SUSTAINABLE BIOINSPIRED WATER PURIFICATION

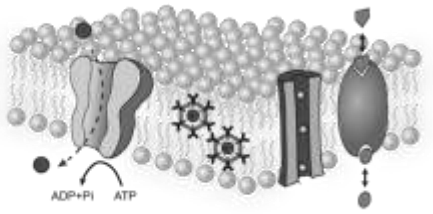
Manish Kumar and Stephanie Velegol

Department of Chemical Engineering

Pennsylvania State University

www.kumarresearchgroup.com

PennState



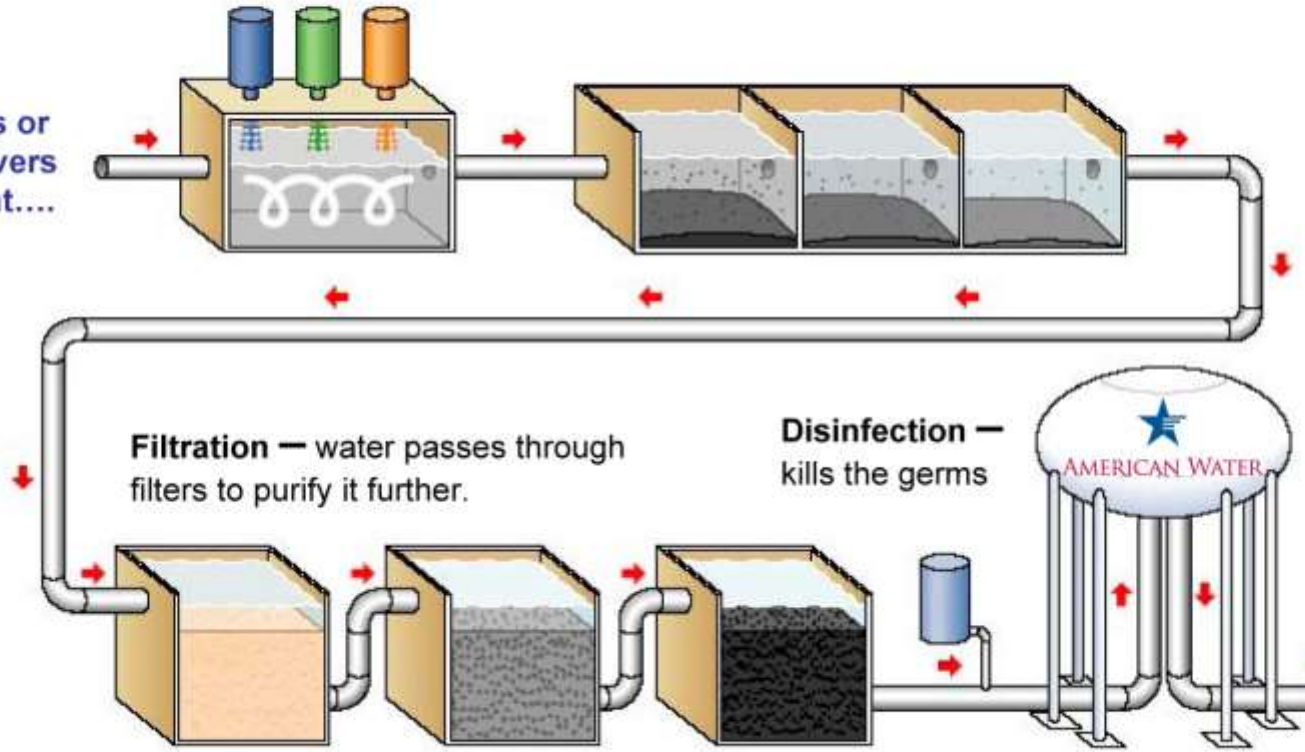

1976
Village in Eastern
India
Still no electricity
No running water
No sanitation
Beautifully isolated

How a Water Treatment Plant Works

Coagulation – special compounds remove the dirt particles from the water

Sedimentation – the dirt settles to the bottom and the water becomes cleaner

From wells or lakes or rivers to the plant….



Filtration – water passes through filters to purify it further.

Disinfection – kills the germs

From the water tower to your home!

SAND FILTRATION IS AT THE HEART OF WATER TREATMENT

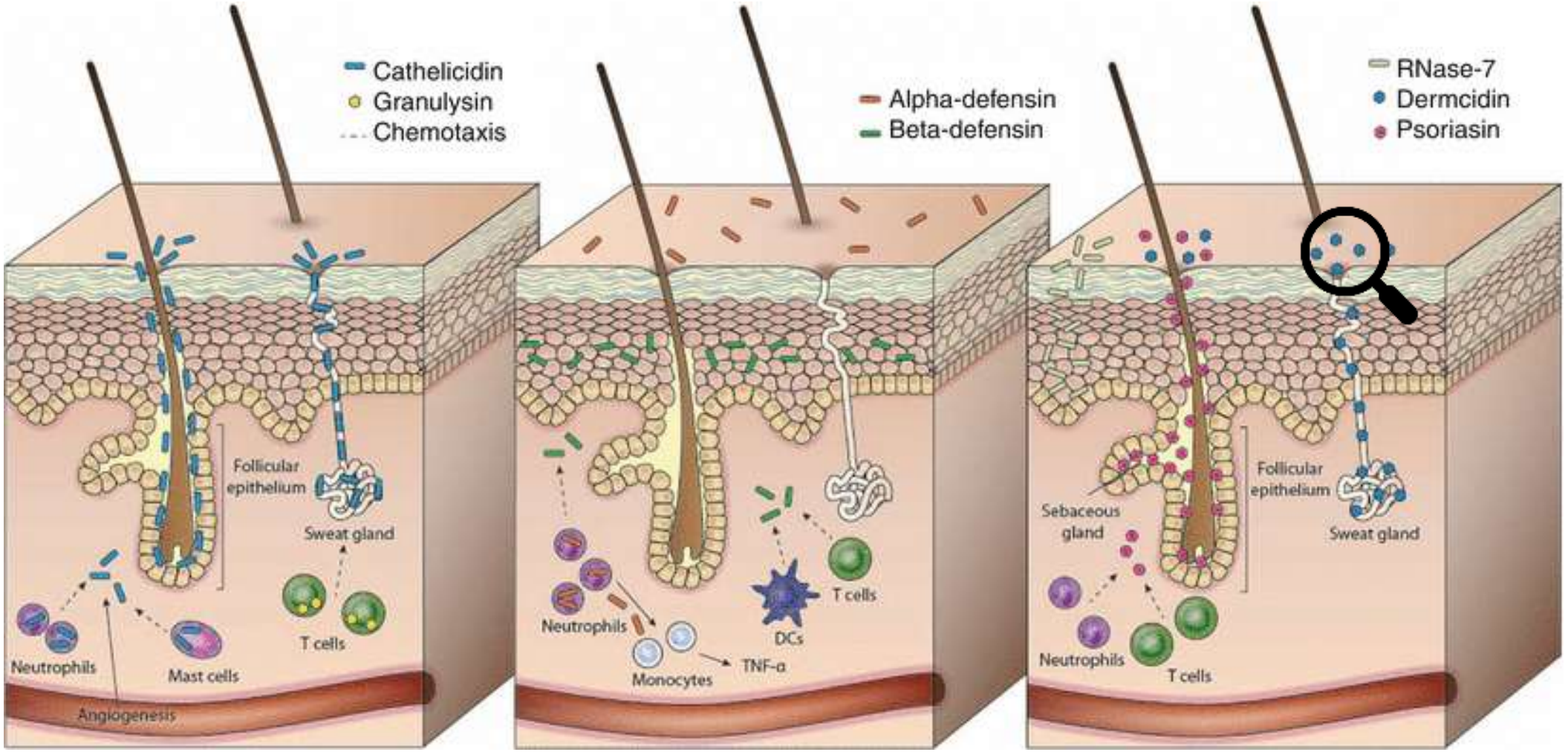
- Coagulation – Filtration – Disinfection

