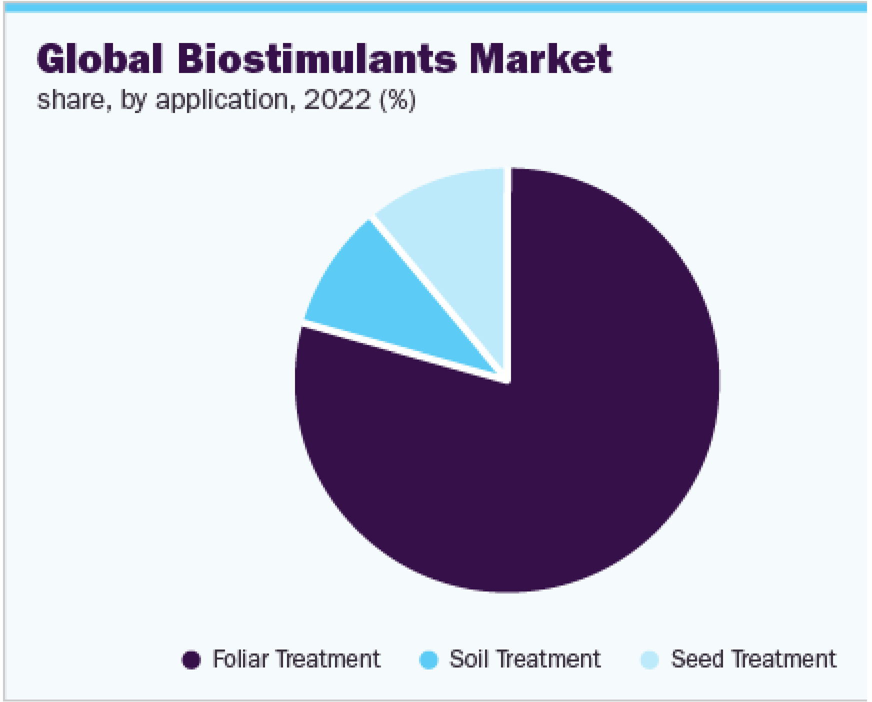
2018 Farm Bill

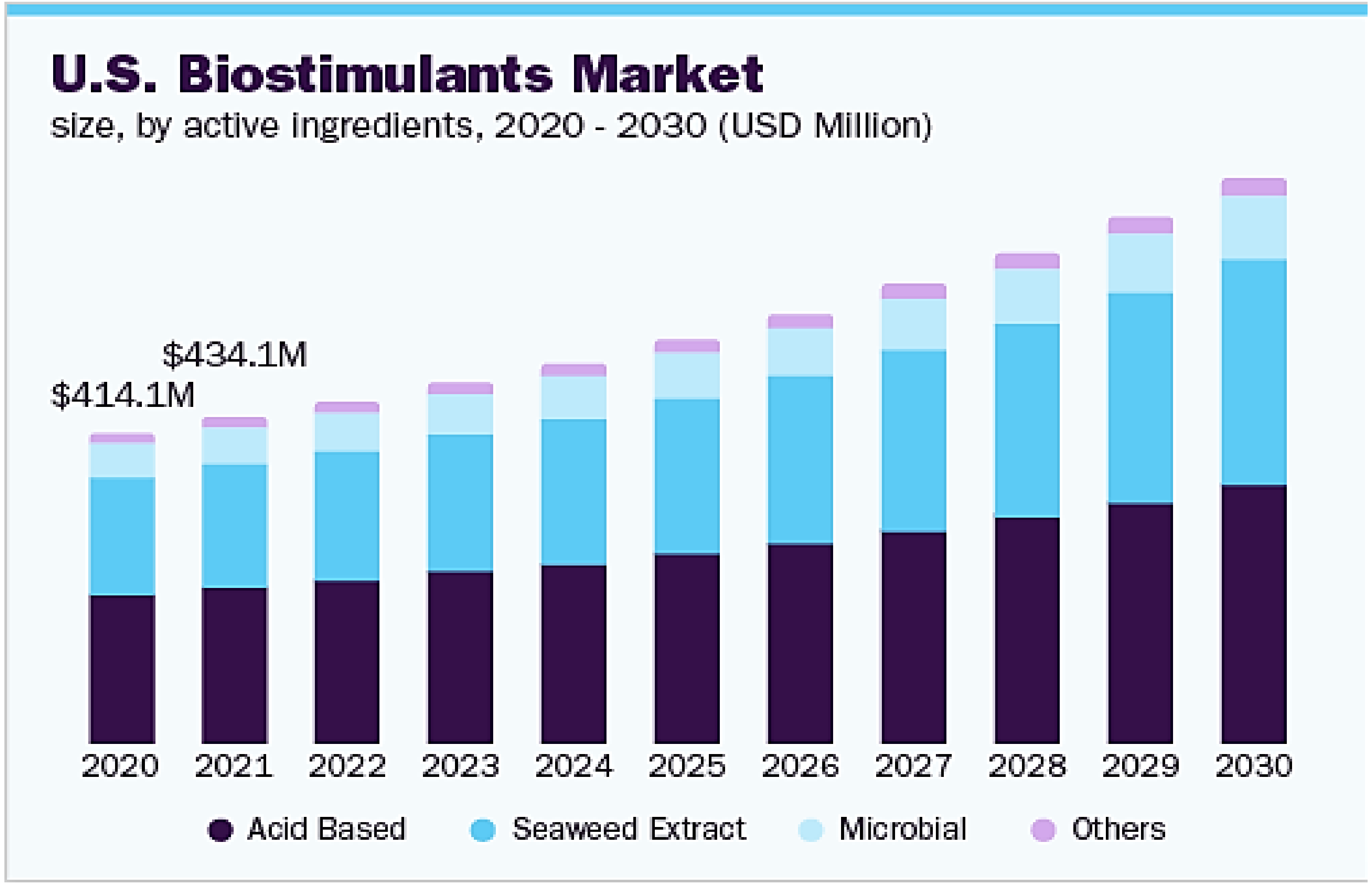
https://www.bpia.org/2018/12/biostimulants-in-farm-bill/

Alternative definition have been proposed:

https://www.epa.gov/pesticides/draft-guidance-plant-regulators-and-claims-including-plant-biostimulants

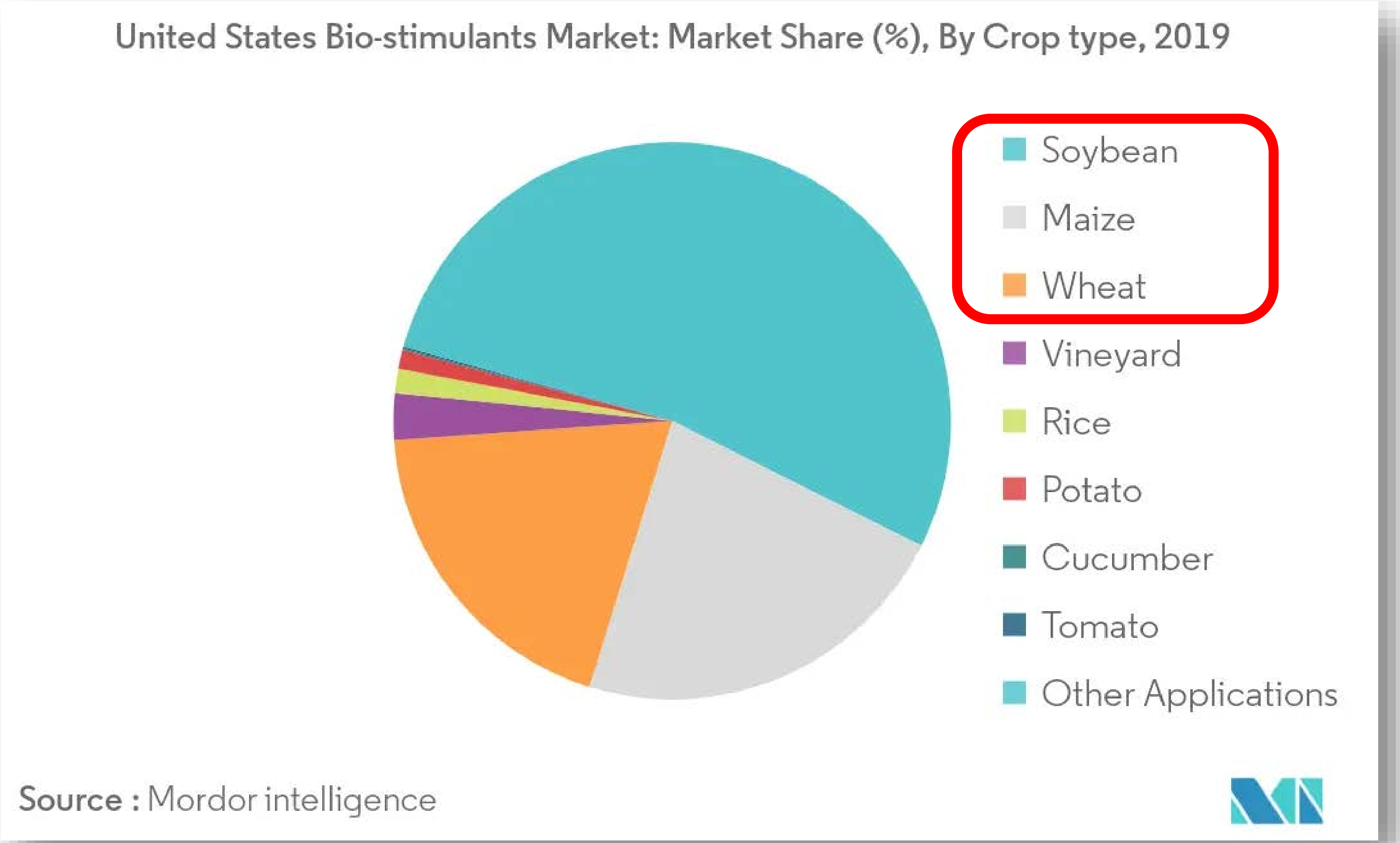
Market size





https://www.grandviewresearch.com/industry-analysis/biostimulants-market

US market



United States Bio-stimulants Market: Market Share (%), By Crop type, 2019
Soybean
Maize
Wheat
Vineyard
Rice
Potato
Cucumber
Tomato
Other Applications
Source : Mordor intelligence

