Better lives through livestock

Harnessing bacteriophages for mastitis prevention in Kenyan goat farms

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Health Program - ILRI

WOAH-English Speaking Africa Workshop on
Vaccination and Alternatives to Antimicrobials

Entebbe, Uganda
29 October 2025

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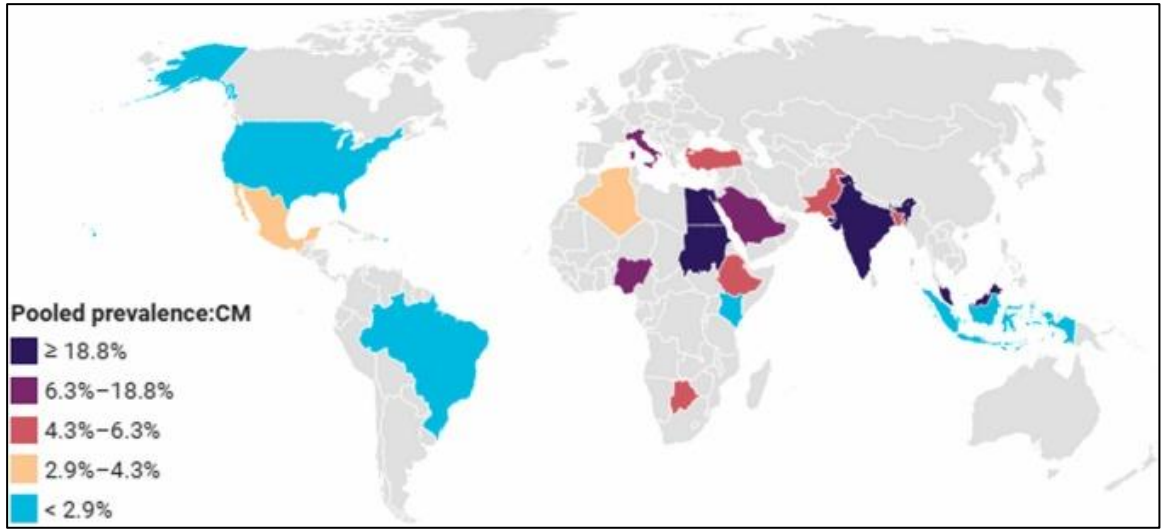
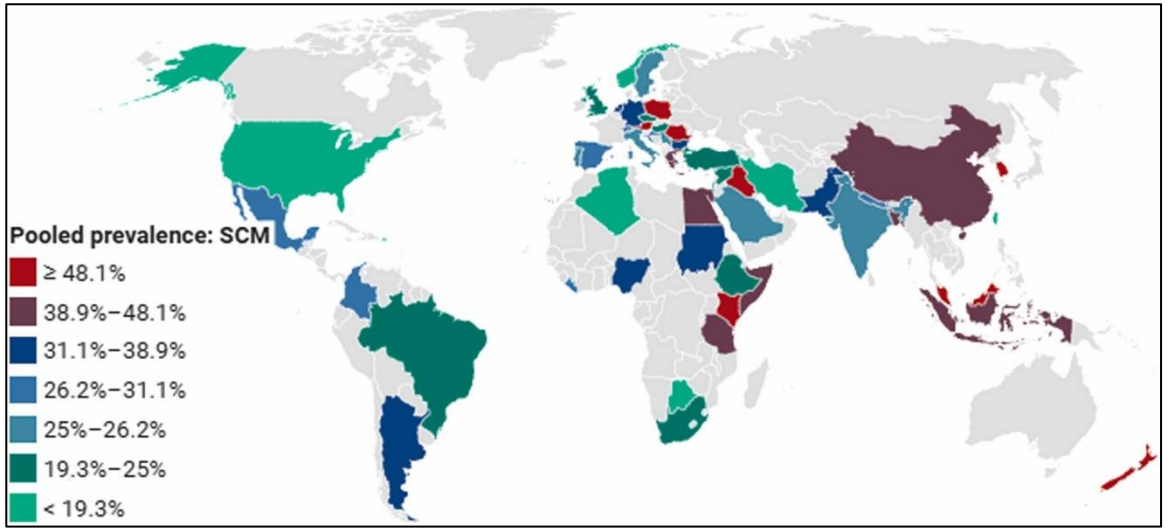
A Samburu woman pastoralist benefiting from goat farming. Samburu, 2023.

Mastitis – A Global Challenge in Goats

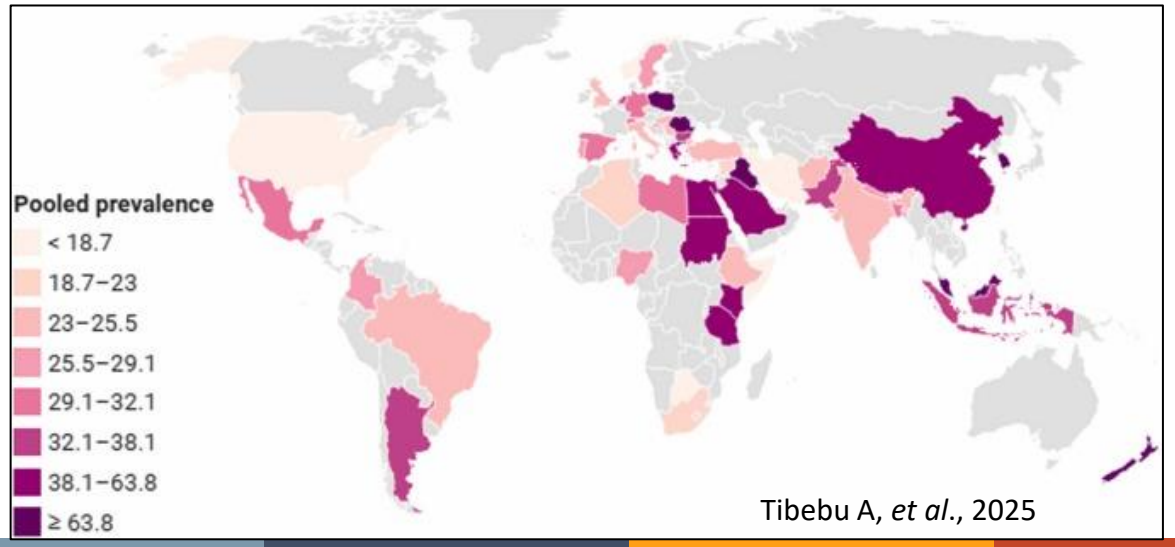
Pooled prevalence of CM at goat level studies by country



Subgroup pooled prevalence of SCM by country at goat level



Pooled prevalence of mastitis at goat level by countries



Tibebu A, *et al*., 2025

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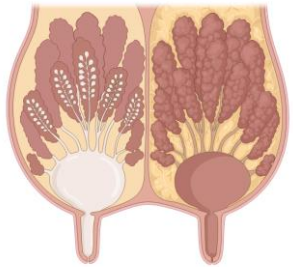
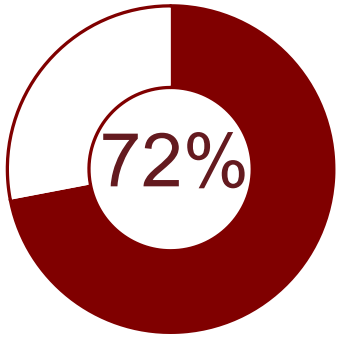
Mastitis and Its Impact on Goat Farming