- Most water purification strategies involve sand filtration
  - Improving sand filters in developing countries
    - Prevent fecal contamination based disease outbreaks
    - Could be large community based filters or point of use filter
  - Improving sand filters in developed countries
    - If high microbial removal can be achieved, less chemicals will be used leading to lower formation of disinfection by products

A SOURCE OF INSPIRATION

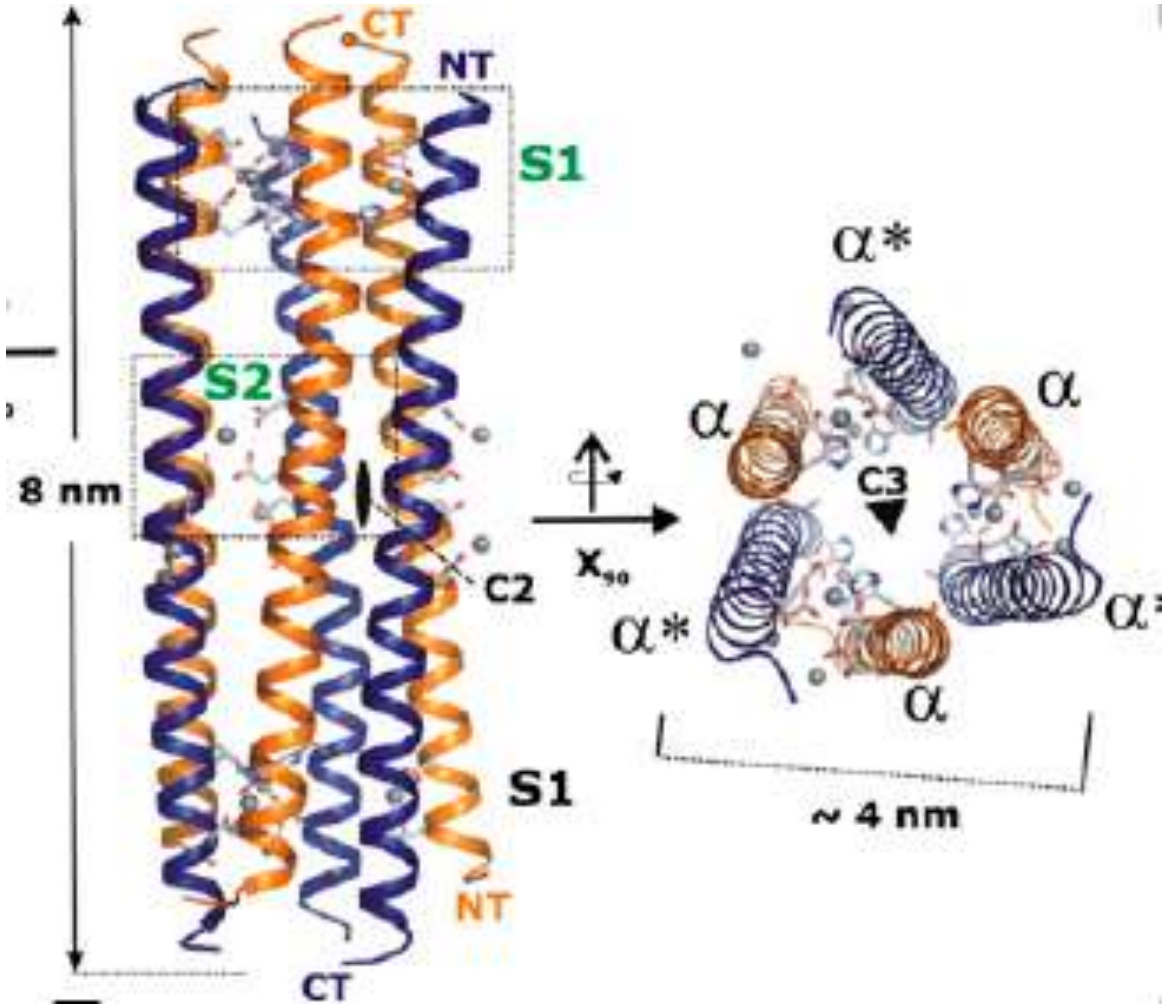
Photo from John Rogers, Northwestern University

THE SWEATY HUMAN SKIN DISINFECTS

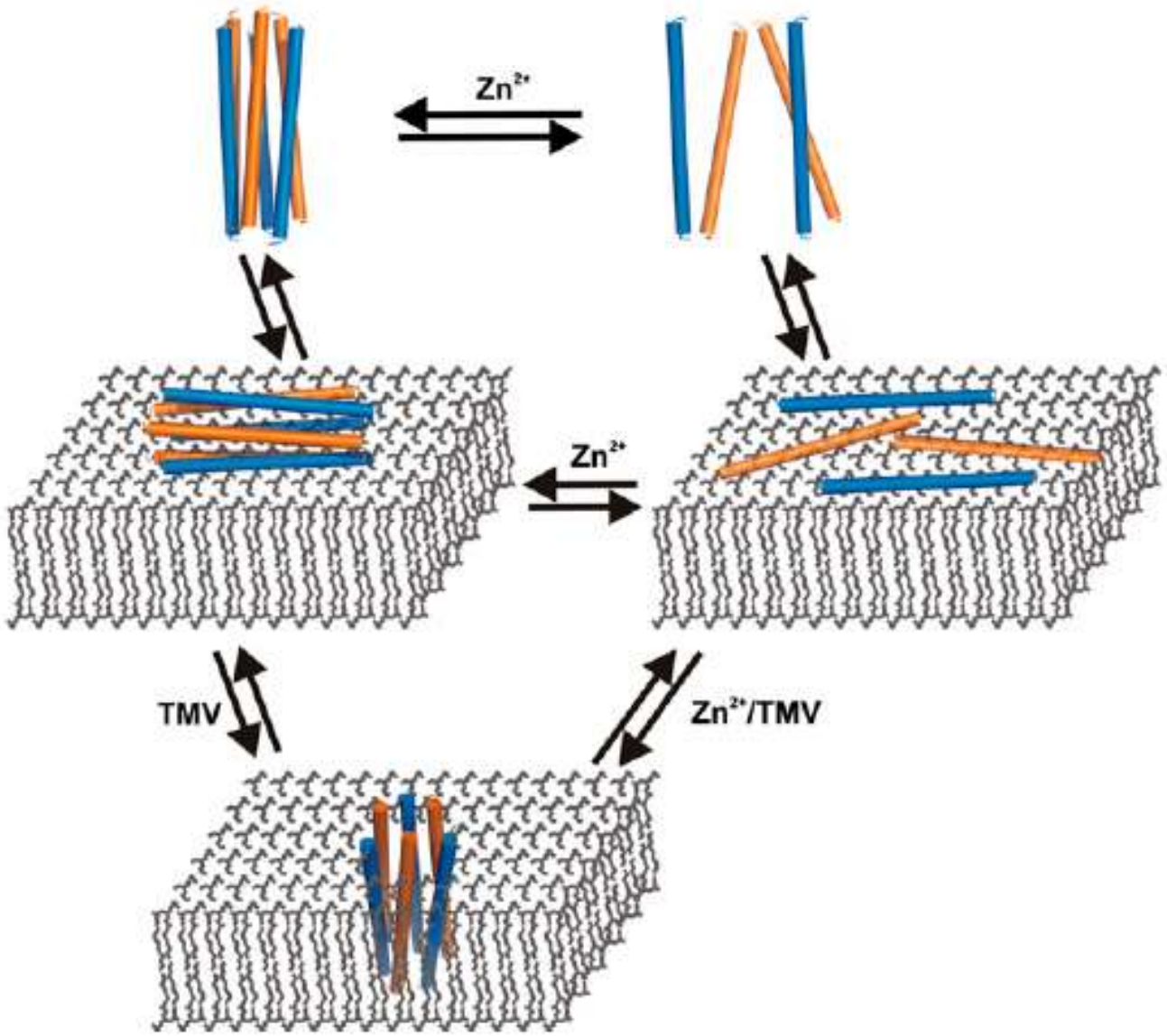


Park et al, Antimicrobial Peptides, Clinical and Basic Immunodermatology (2017) pp 81-95 |

DERMCIDIN IN SWEAT IS A CATIONIC ANTIMICROBIAL PEPTIDE



Song, C., Weichbrodt, C., Salnikov, E. S., Dynowski, M., Forsberg, B. O., Bechinger, B., ... & Zeth, K. (2013). Crystal structure and functional mechanism of a human antimicrobial membrane channel. *Proceedings of the National Academy of Sciences*, *110*(12), 4586-4591.