Categories

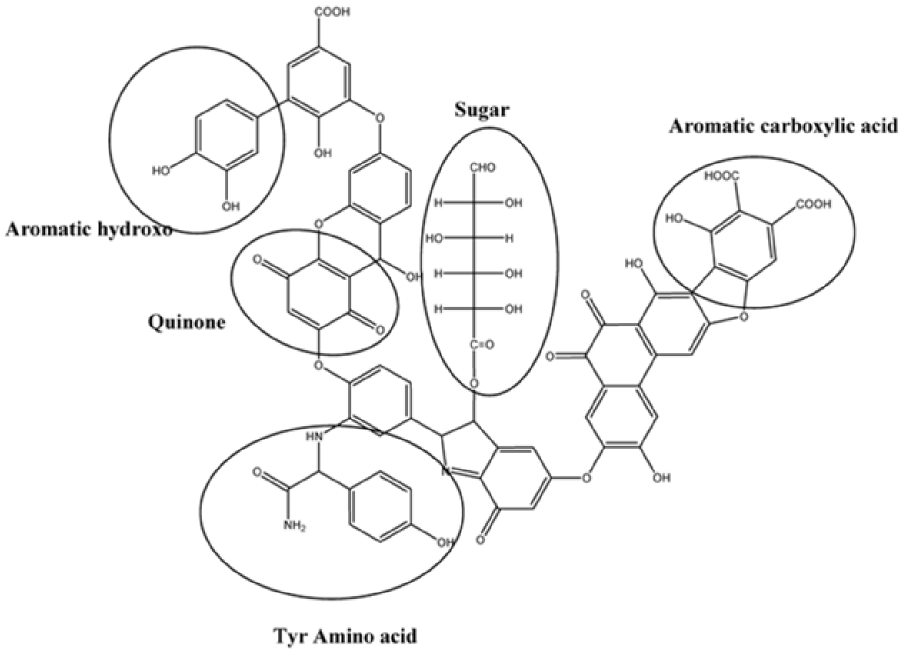
- Humic and Fulvic acids
- Seaweed Extracts
- Beneficial Bacteria
- Beneficial Fungi
- Silicon
- Chitosan

Humic Substances

Humic and Fulvic Acids

Humic Substances

- Largest constituents of the soil organic matter
- Result from the decomposition of plant, animal and microbial residues and the interaction between the organic matter, microbes and plant roots
- They form dynamic aggregates that are composed of different types of molecules



Humic Substances

Non-renewable sources → natural humidified organic matter (peat, volcanic soils), mineral deposits (leonardite)

Renewable sources → compost, vermicompost

Humic Substances

Humins

Humic Acids

Humic Acids

Fulvic Acids

Fulvic Acids

- Decrease in color intensity
- Decrease in polymerization
- Decrease of molecular weight
- Decrease of carbon content
- Increase in degree of solubility

Humic Substances

Reported effects

- Enhanced efficiency of nutrient use
- Improved lateral root development
- Phytohormonal effects
- Capacity to chelate metal ions
- Ideal carriers for beneficial microbes

Humic Substances

Although high in nutrients and organic matter, humic substances have a very slow rate of mineralization.

→ Not appropriate as direct source of nutrients or as replacement for N and P based fertilizers

→ Positive effects are not related to nutrient content

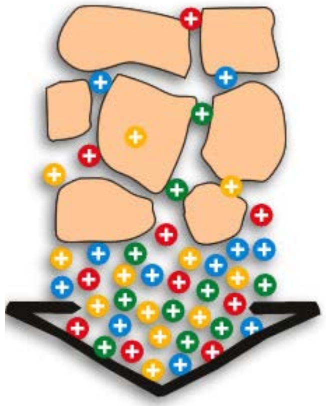
Humic Substances

Polyanionic nature

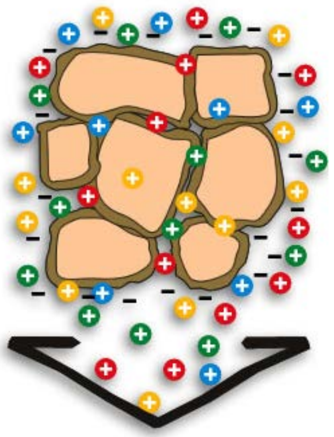
→ increase the **cation exchange capacity** of the soil

→ improved nutrient retention and nutrient use efficiency

Poor soils:
nutrient leaching



Soils rich in humic substances:
nutrient retention



Challenges

Effects are highly dependent on:

- Plant species
- Plant developmental stage
- Mode and rate of application
- Humic substances source
- Environmental conditions
- Management

Seaweed Extracts





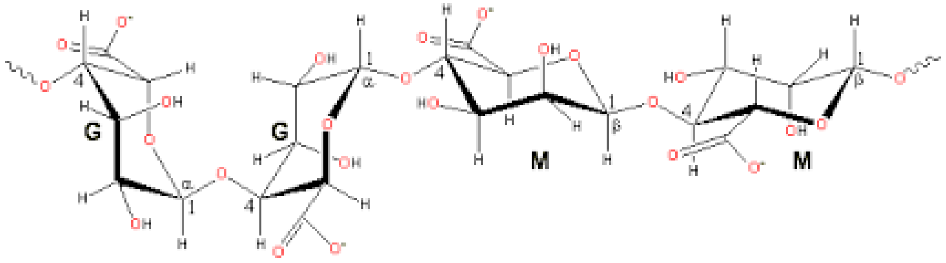

Seaweed Extracts

The most used seaweeds in agriculture are the brown seaweeds (*Ascophyllum nodosum*, *Fucus spp*., *Laminaria spp*., etc.)

Seaweed extracts

The major components of seaweeds are polysaccharides:

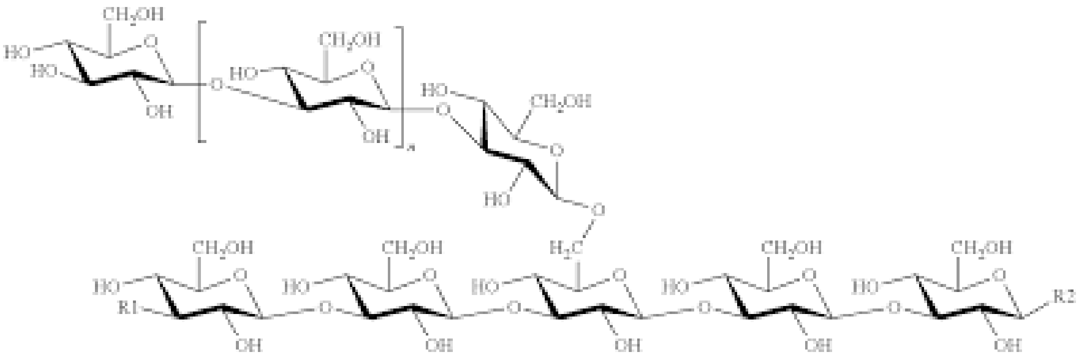
Alginates: Polymers of mannuronic and guluronic acids



→ Plant **growth-promoting** activities

Laminarins: Polymers of glucose

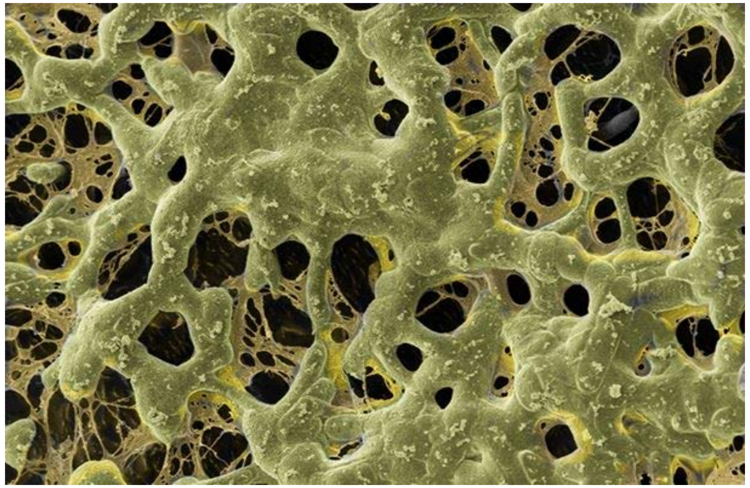
→ Important **elicitors of plant defense** responses