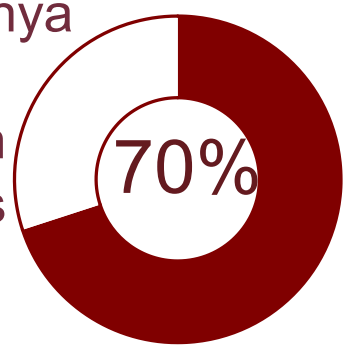
Intramammary inflammation of the udder

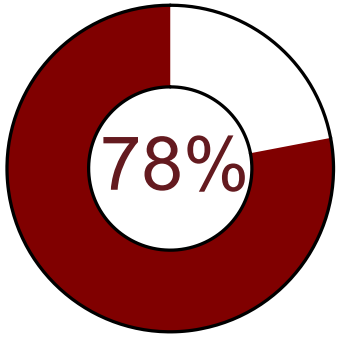




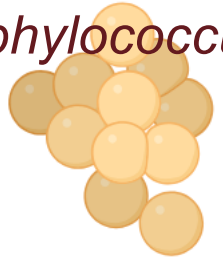
The proportion of goats affected by subclinical mastitis in some parts of Kenya

The reduction in milk production in goats with clinical mastitis

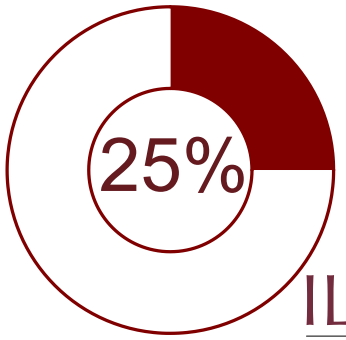




Cases of mastitis in small ruminants caused by *Staphylococcus sp*.



Production losses due to subclinical mastitis in goats.



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Goat Farming in Kenya

28 M goats in Kenya

17 M cattle

17 M sheep

2.8 M households keep goats (24% of the Kenyan population/40% of livestock-keeping households)

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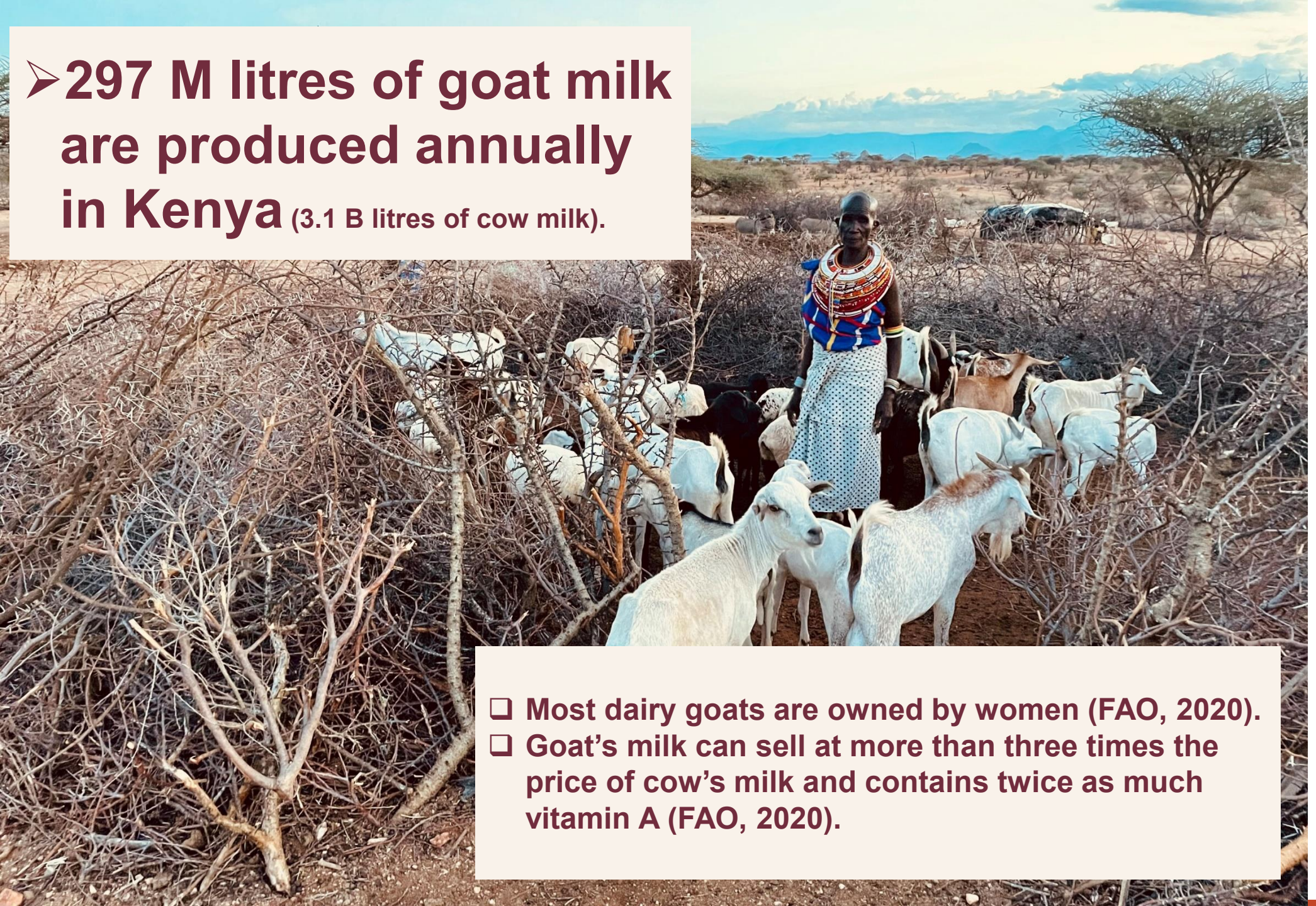
Goat Farming in Kenya



- **297 M litres of goat milk are produced annually in Kenya (3.1 B litres of cow milk).**

- **Most dairy goats are owned by women (FAO, 2020).**
- **Goat's milk can sell at more than three times the price of cow's milk and contains twice as much vitamin A (FAO, 2020).**