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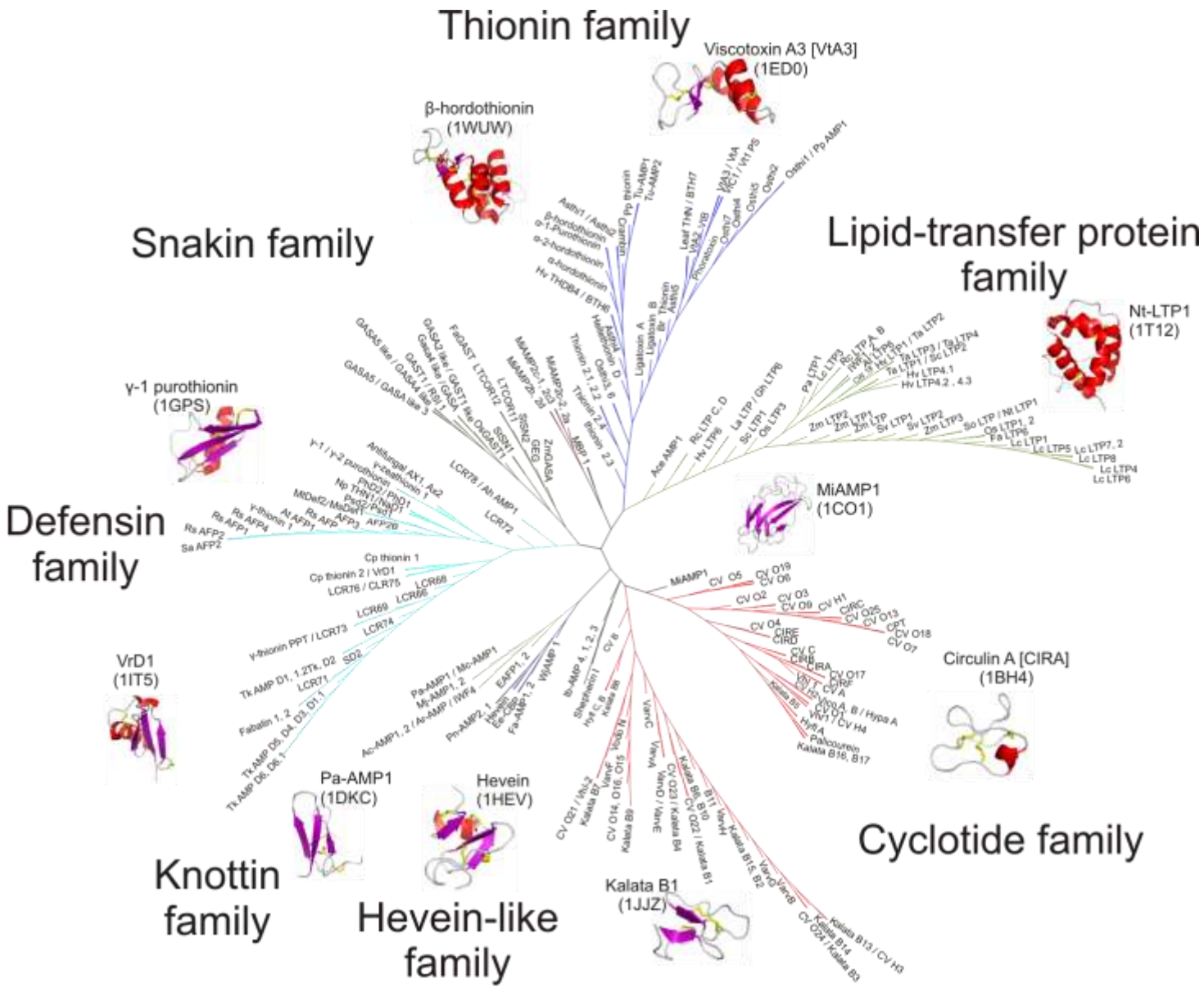
PLANT ALSO HAVE SUCH DEFENSES



ANTIMICROBIAL SAND FILTERS

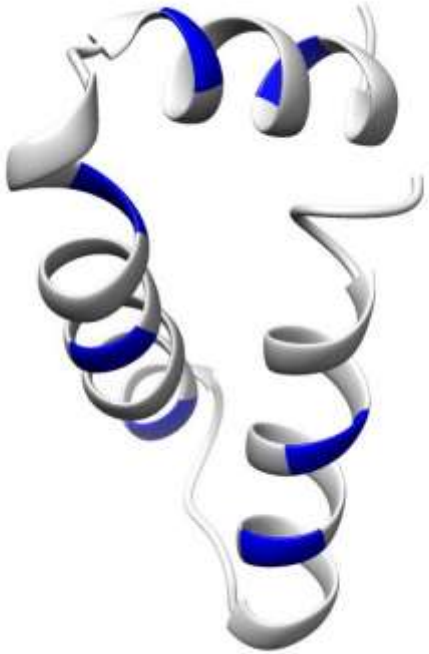
Filtration while disinfection using a plant derived peptide with surprising properties

Moringa oleifera trees offer a locally accessible cost effective antimicrobial peptide

Moringa oleifera tree

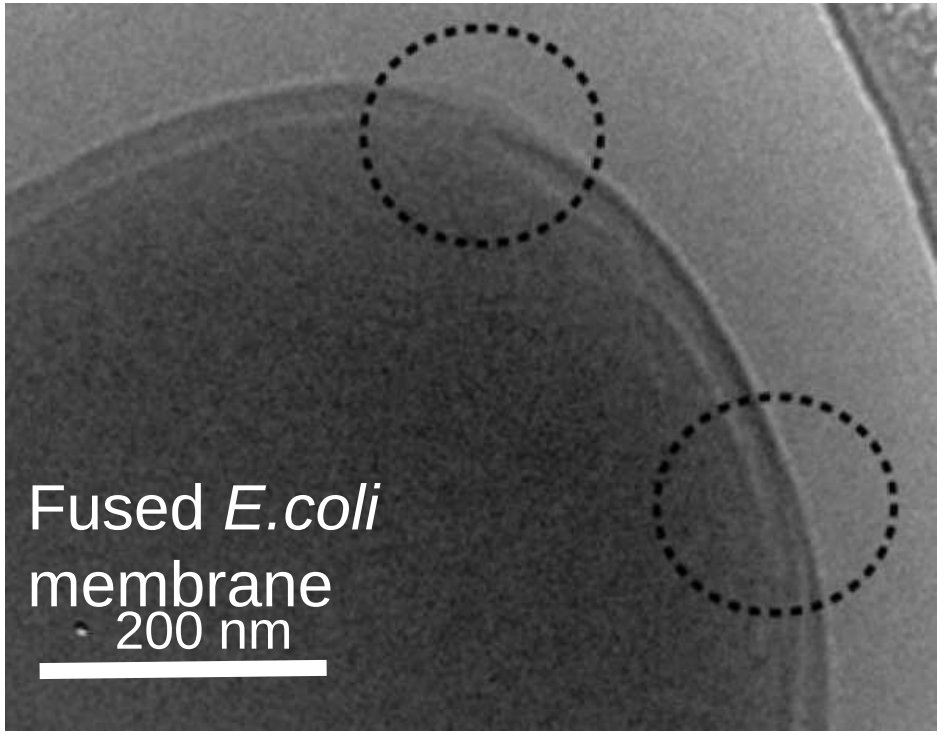
Moringa oleifera dry seeds

Moringa seeds contain a cationic antimicrobial protein that can act as a flocculant