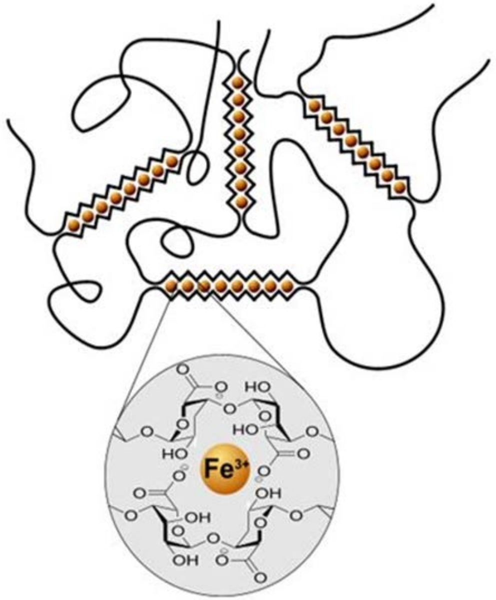
Seaweed Extracts

- In soils, the polysaccharides contribute to gel formation, water retention, and aeration
- Metal-chelating properties
- Medicinal uses: hydrogels, wound dressings

https://advancedtissue.com/2015/09/treating-wounds-with-absorbent-alginate-dressings/



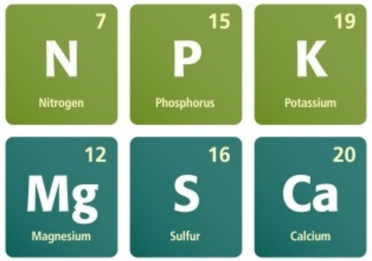
https://www.materialstoday.com/amorphous/articles/s1369702115003375/

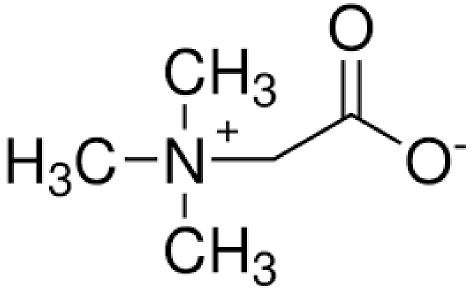


Seaweed extracts

<ins>Inorganic components</ins>

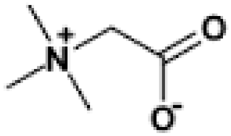
- Essential plant elements



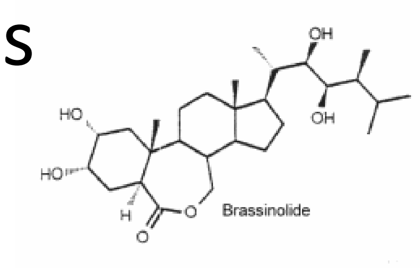


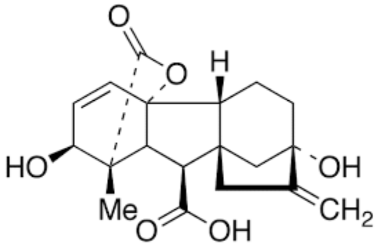
<ins>Organic components</ins>

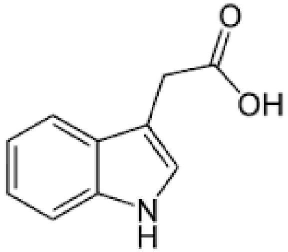
- Amino acids
- Phenolic compounds (antioxidant activity, metal chelating properties)
- Betaines and betaine analogs (osmoprotection)
- Phytohormones



Betaine







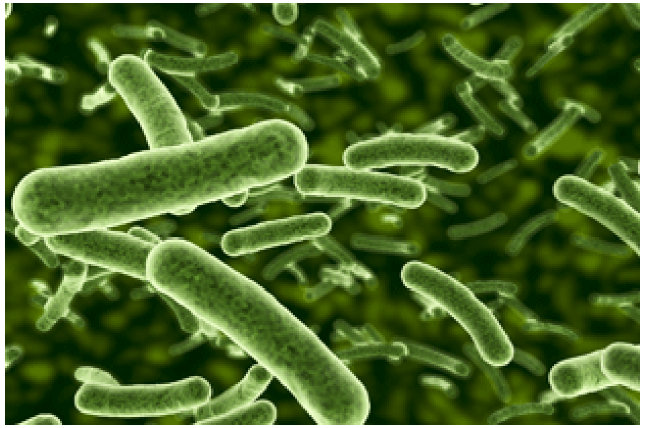
Challenges

- The extraction process used by different manufacturers varies considerably (alkali extraction, acid extraction, cell burst technology, etc.)
- → Not all seaweed extracts are the same - the same raw material processed differently results in extracts with different characteristics
- Effects depend on crop type, timing and frequency of application and developmental stage of the plant

Beneficial Bacteria

Plant Growth Promoting Bacteria (PGPB)

Plant Growth Promoting Rhizobacteria (PGPR)



Beneficial bacteria

- **Free-living** bacteria inhabiting the zone around the root (ectorhizosphere).
- Bacteria colonizing the **root surface** (rhizoplane).
- Bacteria living **within the roots** (endorhizosphere).

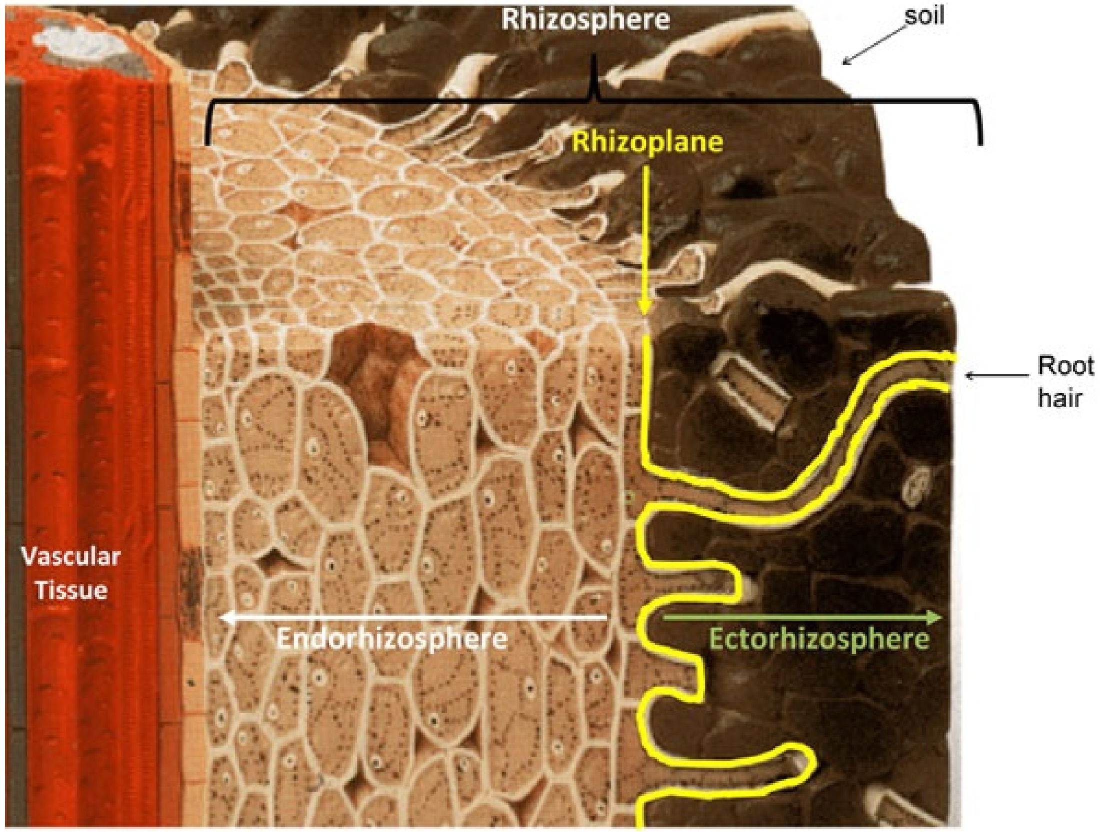
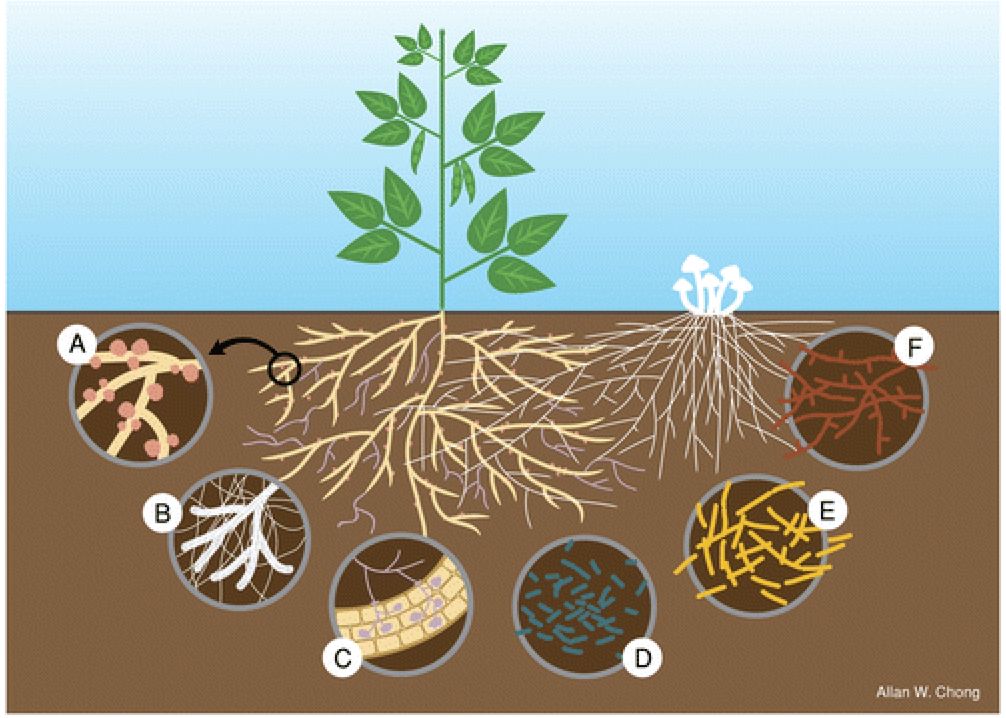


