Emerging mycotoxin remediation methods

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Regulated mycotoxins

Mycotoxin	Fungal species	Human health end point of concern
Aflatoxins (sum of B1, B2, G1, G2)	*Aspergillus* spp.	Liver cancer
Ochratoxin A	*Aspergillus* spp., *Penicillium* spp.	Kidney disease, kidney tumours
Patulin	*Penicillium* spp.	Acute and chronic effects
Deoxynivalenol (DON)*	*Fusarium* spp.	Reduced bodyweight gain
Zearalenone (ZEN)	*Fusarium* spp.	Estrogenicity
Fumonisins (B1 + B2)	*Fusarium* spp., *Aspergillus* spp.	Liver toxicity
T-2 and HT-2 (sum)*	*Fusarium* spp.	Reduced white blood cells
Citrinin	Red yeast *Monascus purpureaus*	Kidney damage
Ergot alkaloids	*Claviceps* spp., *Aspergillus* spp., *Penicillium* spp.	Neurological disorders

* Trichothecenes

Example of global situation

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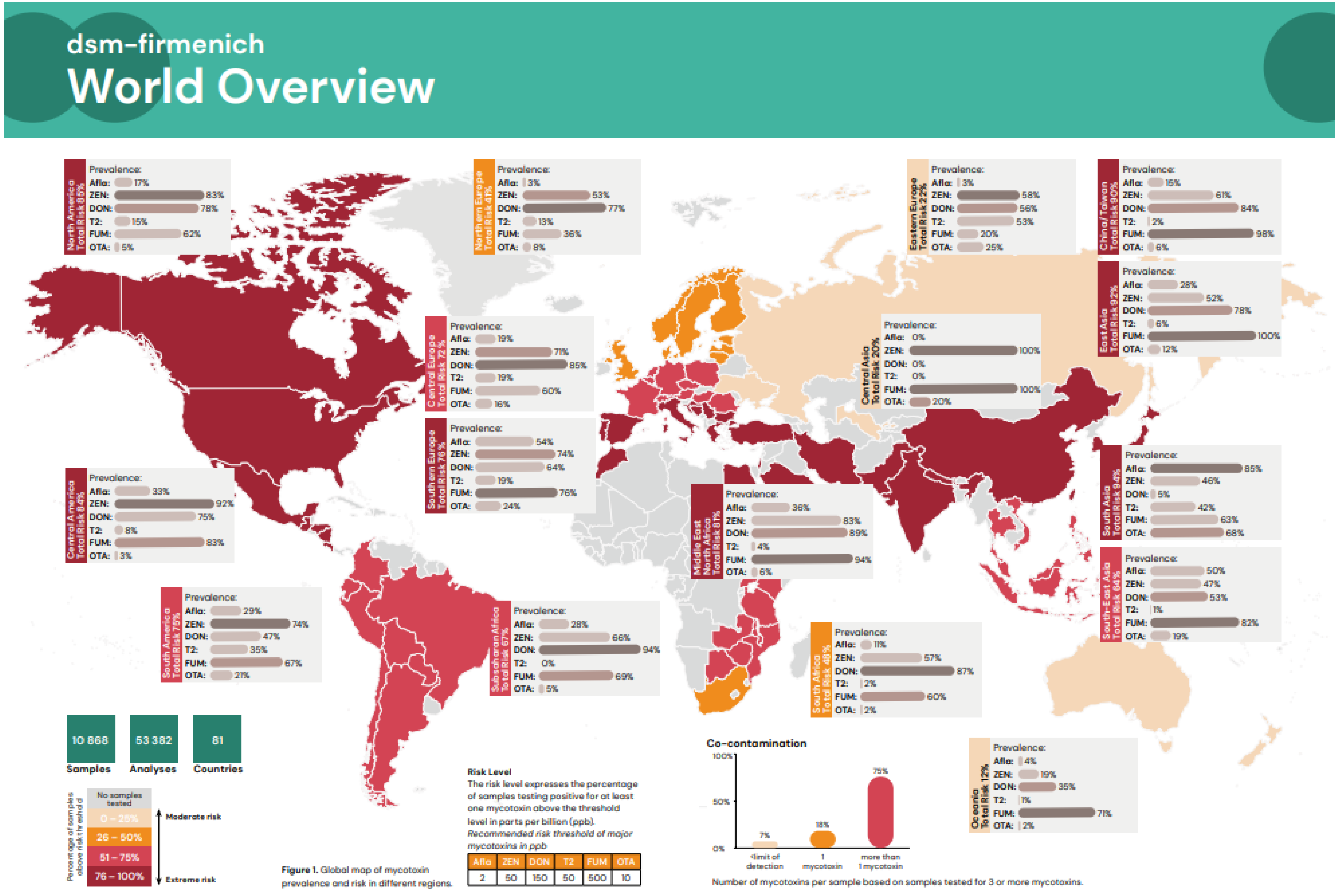