Moringa oleifera cationic protein ($MOCP_{2.1}$)

Net positive charge



Amphiphilic nature

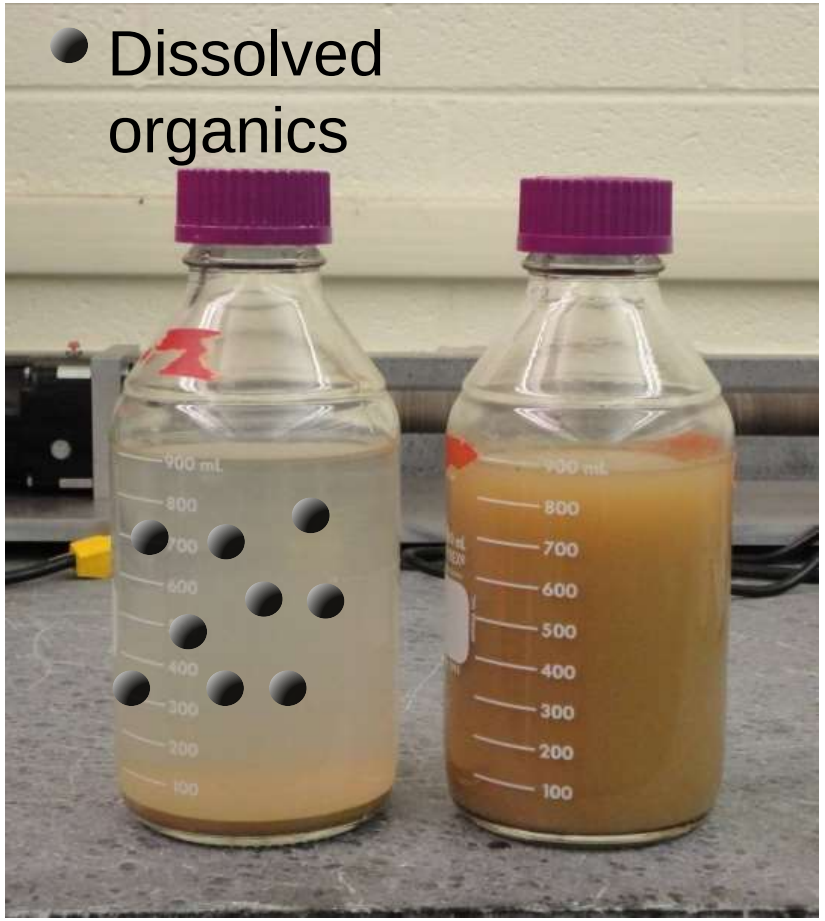
Shebek, Kevin, et al. *Langmuir* 31.15 (2015): 4496-4502.

Suarez, Mougli, et al. *Antimicrobial agents and chemotherapy* 49.9 (2005): 3847-3857.

Flocculation and sedimentation is not effective water treatment with just seed extracts

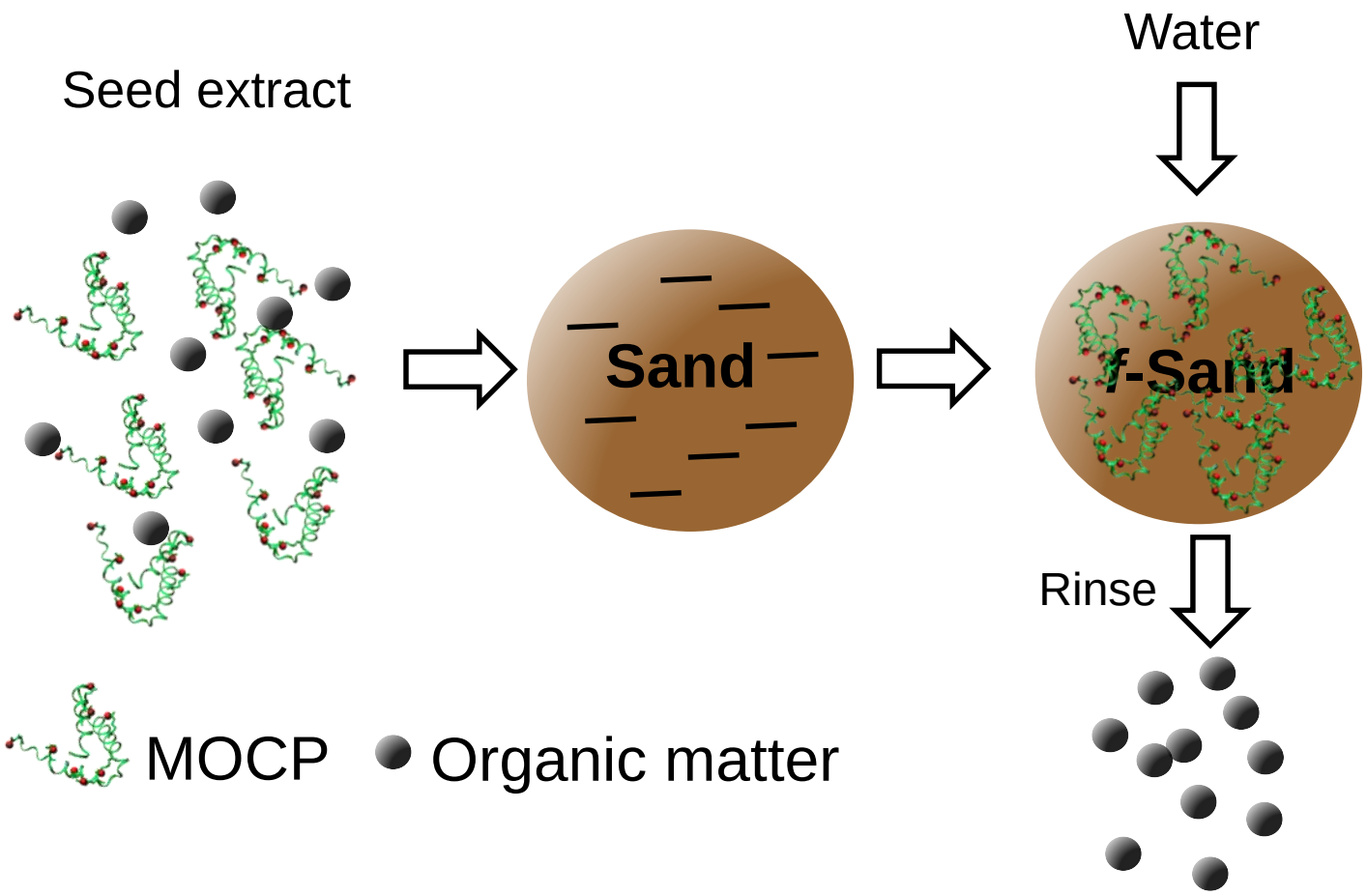
- Dissolved organic matter causes regrowth of pathogens