Image source: https://www.nature.com/scitable/knowledge/library/the-rhizosphere-roots-soil-and-67500617

Beneficial bacteria

Genera

Rhizobium, *Bacillus*, *Pseudomonas*, *Azospirillum*, etc.

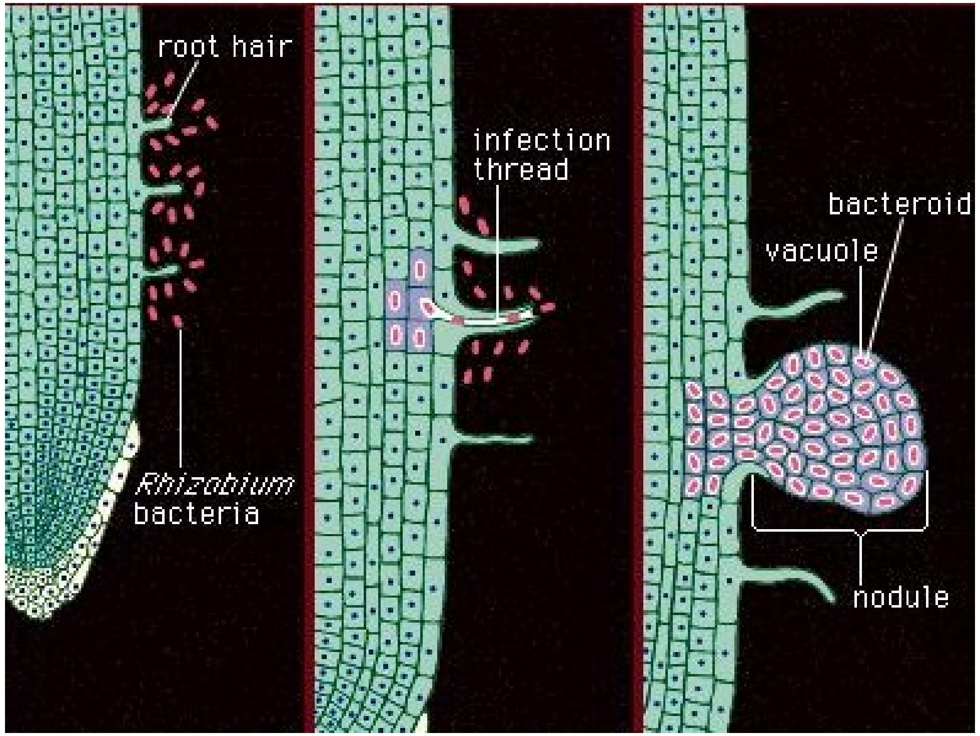


https://apsjournals.apsnet.org/doi/10.1094/PBIOMES-12-16-0019-RVW

- Improve root structure
- Improve water use efficiency
- Improve nutrient uptake
- Inhibit growth of soil-borne plant pathogens
- Increase disease resistance

Beneficial bacteria

Nitrogen fixation



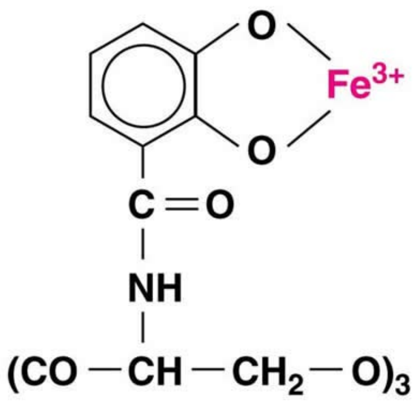
Symbiotic rhizobacteria invade the root hairs and stimulate formation of root nodules where they convert free nitrogen to ammonia.

(Image source: https://www.britannica.com/science/nitrogen-fixation)

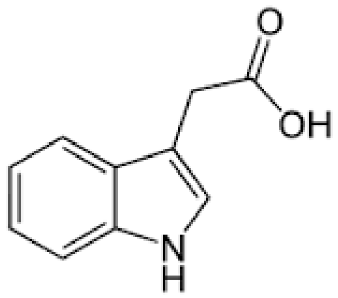
Beneficial bacteria

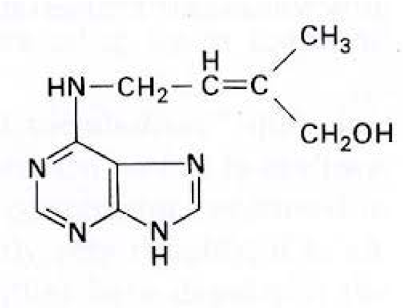
- PGPB can produce siderophores (small high affinity Fe^{3+} chelating compounds)

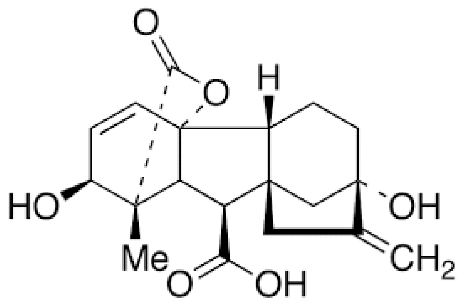
  → Reduce growth of deleterious soil-borne pathogens



- PGPB can produce different plant hormones (auxins, cytokinins, gibberellic acid) or induce hormonal changes in the plant