Animal feed ingredients and finished feed, January-June 2025

- 10,868 samples from 81 countries

No samples tested
0 – 25%
26 – 50%
51 – 75%
76 – 100%

% samples positive for at least one mycotoxin above threshold concentration

Source: dsm-Firmenich (Switzerland) https://www.dsm-firmenich.com/anh/products-and-services/tools/mycotoxin-contamination/mycotoxin-survey.html

References (reviews)

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Remediation methods

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PHYSICAL

- Sorting
- Drying
- Washing
- Milling
- Heat
- Ultrasound
- Pulsed light
- Other irradiation
- Cold plasma
- Pulsed electric field
- High pressure processing

CHEMICAL+PHYSICAL

- Inorganic/organic binders
- Nanoparticles

CHEMICAL

- Chitosan
- Ozone
- Essential oils
- Polyphenols
- Salts

BIOLOGICAL

- Antagonistic fungi/bacteria
- Fermentation
- Enzyme detoxification
- Nanozymes
- Microbial consortia
- Genetically modified competitors

Cold atmospheric plasma

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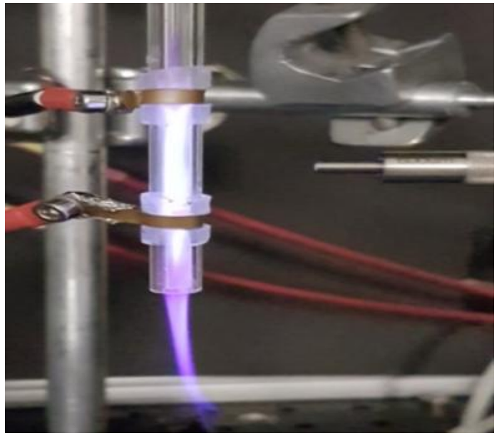
Electrical energy + gas = ionised gas

- Kills microbes, including fungi ; breaks down mycotoxins
- Non-thermal

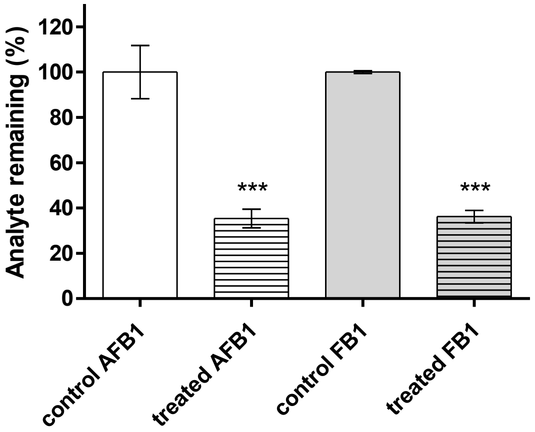
Example: Wielogorska et al. (2019) https://doi.org/10.1016/j.foodchem.2019.125281

Aflatoxin B_1 and fumonisin B_1 on maize treated with gaseous plasma from helium/oxygen