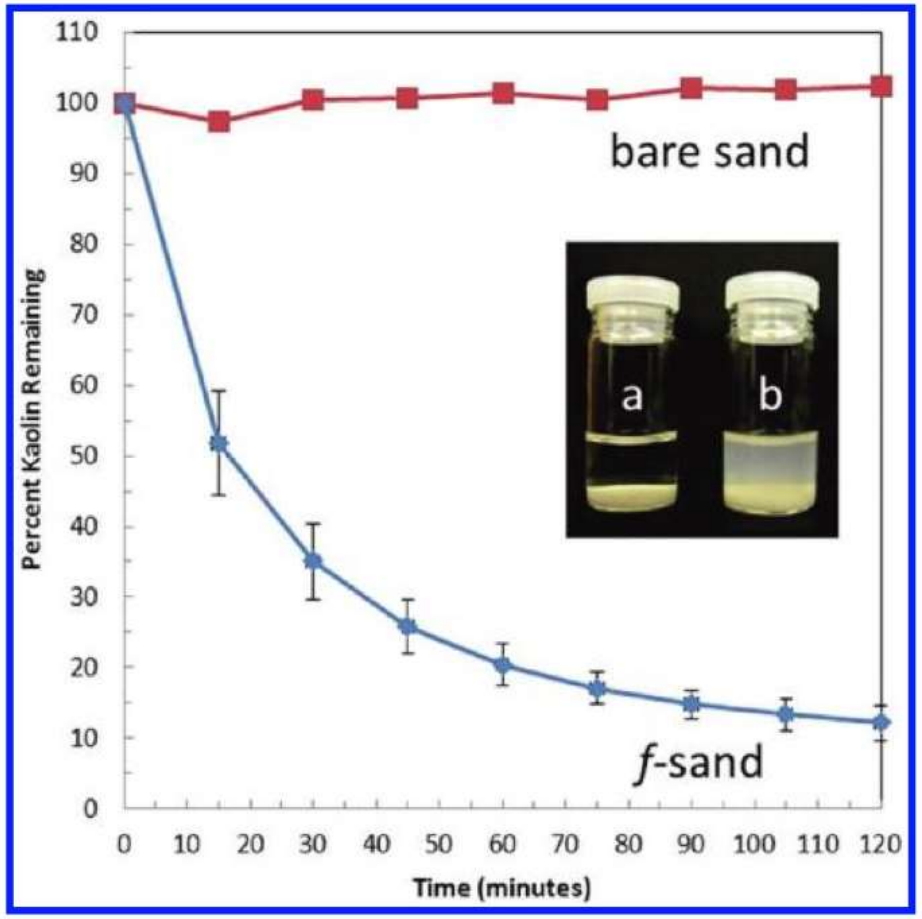
- Low removal efficiency (only 90-99 %, 2 log removal)
  - EPA standards – 4-6 Log removal



Ndabigengesere, A., Narasiah, K. S., & Talbot, B. G. (1995). *Water research*, *29*(2), 703-710.

Adsorption of MOCP onto sand allows removal of organic contamination and results in antimicrobial surface.





Jerri *et al*. *Langmuir* (2012): 2262-268

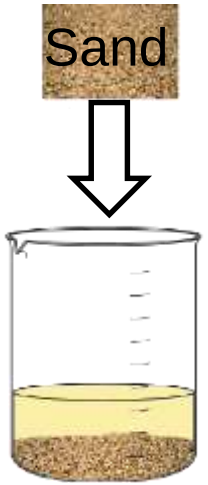
Moringa f-sand filter preparation and design

Crush

5 min mixing

Filter

Seed cake

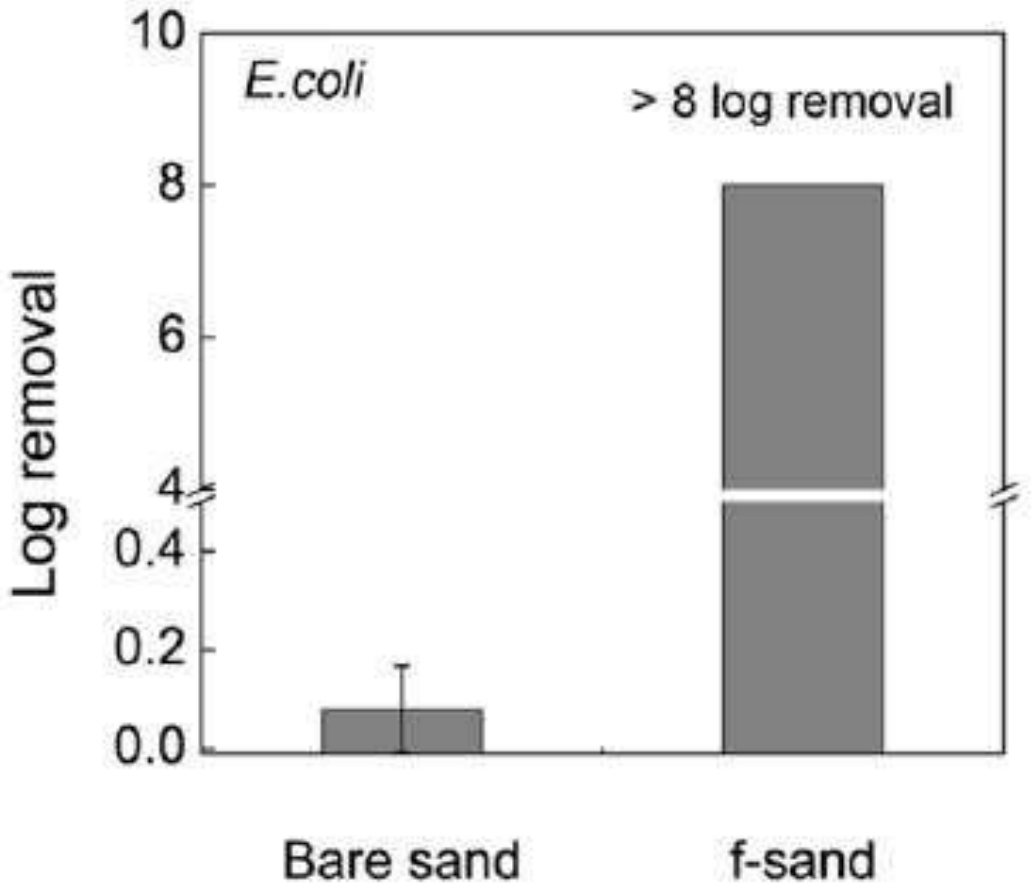


Rinse

Pack

Particle and pathogen removal

Moringa f-sand filter enhances bacterial removal



Xiong, Boya, et al. *Environmental Science & Technology Letters* 5.1 (2017): 38-42.

What is the mechanism?

- Electrostatic enhancement of interaction between bacteria/particles and the sand particles (collectors) in filter
  - Why are electrostatic filters not used in every plant?
    - Not needed – particles grow after coagulation
  - Can electrostatic enhancement of sand filters lead to additional benefits such as lowered chemical dosage for disinfection?

- Disinfection through bacterial membrane damage

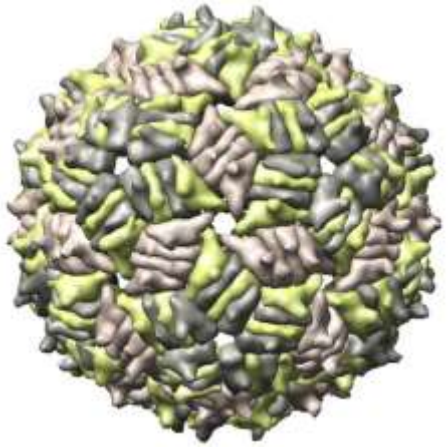
Bacterial Contamination is not the only challenge

- Bacterial removal is not the only challenge with wastewater contamination of drinking water seen in both developing and developed countries
- Viral contamination is also widespread and harder to detect and treat in developing and developed countries
  - Fecal contamination a large source of viruses
  - Affects water supplies directly as well as food through irrigation
  - Rotavirus, Norovirus among most commonly implicated for outbreaks (from food and drinking water)