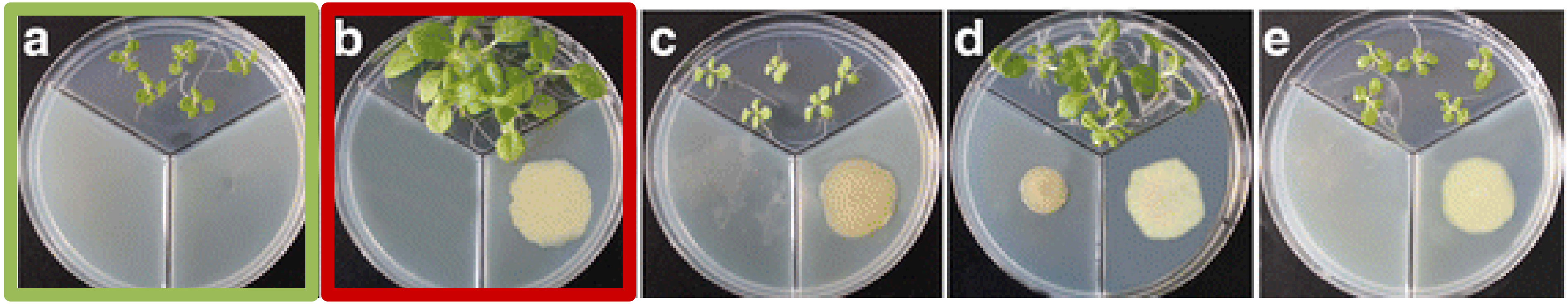






Beneficial bacteria

- PGPRs can emit volatile organic compounds (VOCs) which promote plant growth



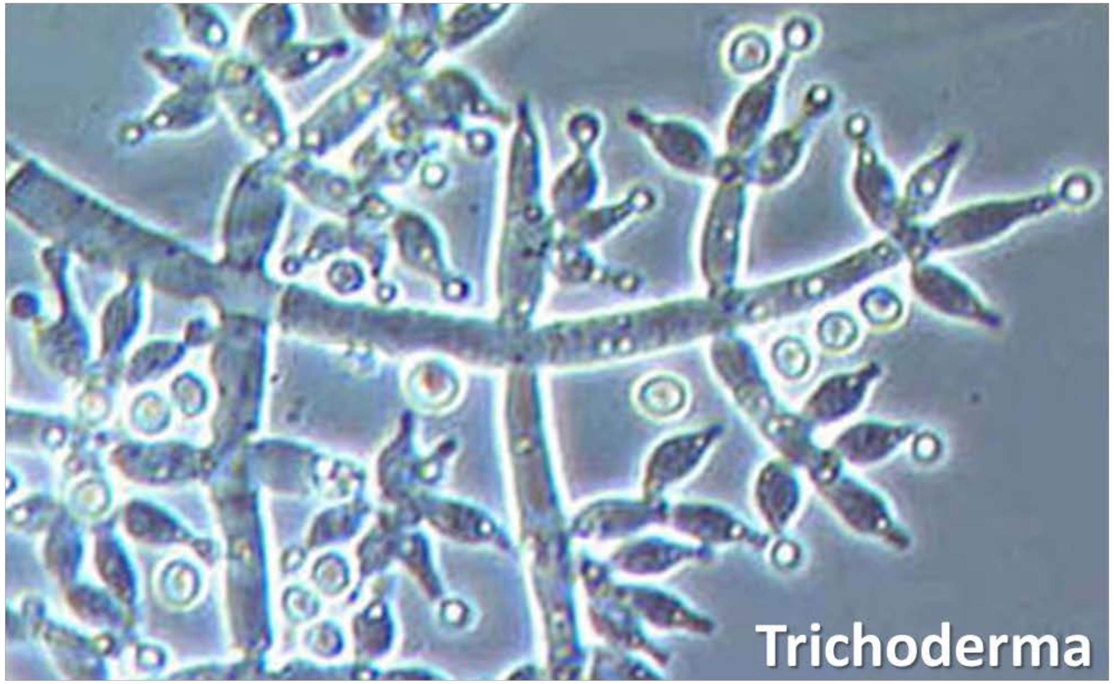
Tahir et al (2017), BMC 17:133, https://bmcplantbiol.biomedcentral.com/articles/10.1186/s12870-017-1083-6

- Commercial formulations of VOCs containing 2,3 butanediol (2,3 BD) and other VOCs increase plant tolerance to pathogens

Challenges

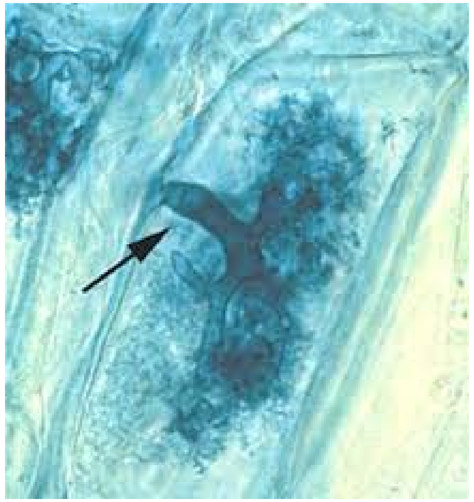
- Survival during formulation storage
- Optimization of the mode of inoculation
- Selection of the proper strain for each plant/soil system
- Persistence of PGPBs in the soil
- Compatibility with chemical fertilizers and standard crop production chemical

Beneficial Fungi



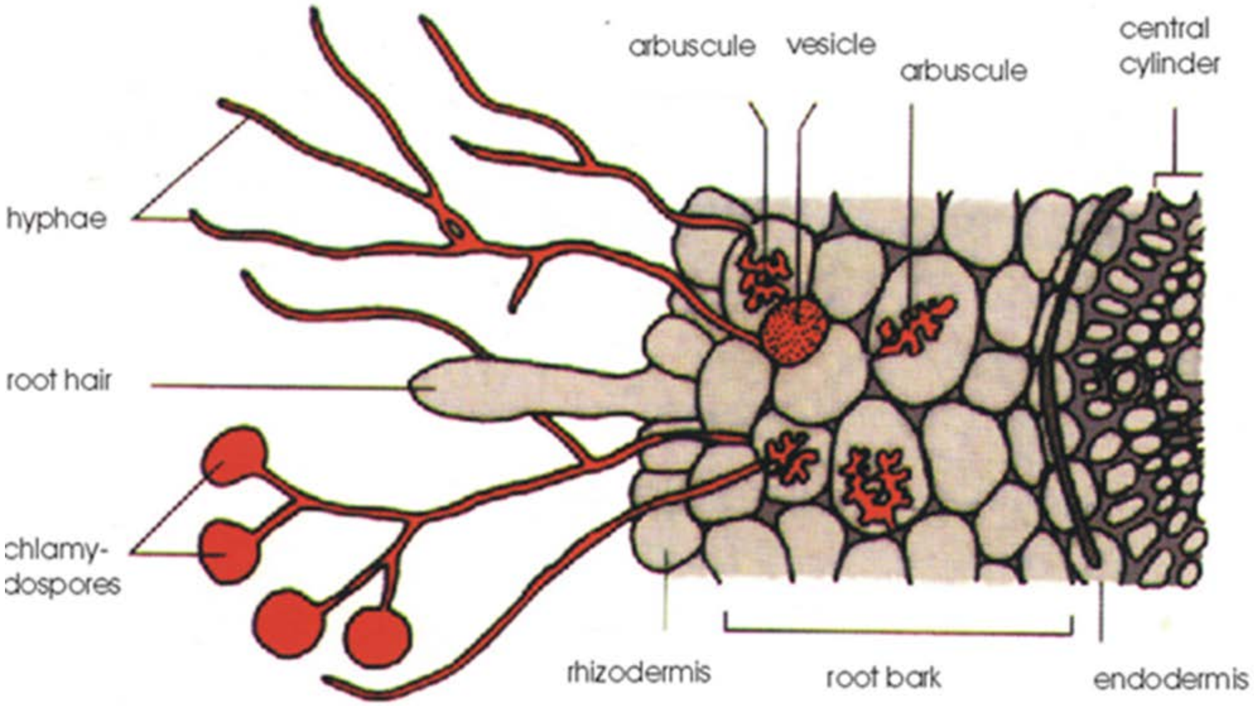
Arbuscular mycorrhizal fungi (AMF)

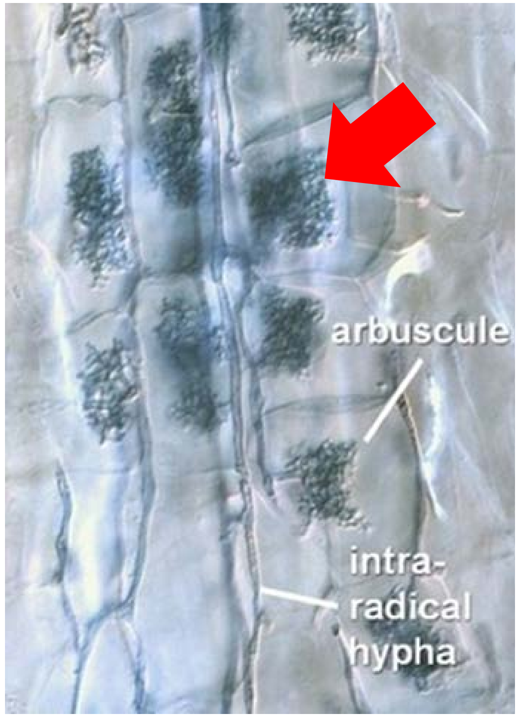
- AMF are formed between plant roots and fungi in the phylum *Glomeromycota*
- Most wide-spread plant symbionts
- Formed by 80-90% of plant species including vegetables, tree crops and herbal plants
- Common genera used commercially: Rhizophagus, Glomus and Funneliformes