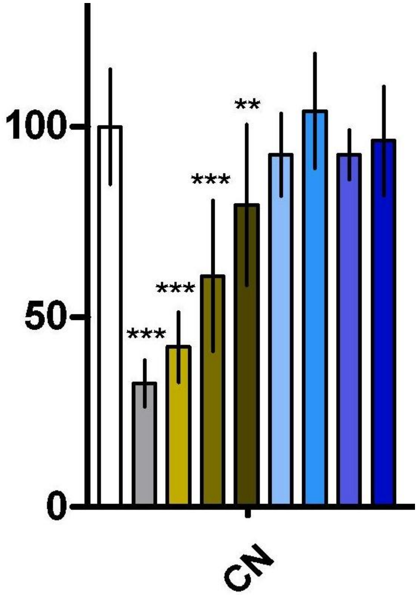
- 60 min soak in AFB_1 or FB_1 solution, dried 60 min



Grains placed ~12 mm beneath plasma jet outlet for 10 min



Mycotoxin concentrations decreased



No-maize solutions less toxic to human cells after CAP treatment (grey/brown), no diff for maize (blue)

CONSIDERATIONS

- Scaling up
- Low penetration for treating bulk product
- Effectiveness when product is naturally contaminated
- Toxicity of break down products
- Changes to food properties and chemistry
- Adds nitrites to food (issues with regulatory limits?)

Pulsed electric field

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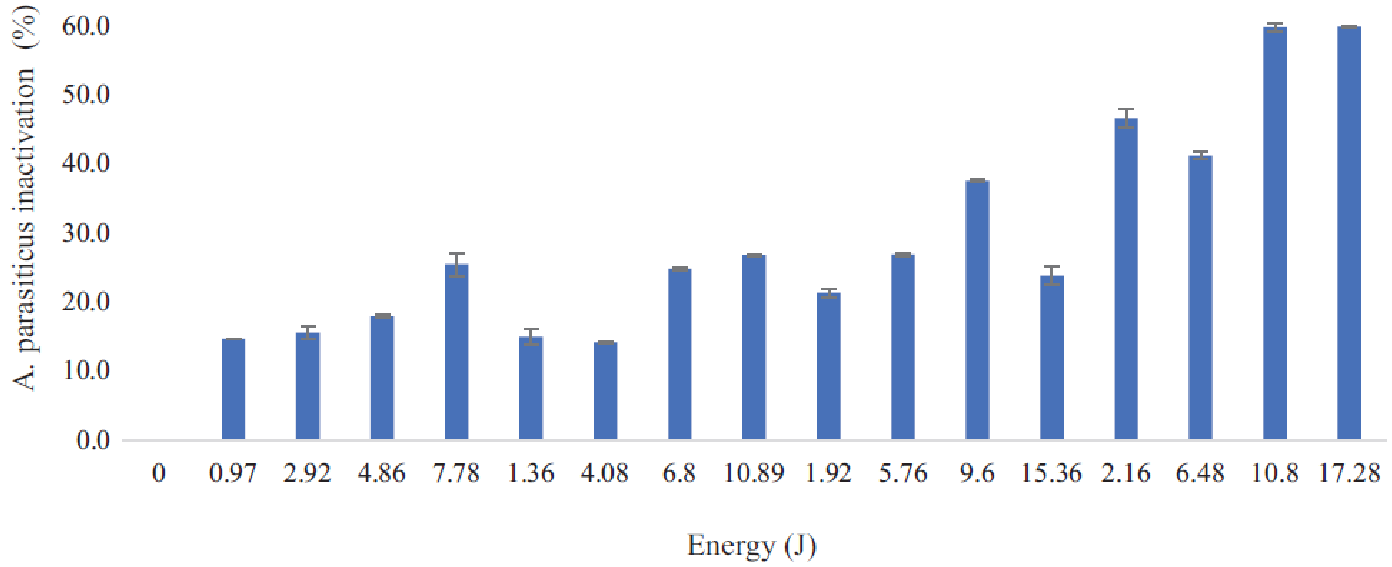
High-voltage electrical pulses

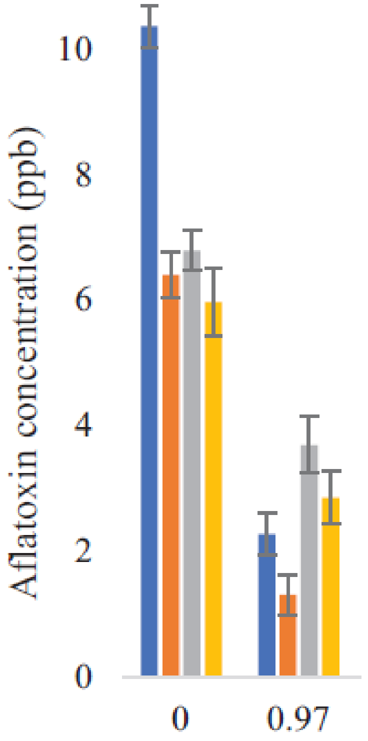
- Kills microbes, including fungi ; breaks down mycotoxins
- Non-thermal