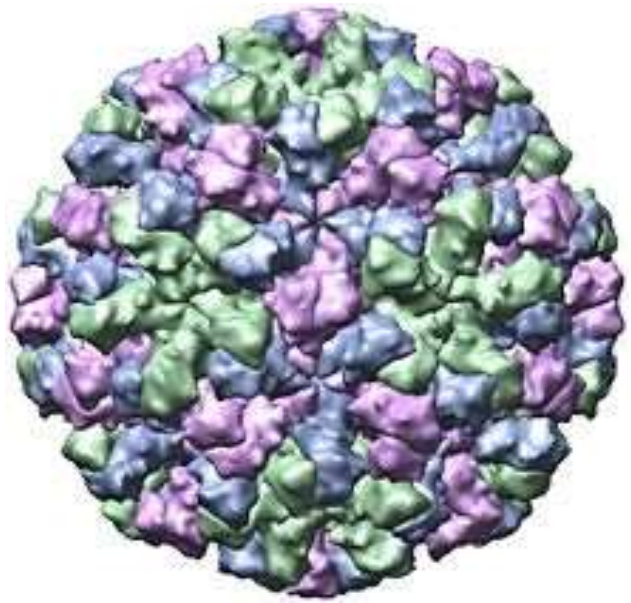
Viral contamination difficult to diagnose and treat

- Difficult to diagnose in resource poor settings (DNA based techniques)
- Treatment using disinfection of water or boiling?
  - Too small to filter easily (< 50 nm)!
  - Disinfection not simple in developing countries
  - Disinfection residual challenges even in developing countries
  - Boiling highly energy intensive
  - Need for a simple point of use treatment technique

MS2 is used as a surrogate for Rotavirus and Norovirus



MS2



Norovirus

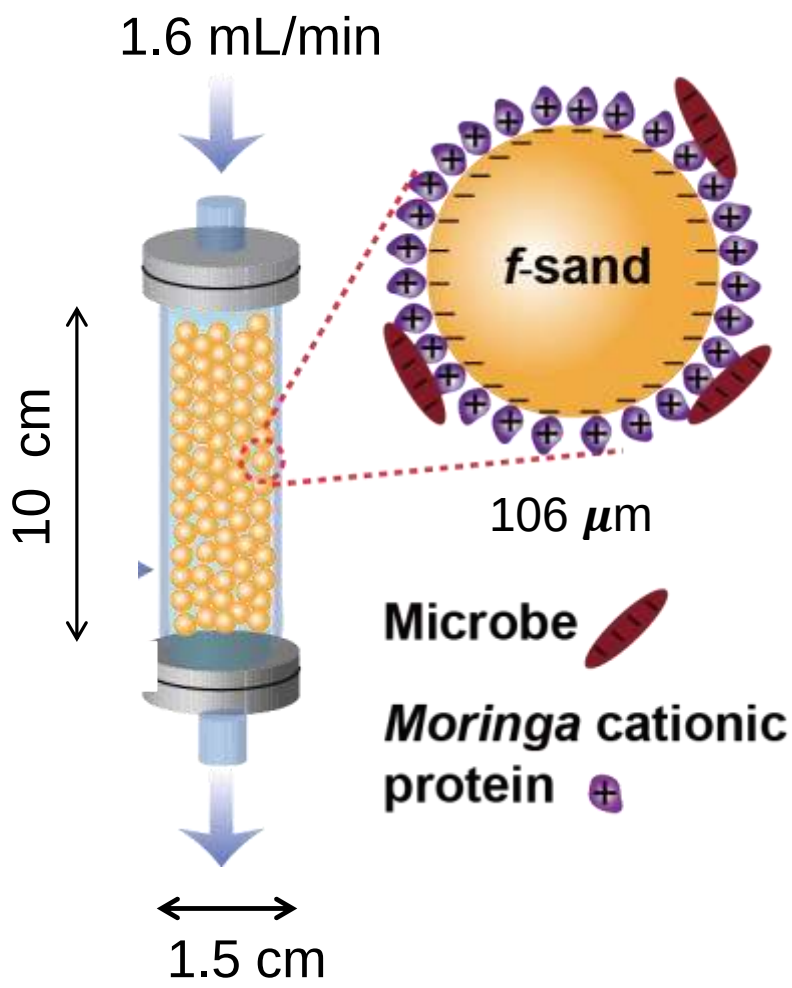
- Safe (a bacteriophage)
- Easy to propagate and quantify concentration
- Strong positive correlation between removals of MS2 and Norovirus and Rotavirus

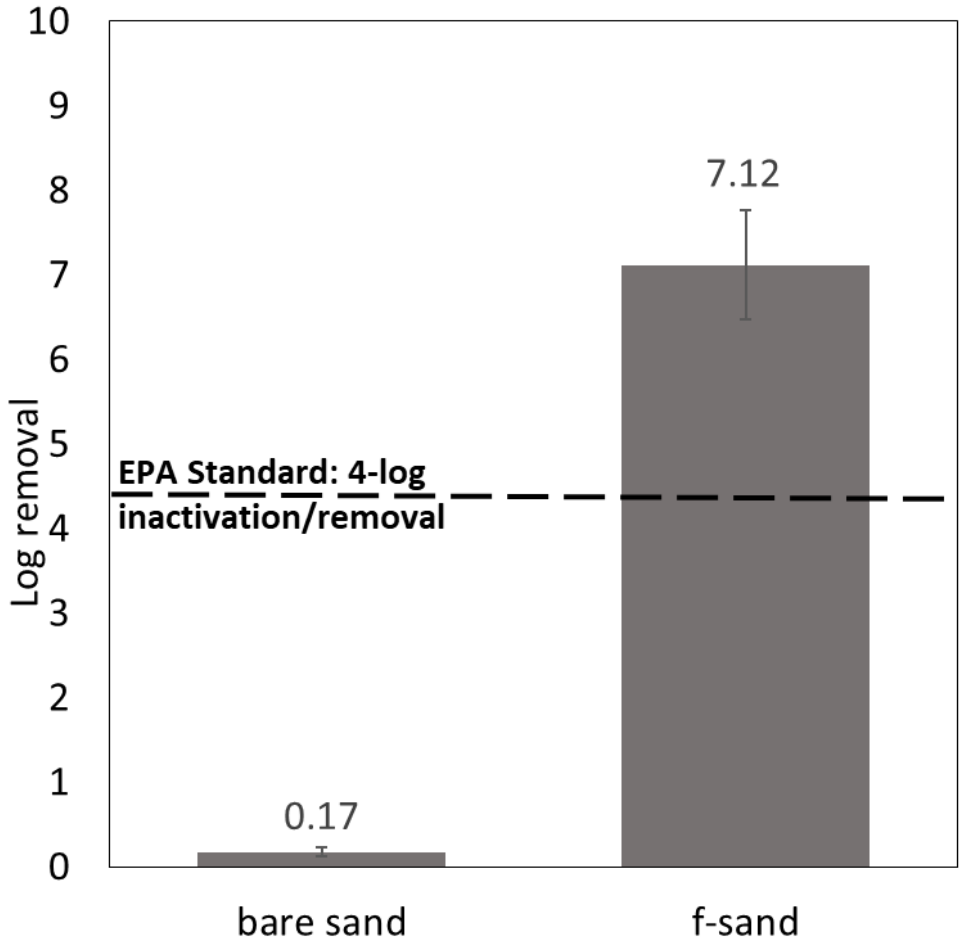
MS2 bacteriophage is used as a model contaminant due to structural similarities with human enteric viruses

Prasad et. Al. *Science*. **1999.** *286*(5438), 287-290
Grahn et. al. *RNA*. **2001**. *7*(11), 1616-27

Pouillot, Régis, et al. *Applied and environmental microbiology* (2015): AEM-00509.