AMF

Life cycle

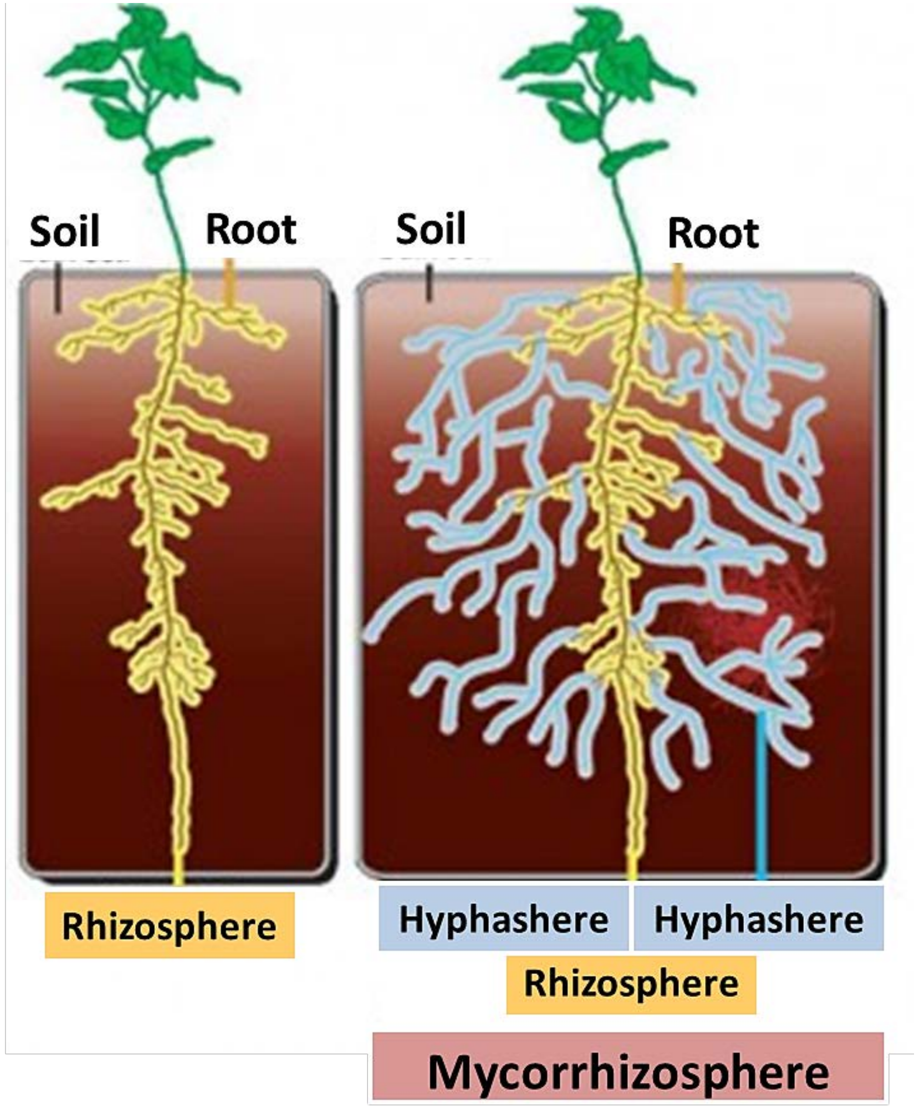




AMF effects

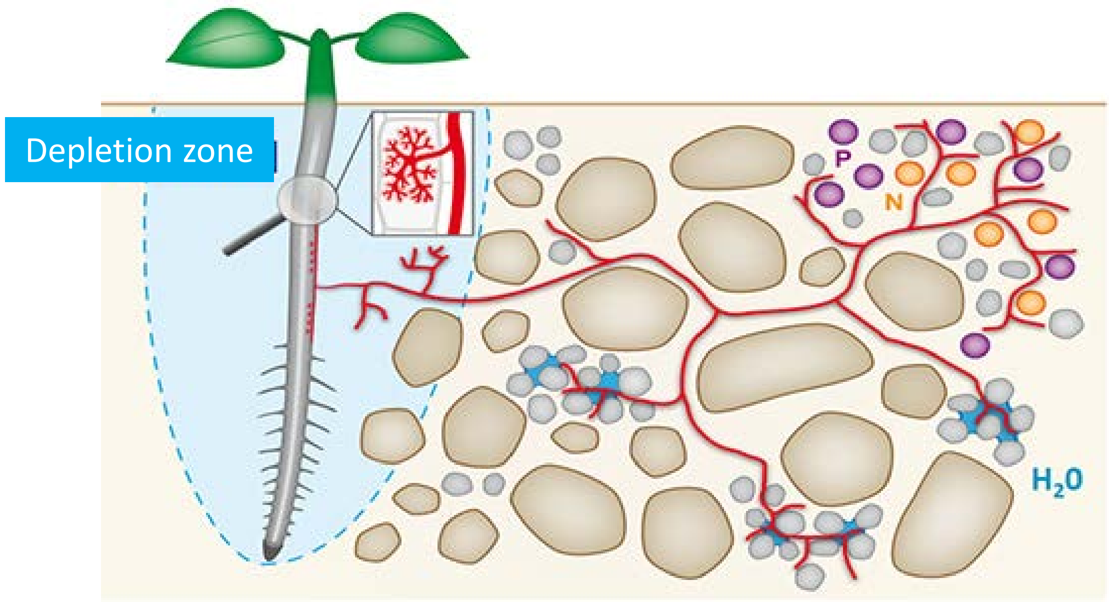
Formation of a web of roots and hyphae →

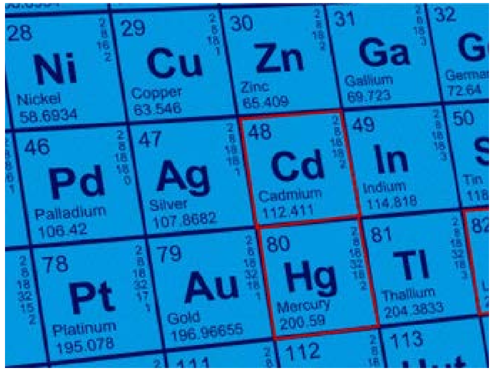
- Extension of the root system beyond the depletion zone
- Enhanced water uptake
- Enhanced nutrient uptake
- Improved stress tolerance



AMF effects

- AMF are best known for their effect on improving phosphorous use efficiency, especially in P depleted soils
- AMF can immobilize detrimental metals in the fungal biomass





Influence of crop management practices

POSITIVE

- Higher diversity of host plants (including agricultural crops, cover crops and weeds)

NEGATIVE

- Non-mycorrhizal host plants (*Brassicacea*)
- Soil tillage
- Enhanced irrigation
- High nutrient supply
- Herbicides
- Some fungicides

Check for updates

Review

New Phytologist

Tansley review

Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops

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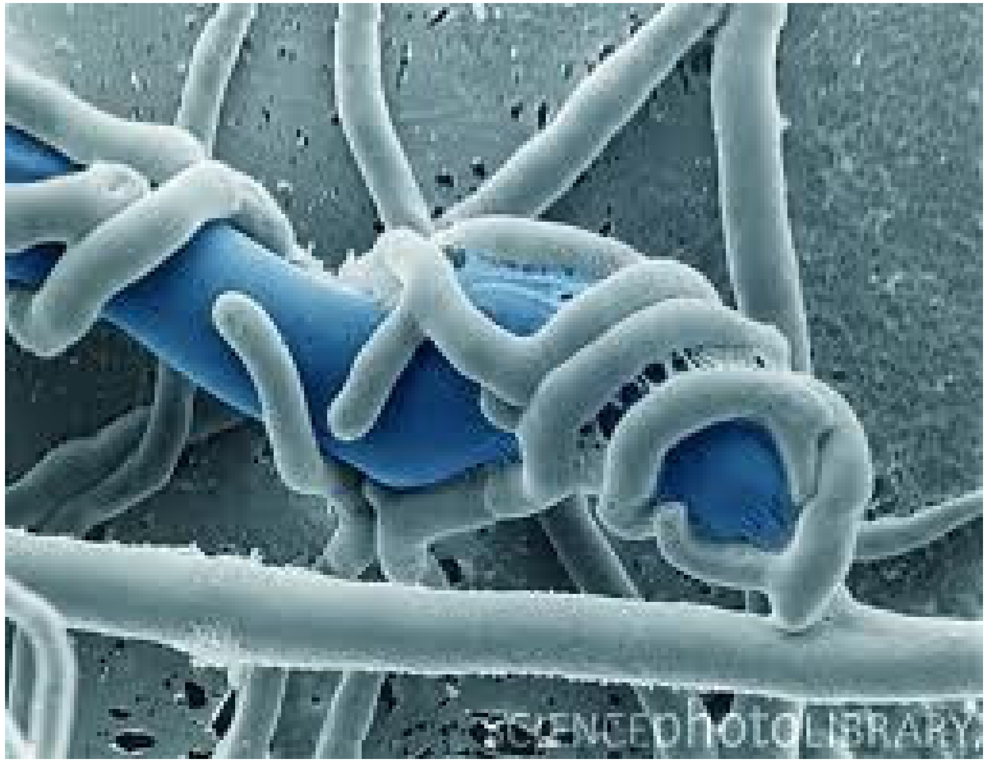
M.H. Ryan & J.H.Graham (2018). New Phytologist 220:1092-1107

Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops

Trichoderma



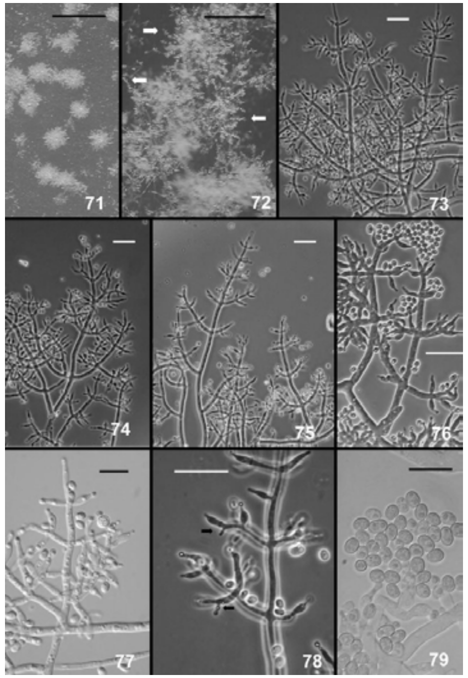
Often found on dead wood and bark.

Parasitize other fungi → Biocontrol of phytopathogenic fungi such as Fusarium, Rhizoctonia, and Pythium

Image sources: https://www.projectnoah.org/spottings/8840348; http://allplantprotection.blogspot.com/ 2012/04/trichoderma-multi-useful-fungi.html

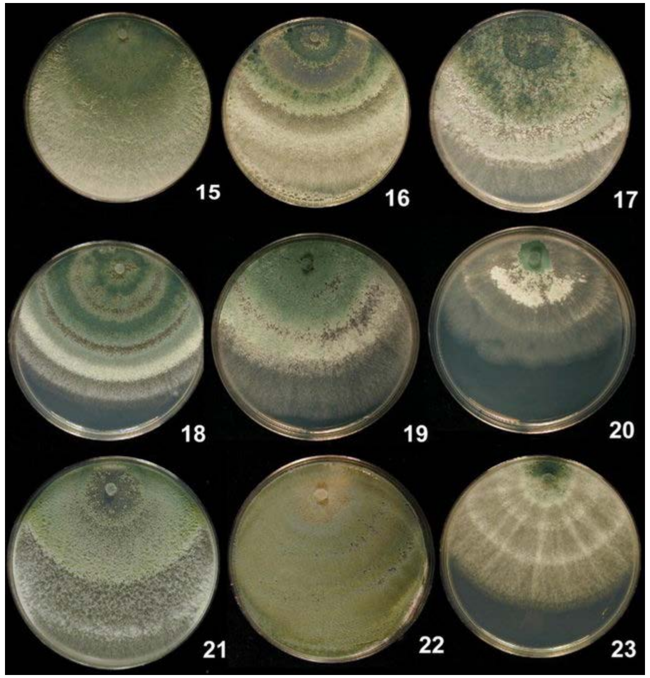
Trichoderma

One of the most used microbial *biopesticides.* Composed of a single Trichoderma isolate or a mixture of Trichoderma species.