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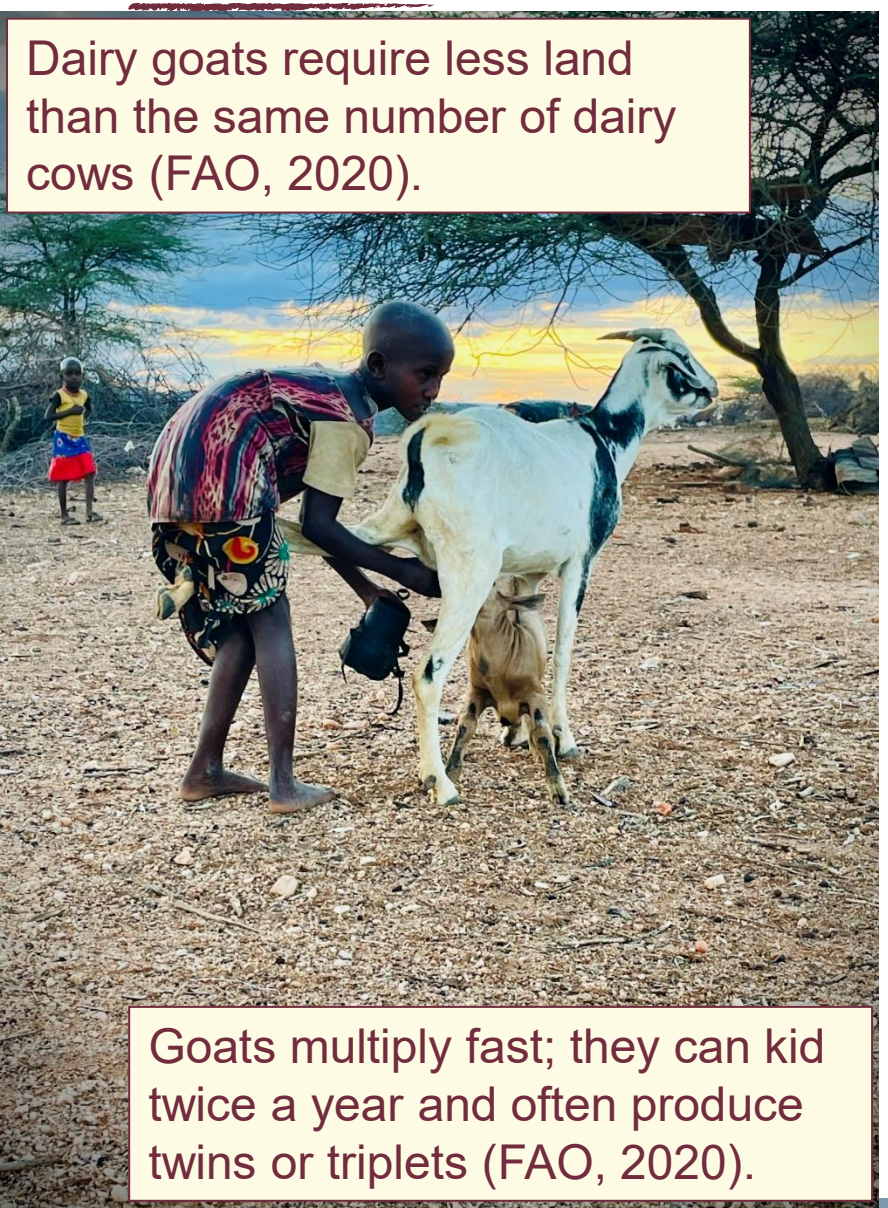
The Advantages of Dairy Goat Farming for Women

Dairy goats require less land than the same number of dairy cows (FAO, 2020).



Goats multiply fast; they can kid twice a year and often produce twins or triplets (FAO, 2020).

- Half a hectare of Napier grass can support five dairy goats but only one dairy cow.
- Goat's milk can generate value-added products, such as cheese and yogurt.
- Older female goats and surplus males can be slaughtered or sold for meat.
- Goats can consume shrubs that are not eaten by other livestock.

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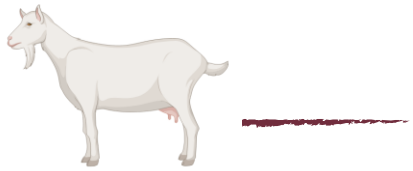
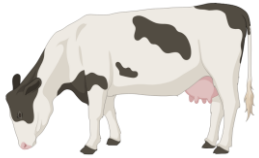
Mastitis Management in Goats and Cow - Kenya



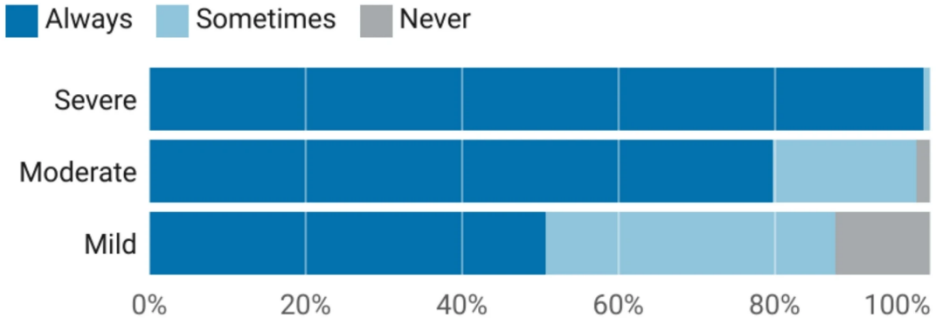
Antibiotics used in Goat Farms in Narok and Kajiado Counties (Josiah Odaba, *et al.*, in preparation)

Drug Name (Brand)	Antibiotic Content (Active Ingredient)
ENROFLOX or **ENRONOR** (Enrofloxacin Solution 10%)	**Enrofloxacin** (Fluoroquinolone class)
TYLONOR (Tylosin 20%) or **TYLOSIN** (Dawa Tylosin)	**Tylosin** (Macrolide class)
TYSIEIN 20% (Tylosin Tartrate 20%)	**Tylosin Tartrate** (Macrolide class)
OXYCYCLINE (Oxycycline Plus, OXYCYCLINE spray)	**Oxytetracycline** (Tetracycline class)
Oxytetra 10%	**Oxytetracycline** (Tetracycline class)
Pen & Strep (Penicillin & Streptomycin Sulphate)	**Penicillin** and **Streptomycin Sulphate** (Beta-lactam and Aminoglycoside classes)
ADAMYCIN 10% (Injectable Solution)	Likely a form of **Oxytetracycline** or **Tylosin** (Common 'mycin' suffix in veterinary antibiotics) or **Amoxicillin**
ABAMYCIN LA 20% (Oxytetracycline Injection 20%)	**Oxytetracycline** (Tetracycline class)
CENTRE PENSTREP	**Penicillin** and **Streptomycin**
TETROXY LA 20% (Oxytetracycline 200mg/ml solution)	**Oxytetracycline** (Tetracycline class)
MERIQUIN (Enrofloxacin Injection 10% w/v)	**Enrofloxacin** (Fluoroquinolone class)
TWIGAMYCIN (Oxytetracycline 10% injection)	**Oxytetracycline** (Tetracycline class)
VETOXY 10% (Oxytetracycline 10%)	**Oxytetracycline** (Tetracycline class)
TETRA	Likely **Oxytetracycline**

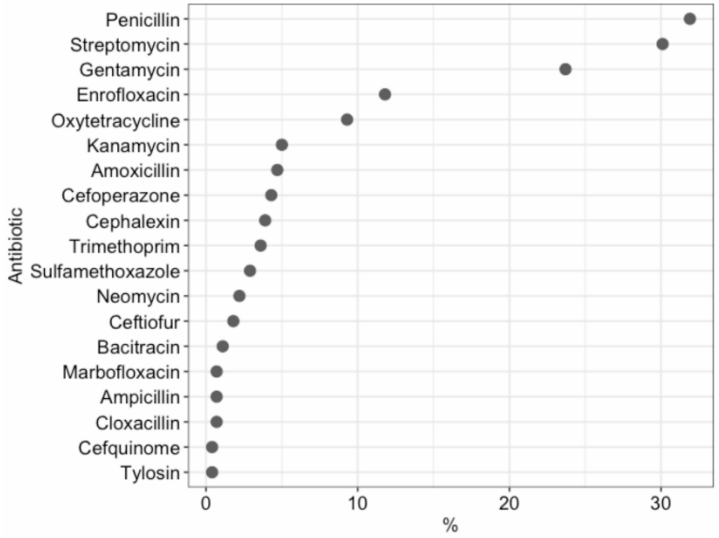


Dishon MM., *et al.*, 2025

"Mastitis drives antibiotic use, worsened by limited diagnostics and treatments in low-income areas."