Example: Bulut et al. (2020) https://doi.org/10.1111/jfs.12855

Aflatoxin-producing *Aspergillus parasiticus* on sesame seeds

- Inoculated with *A. parasiticus*, incubated 22-24°C/3-5 days
- PEF treatment 10 kV max voltage, frequency 100-180 Hz, time 2.5-19.8 s





Inactivated fungus and reduced aflatoxin concentrations (AFG_1 AFG_2 AFB_1 AFB_2) even at lowest energy (0.97 J)

CONSIDERATIONS

- Scaling up, treating bulk product
- Effectiveness when product is naturally contaminated
- Toxicity of break down products
- Corrosion of high voltage electrodes

Nanoparticles

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Magnetic nanoparticles

- Adsorb then recover using magnetism
- Iron and zine oxides, silver, copper, etc.

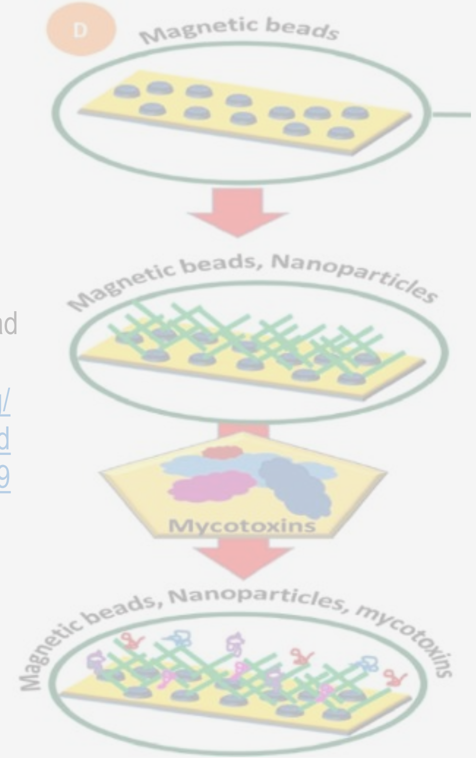


Image: Hamad et al. (2023) https://doi.org/10.1016/j.foodcont.2022.109350

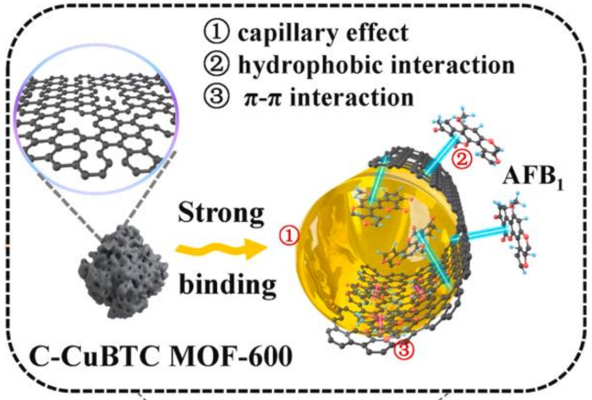
- **Example**: Patulin absorption by chitosan coated Fe_3O_4 (Luo et al. (2017) https://doi.org/10.1016/j.foodchem.2016.09.008

Nanoparticle frameworks

- Metal or non-metal organic structures (adsorption in liquids)