Commonly used species:

T. harzianum
T. asperellum
T. atroviride
T. virens
T. viride



ISamuels et al. 2006, Stud Mycol. 56:67-133

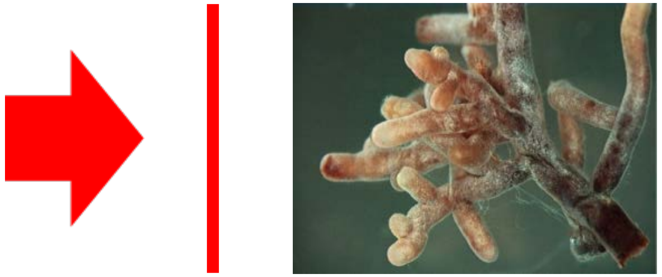
Trichoderma

Biofertilizers

- Modulation of root architecture
- Exudation of siderophores and organic acids
- Increase of plant hormonal levels
- Increase of plant antioxidant compounds

Challenges

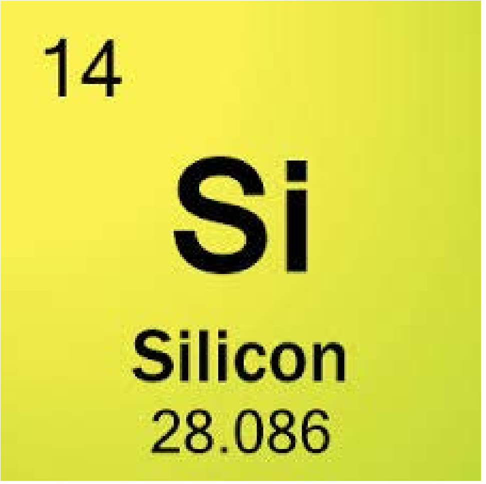
Possible interaction with other plant microorganisms, such as AMF.



→ Positive synergistic effects

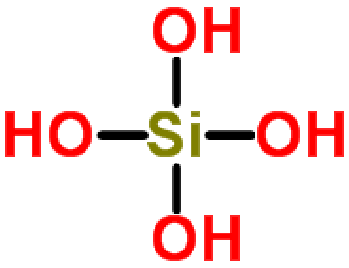
→ Possible negative effects, which may result in inhibition of plant growth

Silicon



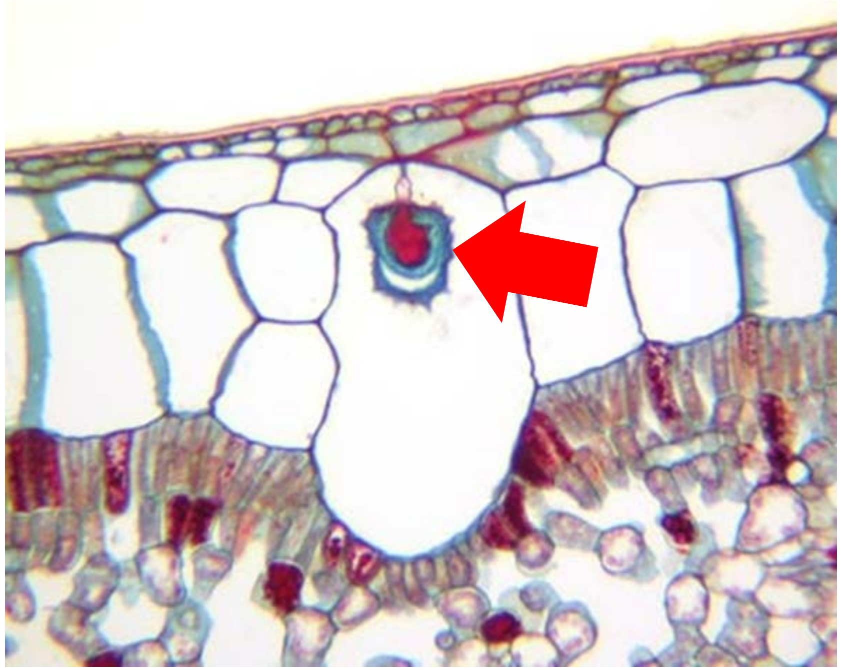
Silicon

- Silicon is the second most abundant element in the earth's crust
- Not essential for plant nutrition except in some monocotyledons
- In the soil solution Si occurs mainly as monomeric silicic acid (H_4SiO_4) → easily taken up by plants



Silicon

- Si is easily absorbed by the roots and transported via the transpiration stream
- Accumulation in the plant tissue is mainly in form of solid amorphous silica around the stomata, in the cell wall, or in intercellular spaces or
- Increased mechanical strength
- Increased light interception and photosynthesis



Phytolith

Chitosan

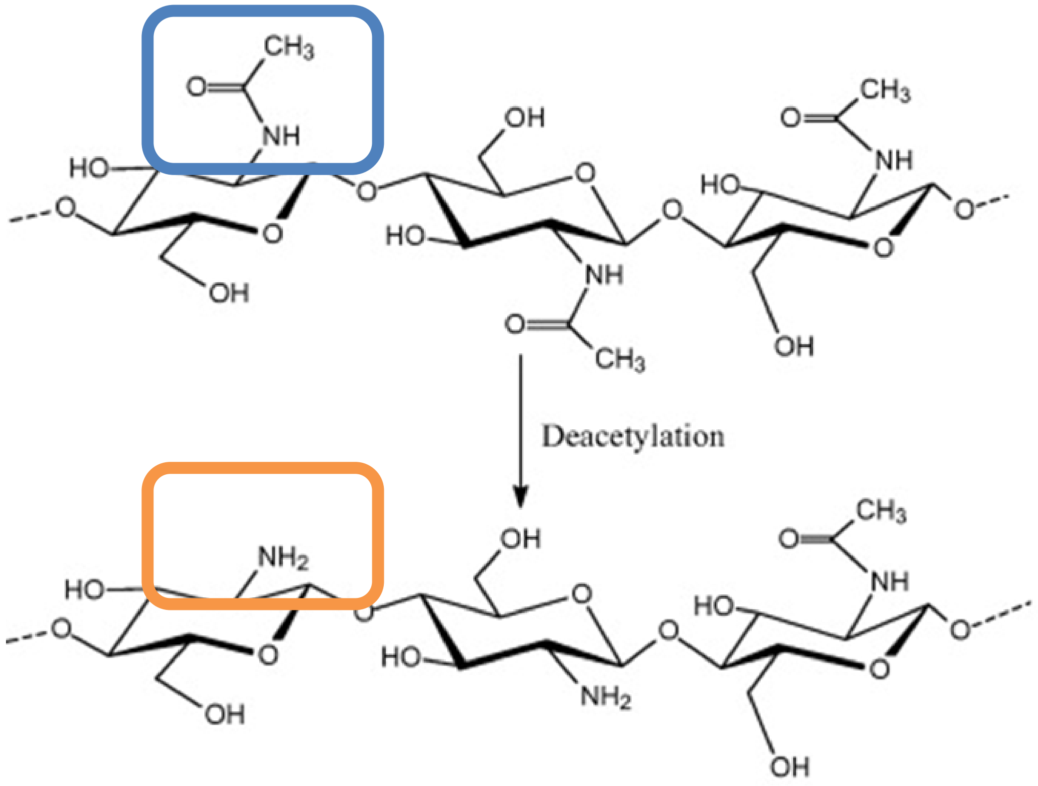
Chitin and Chitosan

- Chitin is a natural component found in insect exoskeletons, and crustacean shells, fungal cell walls, and nematode eggshells