Treatment strategies and antibiotic usage practices in mastitis management in Kenyan smallholder dairy farms



Treatment strategies and antibiotic usage practices in mastitis management in Kenyan smallholder dairy farms.

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Goal: Develop/Design a Phage Cocktail Targeting Mastitis-causing *Staphylococcus sp.* in goats in Kenya

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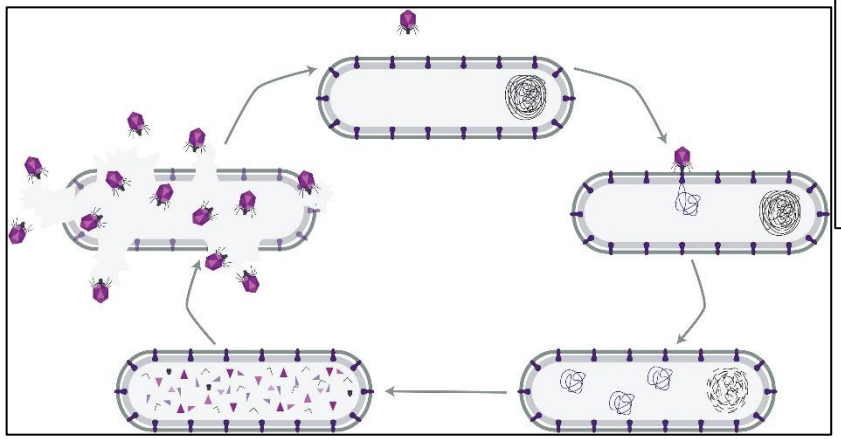
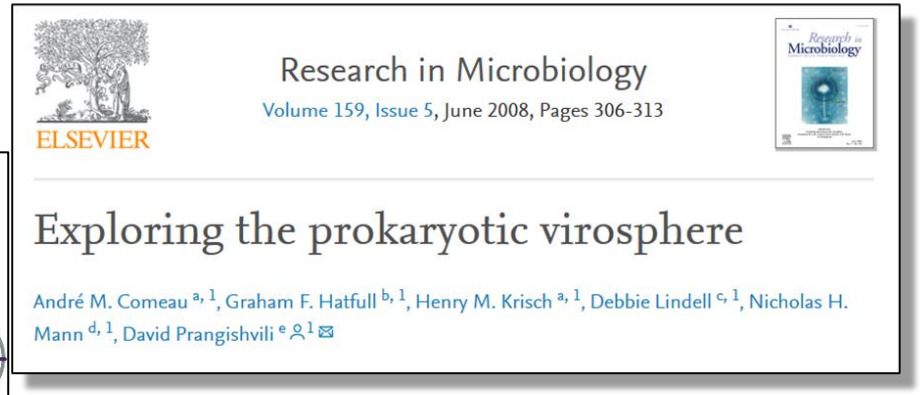
Bacteriophages are the Most Abundant "Lifeform" on Earth

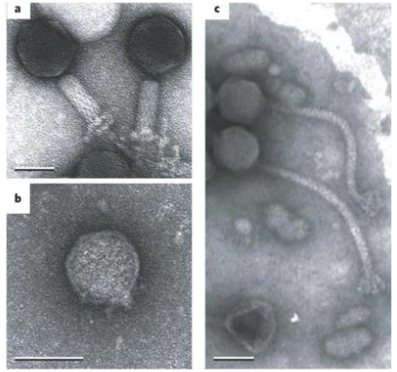
Phages: bacterial viruses able to infect and kill bacteria

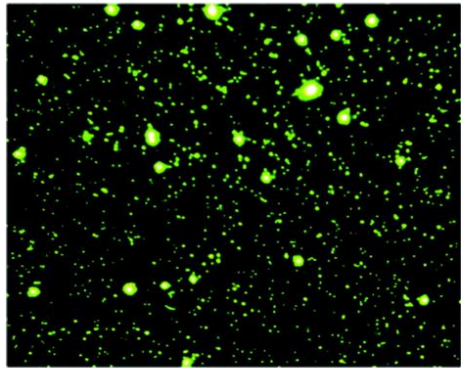


Kaitlyn E. Kortright, *et al*., 2019



- 10^{32} particles on our planet
- Oceans
- Freshwater
- Soil
- Air [up to the stratosphere!]
- Microbiome [animals, humans]
- 10- to 100-fold more abundant than their prokaryotic hosts
- Most abundant entities in feces.





10 to 250 million virus particles per ml in seawater

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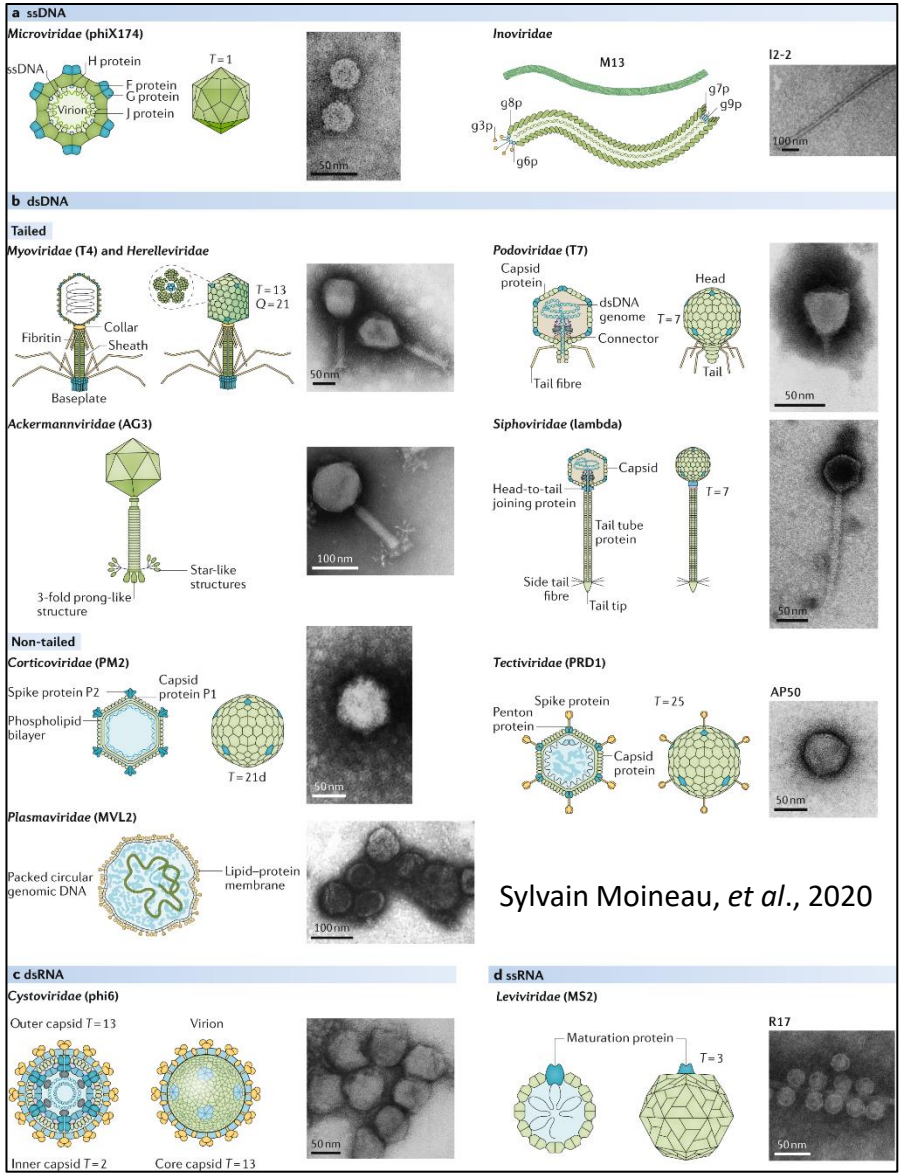
Phages Come in Different Shapes & Sizes