Image: Ma et al. (2021) https://doi.org/10.1016/j.jhazmat.2021.125170

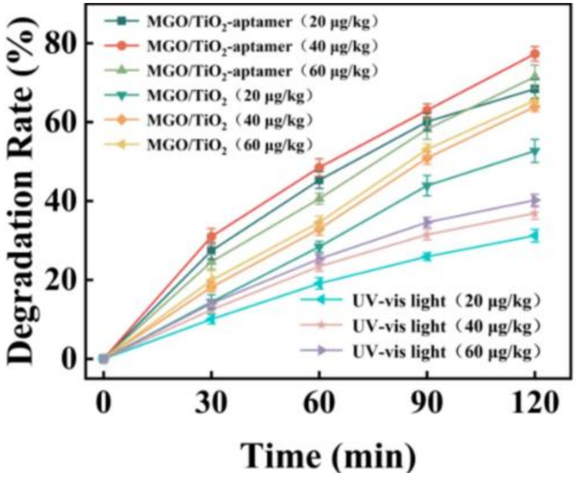
Removing aflatoxin from peanut or corn oil



- Adsorption–photocatalysis systems (adsorption + break down in liquids)

Image: Ku et al. (2025) https://doi.org/10.1016/j.foodchem.2024.142674

Aflatoxin treatment by aptamer-graphene oxide-titanium dioxide particles and light (peanut oil)



CONSIDERATIONS

- Scaling up
- High cost
- Toxicity of break down products
- Toxicity of nanoparticles
- Unexpected interactions with non-targets
- Consumer acceptability
- Environmental concerns

Nanozymes

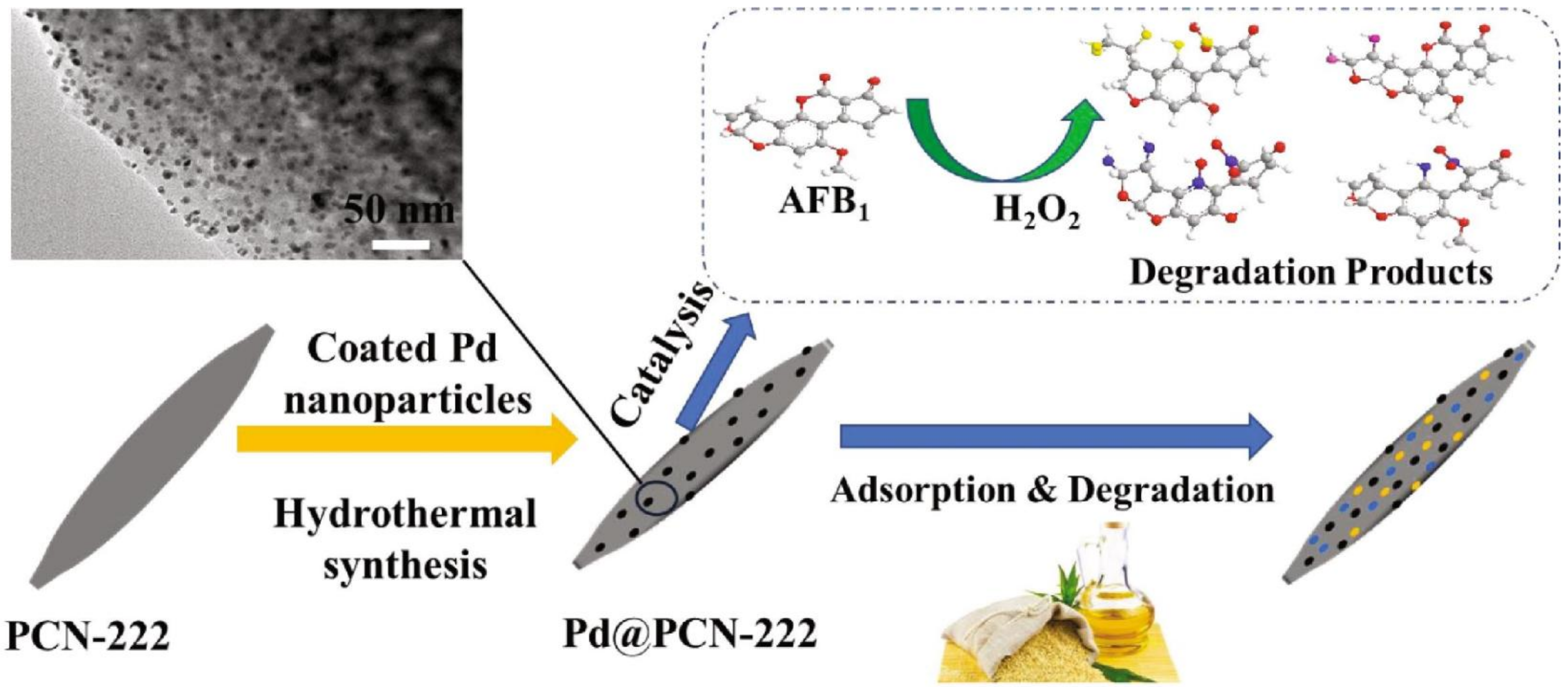
Not new: Microbial enzymes that break down mycotoxins to low toxicity/non-toxic metabolites