- Chitosan can be solubilized in weak organic acids

Chitosan

Chitin

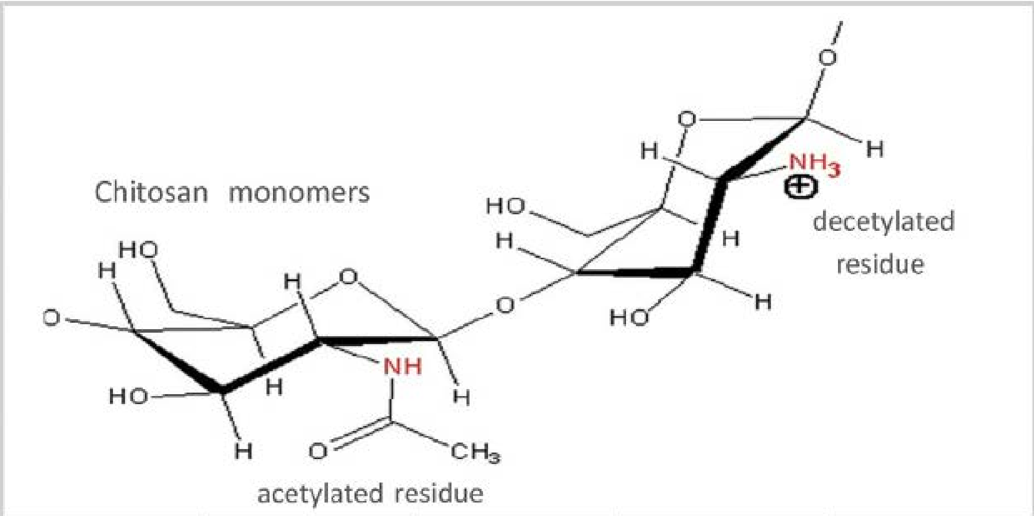


Chitosan

- Both chitin and chitosan are polymers of N-acetyl-D-glucosamine and D-glucosamine
- Chitosan is a deacetylated form of chitin

Chitosan

The difference in starting materials, preparation process, degree of acetylation can greatly affect the physical properties and biostimulant effects on plants

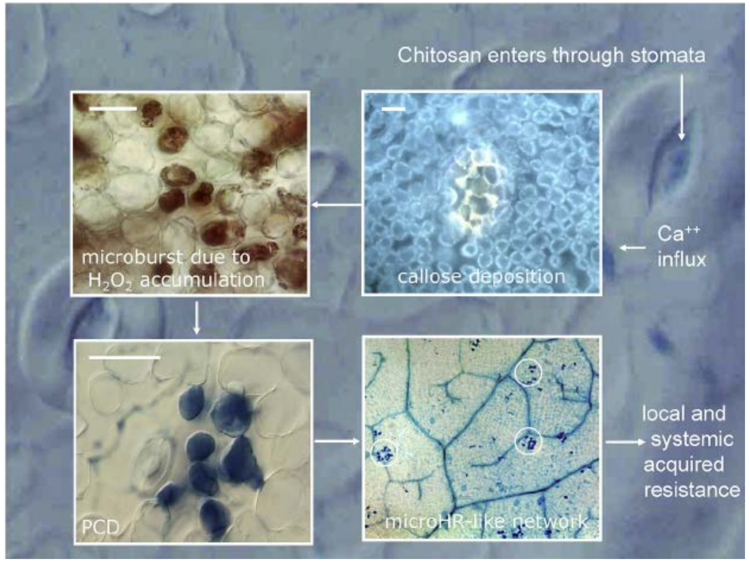


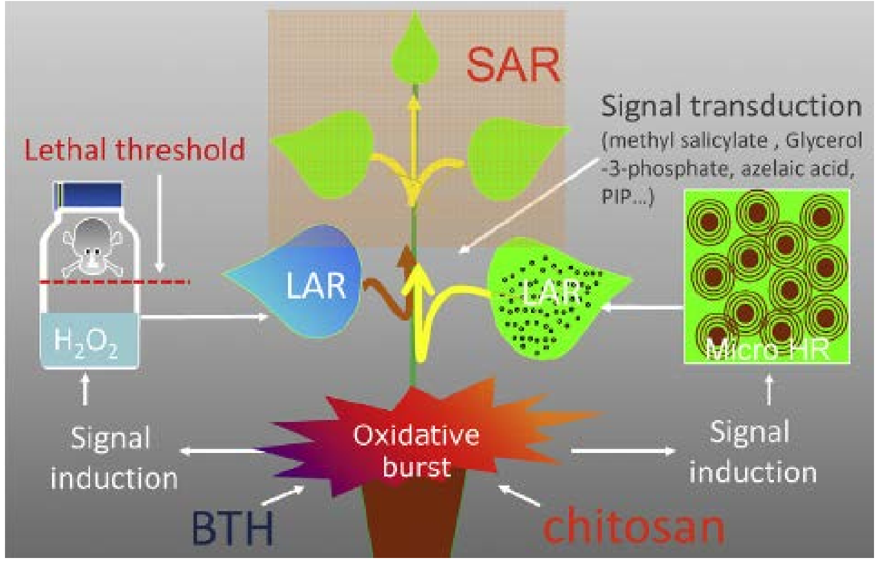
polymers (soluble in acids)	kDa (DD 80 -85%)	monomer units	viscosity mPa·s	activity as elicitors
high m.w.	>300	>2000	>800	low
medium m.w.	190-310	1200-2000	200-800	low
low m.w.	50-190	300-1200	20-200	mild
very low	10-50	10-300	6-20	strong
Oligomers (soluble in water)	≤5	≤30	≤6	very strong

(Faoro & Gozzo (2015) Plant Science 234:1-15

Chitosan

- Induction of local and systemic acquired resistance → enhanced resistance to pathogens

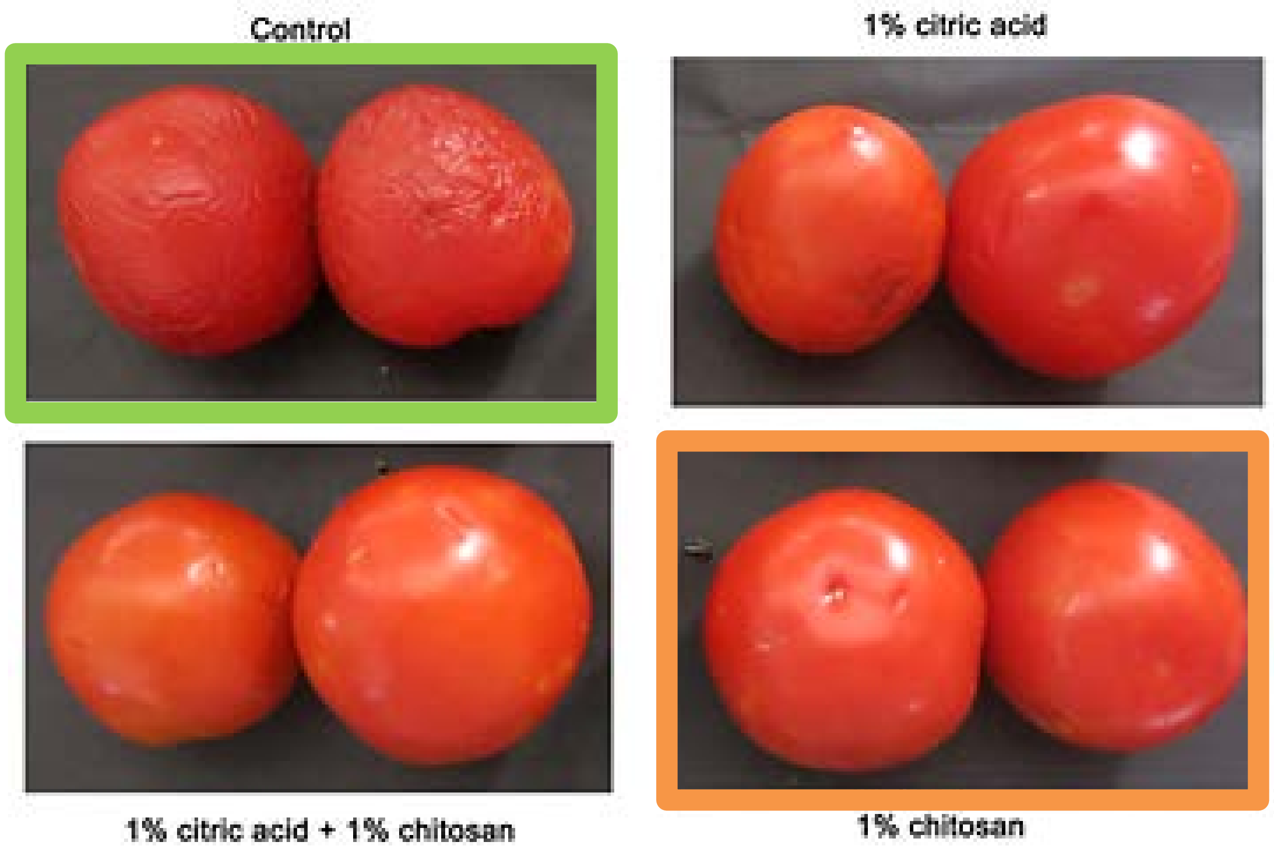




- Reduction of transpiration (stomatal closure)

(Faoro & Gozzo (2015) Plant Science 234:1-15

Chitosan



Zhang et al, J. Food Nutr. (2017) 144-150

Antibacterial, antifungal, and antiviral properties

→ frequently used as

- seed coating agents
- foliar treatments
- post-harvest coatings of fruits and vegetables

→ prevent postharvest decay

→ increase shelf-life

Summary

Biostimulant effects are variable and depend on:

- Plant system (species, age, etc.)
- Source and composition of materials used
- Dose and manner of application
- Management practices
- Different environmental conditions

→ *Their mode of action is mostly unknown*

→ *Results are inconsistent, but effects are said to be better under stress conditions*

Biostimulant research at SWFREC

Ongoing research at SWFREC



CRDF #19-030C and USDA-NIFA ECDRE #2020-70029-33202

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