Sylvain Moineau, *et al*., 2020

Phage	Filamentous	T4	T7	λ	MS2	Qβ
Structure	Filamentous	Icosahedron + tail	Icosahedron + tail	Icosahedron + tail	Icosahedron	Icosahedron
Major dimensions	900 nm × 7 nm	120 nm × 86 nm	56 nm × 29 nm	60 nm × 150 nm	26 nm	28 nm

Krystina L. Hess, *et al*., 2019

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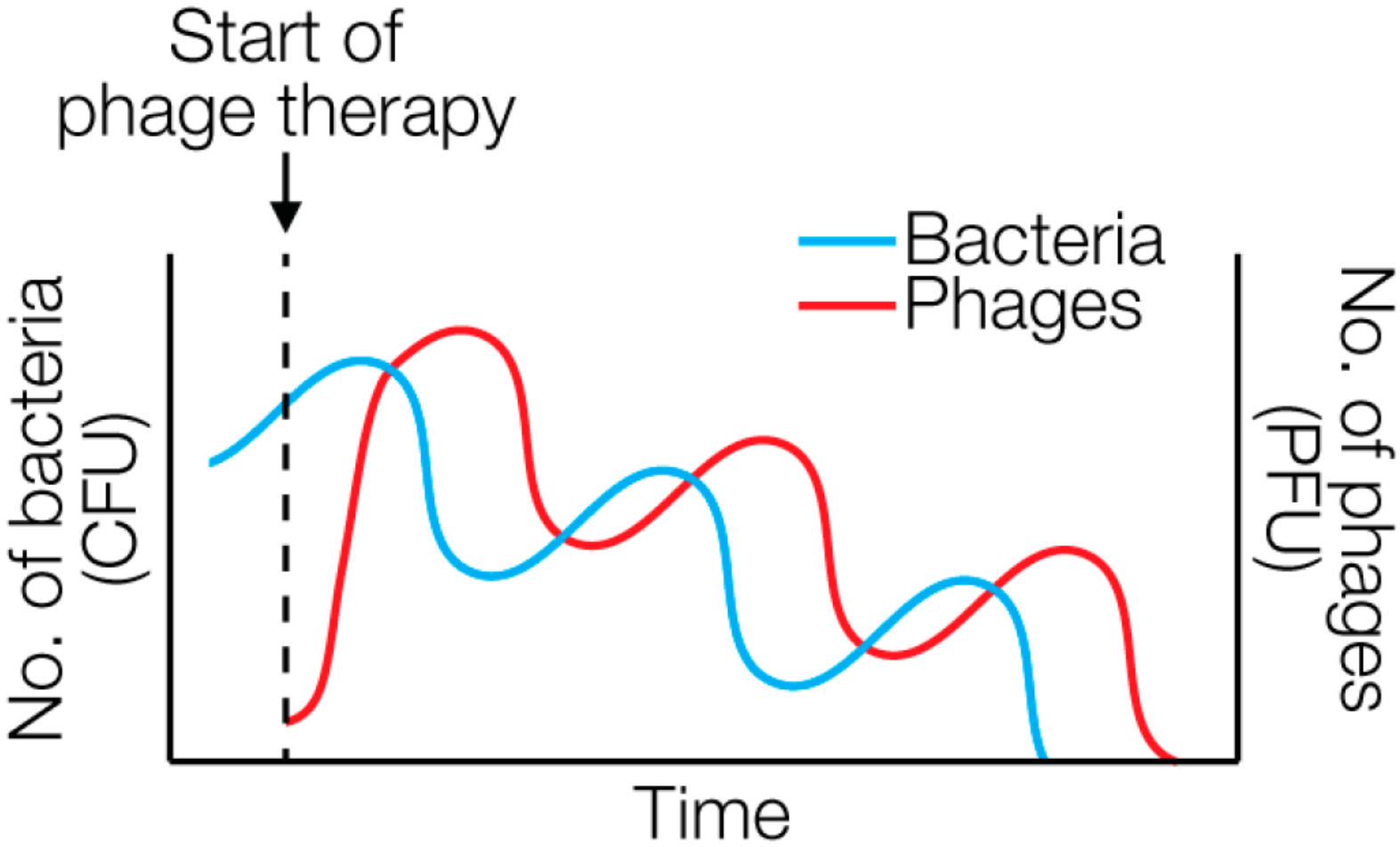
Phages can Self-Amplify

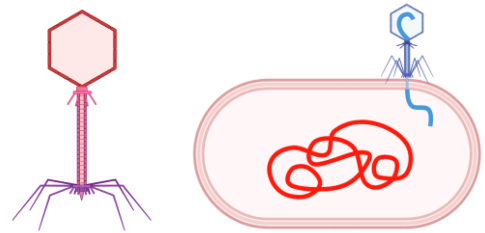
- Larger population sizes [10 to 100 more abundant].
- Shorter generation time compared to their corresponding bacterial host.
- Leads to a higher diversification of the phage community compared to its host.
- Phages are quick to mutate and evolve, and under the same circumstances, phages may switch from a narrow to a broad host range, and back.



Karin Moelling, *et al.*, 2018

Comparing and Contrasting Antibiotics & Phages

Adapted from Kaitlyn E. Kortright, *et al.*, 2019



Activity and Mechanism of Action

Bacteriostatic or Bactericidal		Bactericidal
Typically disrupts **ONE** bacterial process		Disrupts **MANY/ALL** bacterial processes
Broad spectrum more common than narrow spectrum		High degree of species or strain specificity
Disruption of microbiome		Only disrupts target bacteria
Not effective against biofilms		Penetration and destruction of biofilms

Clinical Use

Minimal identification of bacteria		Phage tested against target bacteria
Short time between diagnosis and treatment		Longer time between diagnosis and treatment
Constant dosing to maintain inhibitory concentrations		Self-amplifying while target bacteria are present
Adverse Reactions / TOXICITY		SAFE & no SIDE EFFECTS, **NO WITHDRAWAL PERIOD**