New: **Nanozymes**, manufactured nanoparticles with enzyme-like properties

- Most research is on use for contaminant detection
- Potential use for mycotoxin absorption and break down

Example: Wei et al. (2022) https://doi.org/10.1016/j.foodchem.2021.132037

Aflatoxin treatment by palladium-coated nanoparticles (metal-organic framework) and hydrogen peroxide



CONSIDERATIONS

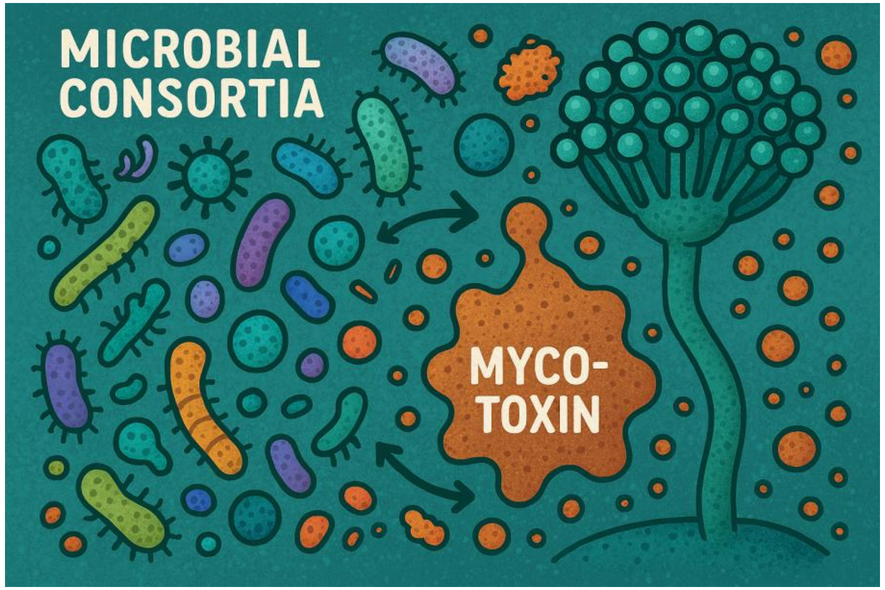
- (same as for nanoparticles)
- May require addition of other chemicals to stimulate reaction

Microbial consortia

Not new: Microorganisms that break down mycotoxins to low toxicity/non-toxic metabolites

New: **Multi-species microbial communities**

- Multiple mechanisms of action (fungi antagonists, mycotoxin binders, mycotoxin degraders)
- Can target a range of toxigenic fungi/mycotoxins
- A balancing act: Compete or co-operate, more effective together or apart
- Informed by ‘omics methods (metagenomics, proteomics, metabolomics)



CONSIDERATIONS

- Scaling up
- Cost effectiveness
- Microbial safety
- Strain compatibility
- Different culture requirements
- Strain stability
- Effectiveness on food/feed under normal conditions
- Toxicity of break down products
- Consumer acceptability
- Environmental concerns

Overall comments

If prevention fails:

Divert product, bind/remove mycotoxin, degrade mycotoxin

- Low technology readiness
- Technical and economic gaps between research and practical application
- Insufficient evidence of efficacy in real world conditions
- Concerns about toxic residues and food quality changes
- Pressure not yet strong enough?
  (low perceived risk, low cost of raw materials, able to downgrade/divert product, high cost of research, regulatory approvals needed for commercialisation)
- Potential concerns about adding ‘unnatural’ substances to food or feed, or treating with unfamiliar processes