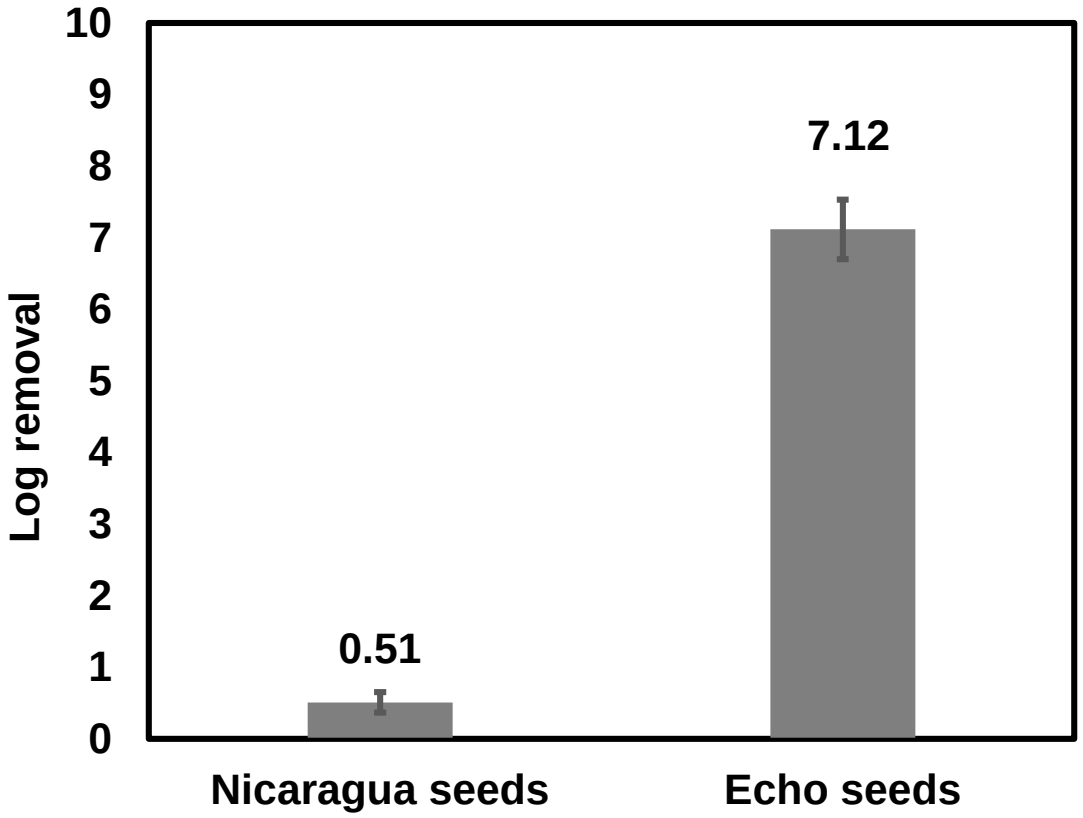
f- sand filters remove ≈ 7 log (99.99999 %) MS2 under some conditions!





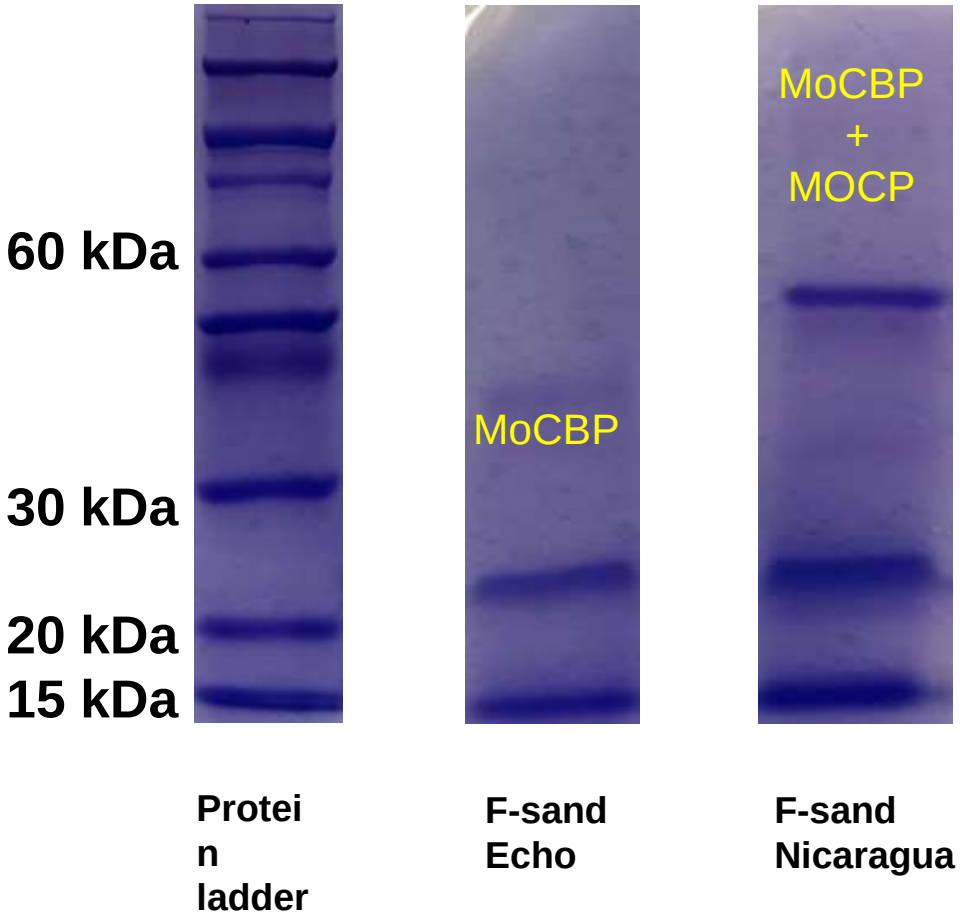
But this removal was not consistent!

Protein composition of water extract and *f*-sand has correlation with MS2 virus removal



	Chitin binding protein (MoCBP)	Coagulant protein (MOCP 2.1)
Echo seed f-sand	✓	✓
Nicaragua seed f-sand	✓	

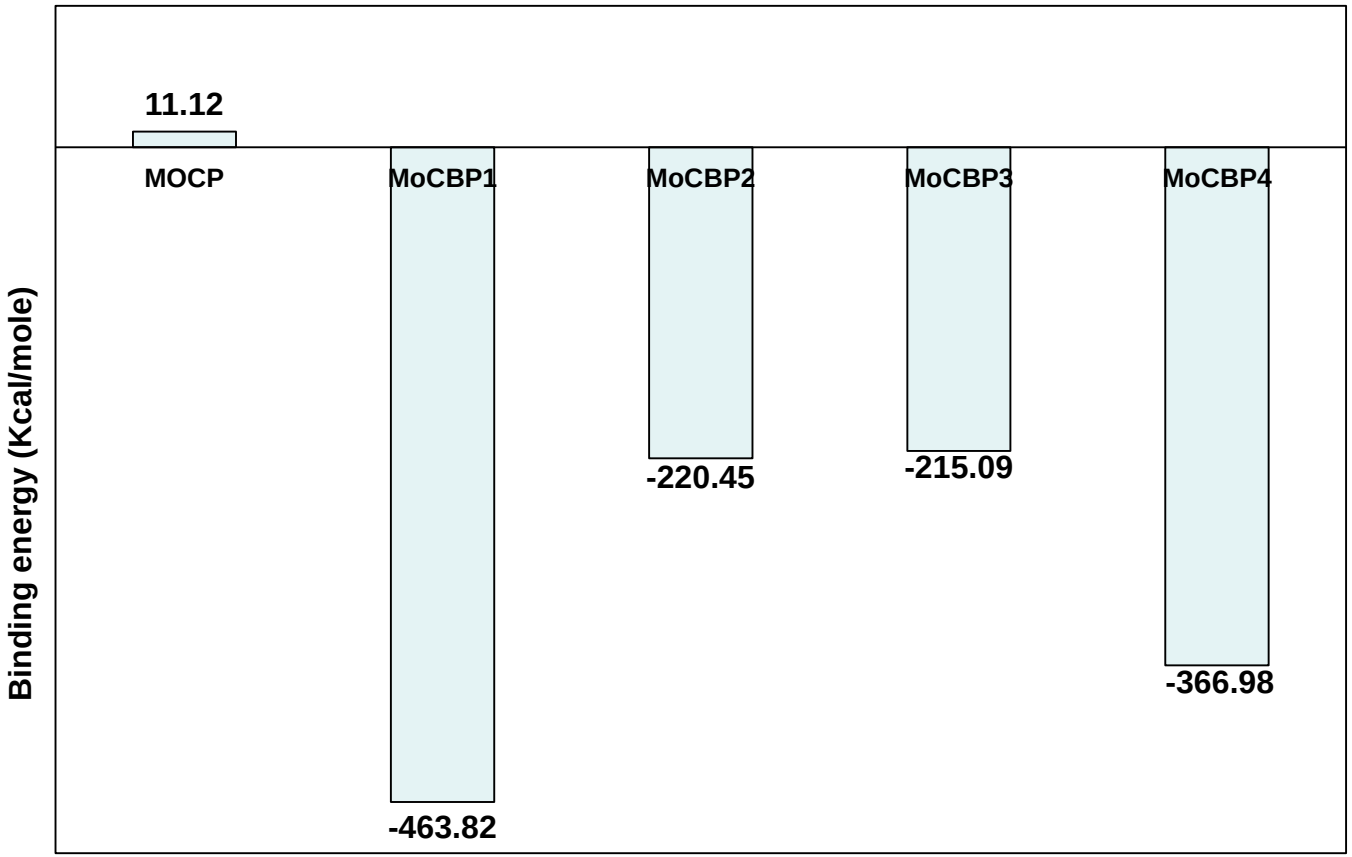
Mass spectroscopy results show that presence of MOCP on *f*-sand hinders MS2 removal