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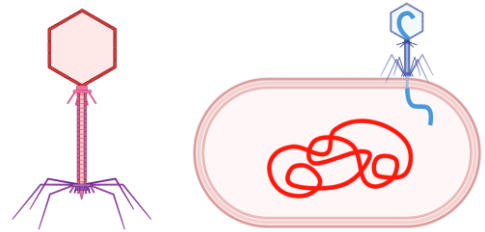
Comparing and Contrasting Antibiotics & Phages

Adapted from Kaitlyn E. Kortright, *et al*., 2019

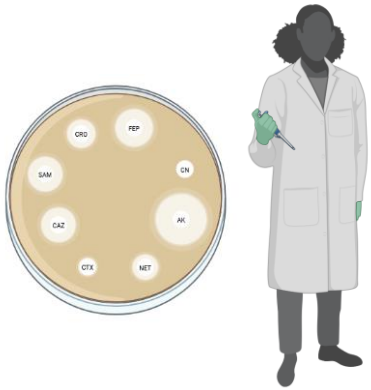


Discovery, Production, and Manufacturing

Slow discovery process

Production methods in place to ensure safety of products

Regulations for production and manufacturing in place



Rapid discovery process

Ensure of removal of contaminating bacterial antigens during production

Require new regulations for production and manufacturing

Resistance

Resistance inevitable

Resistance inevitable, but **phage can co-evolve to infect resistant bacteria [arms race]**
(resistance harder to achieve)

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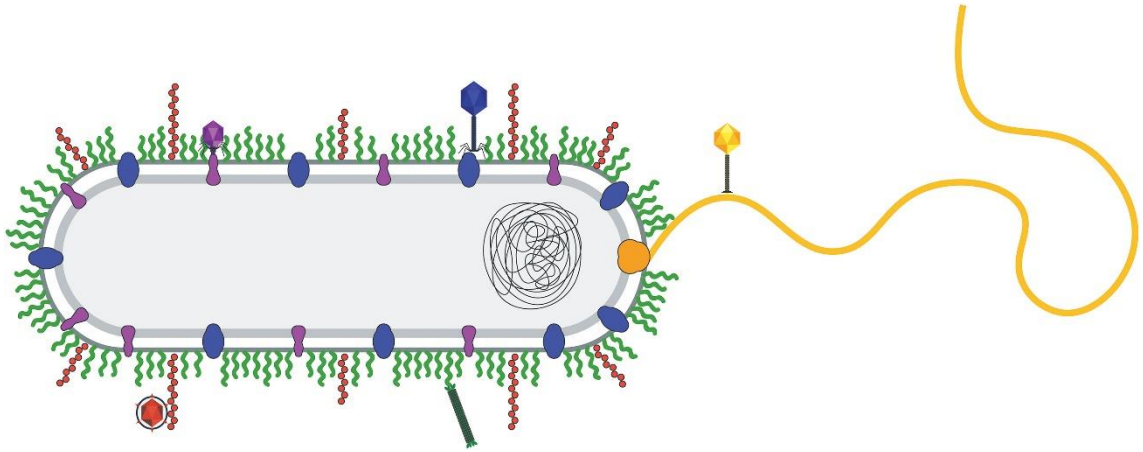
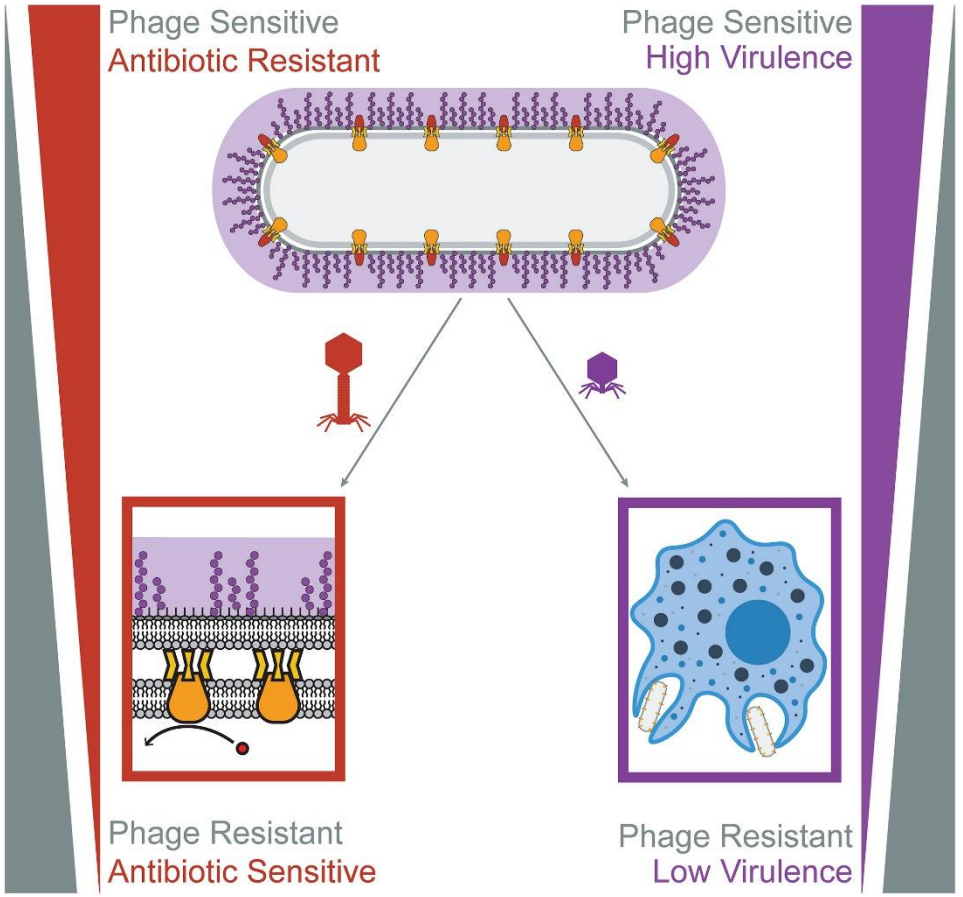
Phage + Antibiotic Synergy



Kaitlyn E. Kortright, *et al*., 2019

Phage encode binding proteins that recognize and attach to sites on the surface of a bacterial cell. Many phage bind to protein structures on the bacteria such as **pili**, **flagella**, **porins**, or **efflux pumps**. Phage have also been reported to bind to specific sugar **moieties in LPS**.



Phage that use antibiotic efflux pumps as receptors (red) can select for phage-resistant bacterial mutants with impaired efflux pumps; these phage-resistant bacterial mutants become more sensitive to antibiotics.

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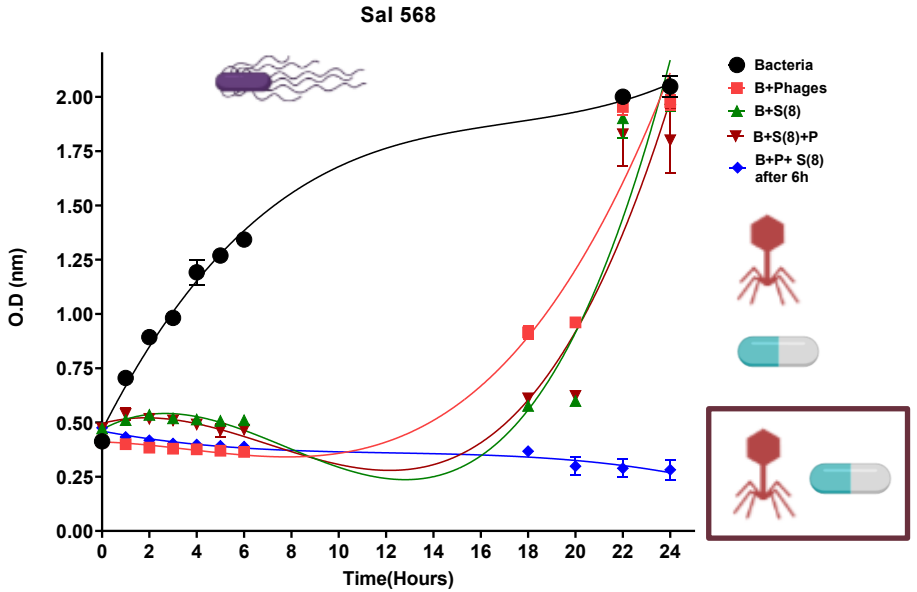
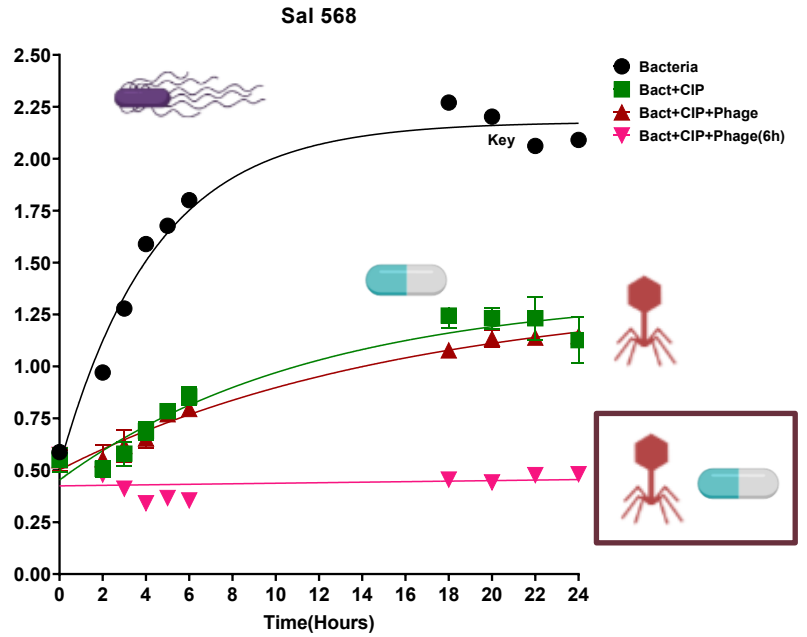
Phages Synergize with Antibiotics Better when Antibiotics Added 6 Hours Post-Phage Treatment

Streptomycin + phage ILRI_K23



Ciprofloxacin + phage ILR_K23



Linda Guantai

Guantai L., et al., in preparation.

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Phage Products for Human and Animal Use

Institute ELIAVA

Co-Founded by d'Herelle and George Eliava (1892–1937) in 1923

Phage Therapy Center™

2003

frontiers in Microbiology

ORIGINAL RESEARCH
published: 07 August 2018
doi: 10.3389/fmicb.2018.01832

Phage cocktails substantially decreased bacterial titers in 6 out of 9 patients (67%), with no adverse events reported.

Adapted Bacteriophages for Treating Urinary Tract Infections

Aleksandre Ujmajuridze[1†], Nina Chanishvili[2†], Marina Goderdzishvili[2], Lorenz Leitner[3], Ulrich Mehnert[3], Archil Chkhotua[1], Thomas M. Kessler[3‡] and Wilbert Sybesma[3‡]*

[1] The Alexander Tsulukidze National Center of Urology, Tbilisi, Georgia, [2] The George Eliava Institute of Bacteriophage, Microbiology and Virology, Tbilisi, Georgia, [3] Department of Neuro-Urology, Balgrist University Hospital, University of Zurich, Zurich, Switzerland

Phage Products for Human and Animal Use

PhageGuard – FDA-Approved Phages to Eliminate *Salmonella*

The PhageGuard advantage is precision. It is targeted to eliminate Salmonella in your food products, without affecting taste, odor or texture.

> Classified as a processing aid by USDA
> 1-3 log reductions in pathogens
> No Organoleptic influence
> Does not dissolve fat
> Does not react away in the presence of organic matter
> Non corrosive to equipment
> Can be used post-slaughter or in later processing stages

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BAFASAL®, a Bacteriophage-Based Feed Additive by Proteon Pharmaceuticals, for Use in Poultry

FEED BUSINESS
MIDDLE EAST & AFRICA

HOME KEY ISSUES INDUSTRY SECTORS THE MAGAZINE ADVERTISE CONTACT US

EU approves first-ever bacteriophage-based feed additive for poultry

This innovative product is already registered in India and Brazil, with additional regulatory submissions underway in several other countries.

Published July 18, 2025

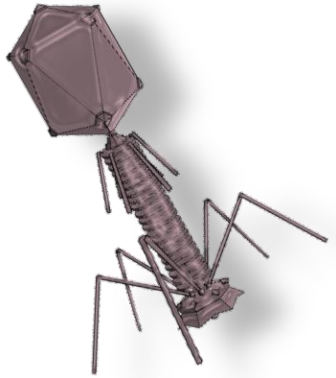
EUROPE – The European Union has officially approved *BAFASAL®*, a bacteriophage-based feed additive developed by Proteon Pharmaceuticals, for use in poultry.

The approval, which took effect on July 15, 2025, marks a significant regulatory breakthrough for phage technology in livestock production across all EU Member States.

The European Commission's decision, now published in the *Official Journal of the European Union*, makes *BAFASAL®* the first product of its kind to receive full EU authorisation under Regulation (EC) No 1831/2003, which governs feed additive approvals.

BAFASAL®

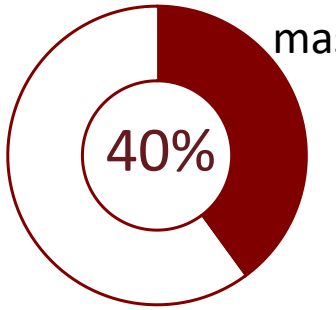
BAFASAL® is a liquid feed additive consisting of 4 strictly virulent bacteriophages and is proposed to be used as a zootechnical feed additive preventing from *Salmonella* Enteritidis and *Salmonella* Typhimurium infection. The product supports the prevention of *Salmonella* and productivity losses with no negative impact on the microbiome, hence improves growth, productivity and performance. BAFASAL® can be used across poultry species and breeds including chickens, turkeys, ducks, pigeons and other fowl.