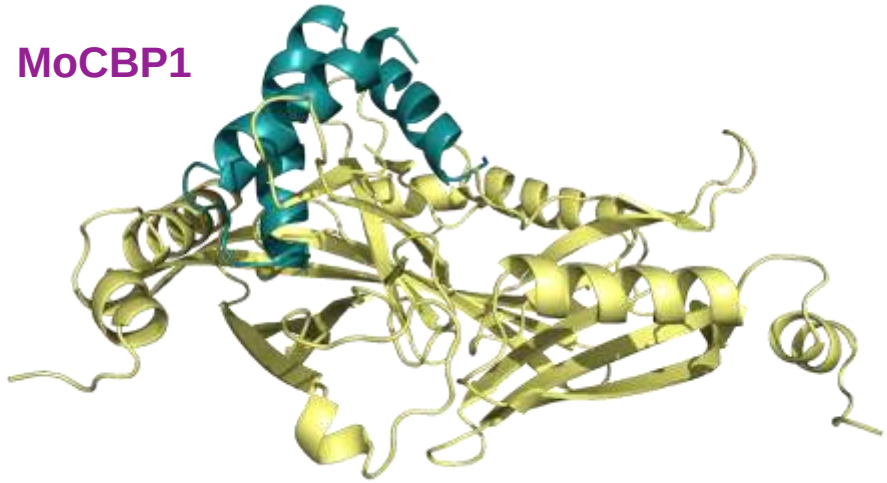
- Presence of *Moringa Oleifera* coagulant protein ($MOCP_{2.1,2.2}$) hinders interaction of *f*-sand with MS2
- Reason behind the differences in coating of *f*-sand?
- Why does MoCBP have favorable interaction with MS2 ?

MoCBP preferentially binds to MS2 capsid protein!

In-Silico binding scores



MoCBP1

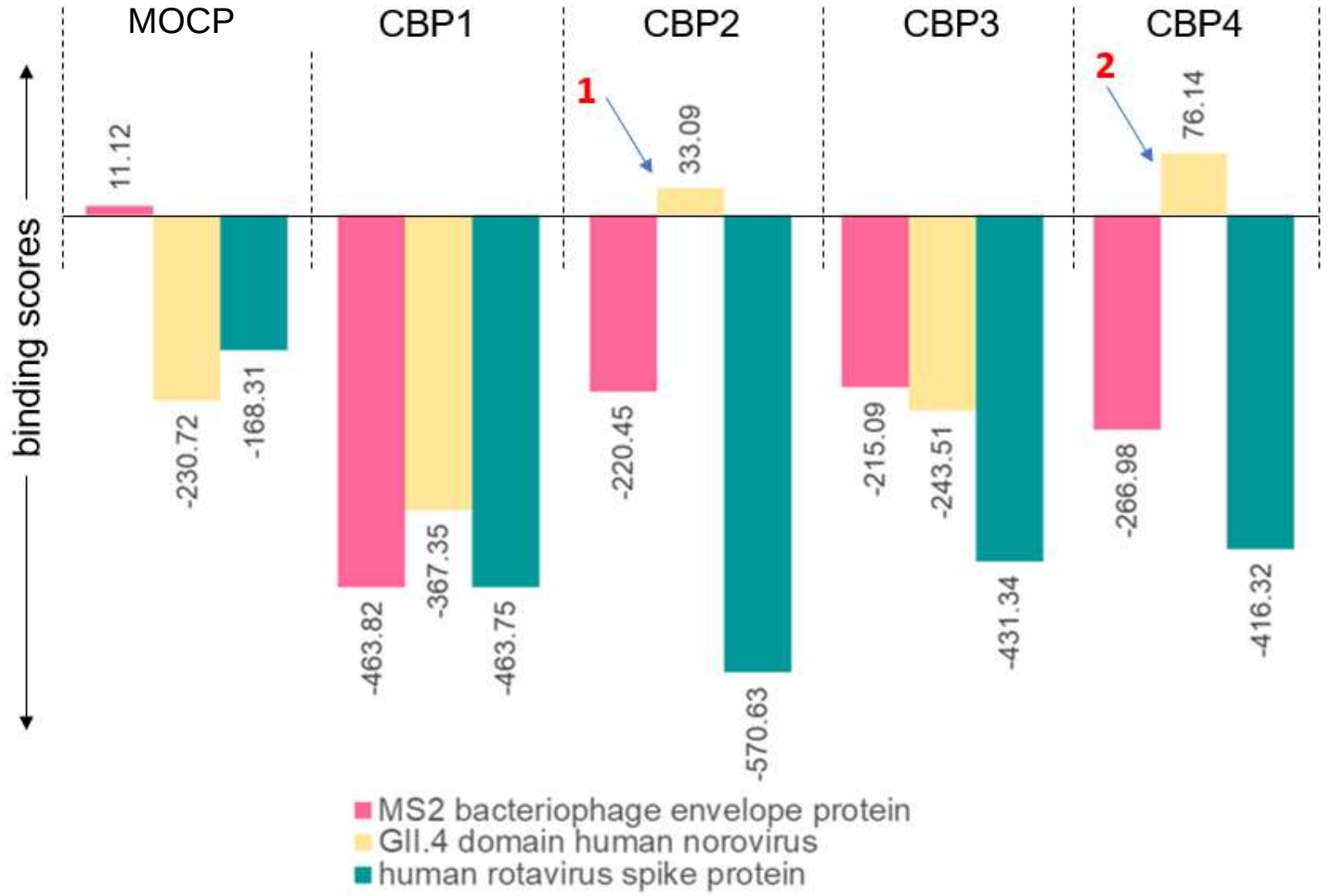


MS2 capsid protein

MOCP 2.1

MS2 capsid protein

How about “real” human viruses?


MOCP
CBP1
CBP2
CBP3
CBP4
binding scores
1
2
11.12
-230.72
-168.31
-463.82
-367.35
-463.75
-220.45
33.09
-570.63
-215.09
-243.51
-431.34
-266.98
76.14
-416.32
MS2 bacteriophage envelope protein
GII.4 domain human norovirus
human rotavirus spike protein

SUMMARY AND OUTLOOK

- Biological systems provide excellent ideas for implementation in many areas
- Antimicrobial peptides are an excellent examples of bioinspired ideas for natural biological control
- Moringa seeds represent the promise of host defense antimicrobial peptides that can be sustainably sourced
- Sand adsorbed moringa proteins can enhance this age-old technology to become high performance filters
- Plant AMP protein *f*-sand filters may hold promise for combating viral and bacterial contamination of drinking

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