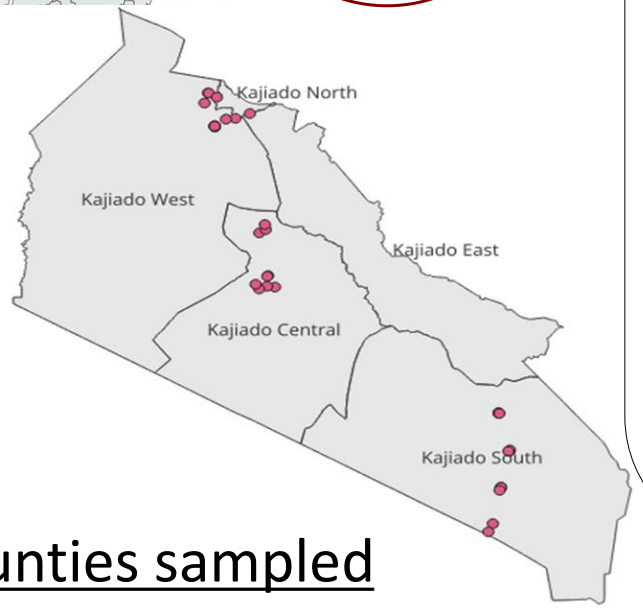
Objectives of the project – *Roadmap to use for other pathogens*

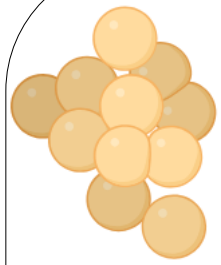
1. Collect *Staphylococcus* from goat farms & type strains for AMR.
2. Test bacteriophages from the U. Laval phage collection for capacity to lyse Kenyan *Staphylococcus* strains.
3. Isolate new bacteriophages from Kenya with lytic activity towards Kenyan *Staphylococcus* strains.
4. Test combination of bacteriophages in mastitis infection models in mice and goats.
5. Optimize spray-drying protocols with selected *Staphylococcus* phages.
6. Assess the impact of phage technology & adoption by women goat farmers.

Isolating *Staphylococcus* and *Staph*-Specific Phages from the Field



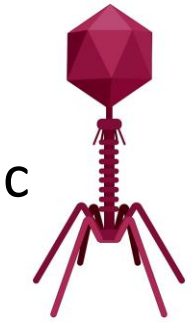
sub-clinical mastitis





40+ *Staphylococcus sp*. isolates from sub-clinical mastitis.

11 new *Staphylococcus*-specific Phages.

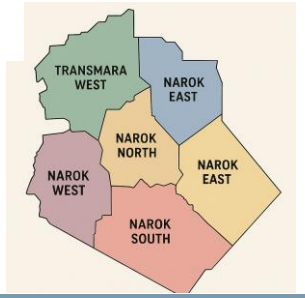


<u>Counties sampled</u>

Kajiado

Narok

Kiambu



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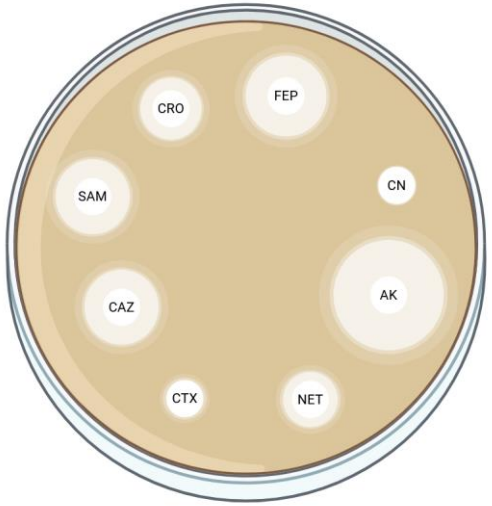
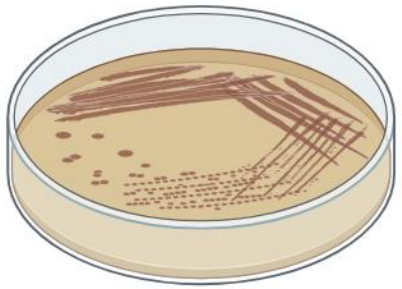
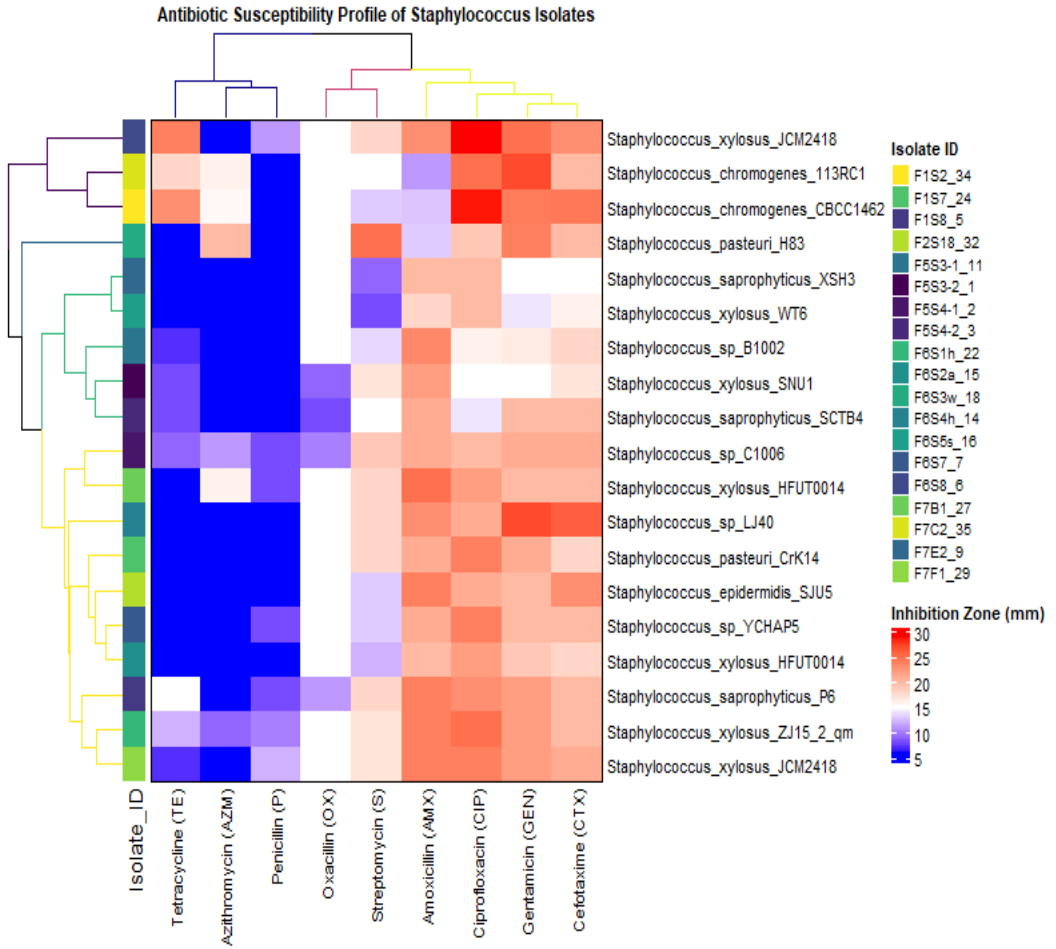
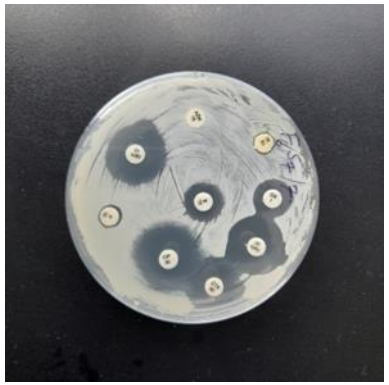
Assessing Antimicrobial Resistance Profiles of *Staphylococcus* Field Isolates



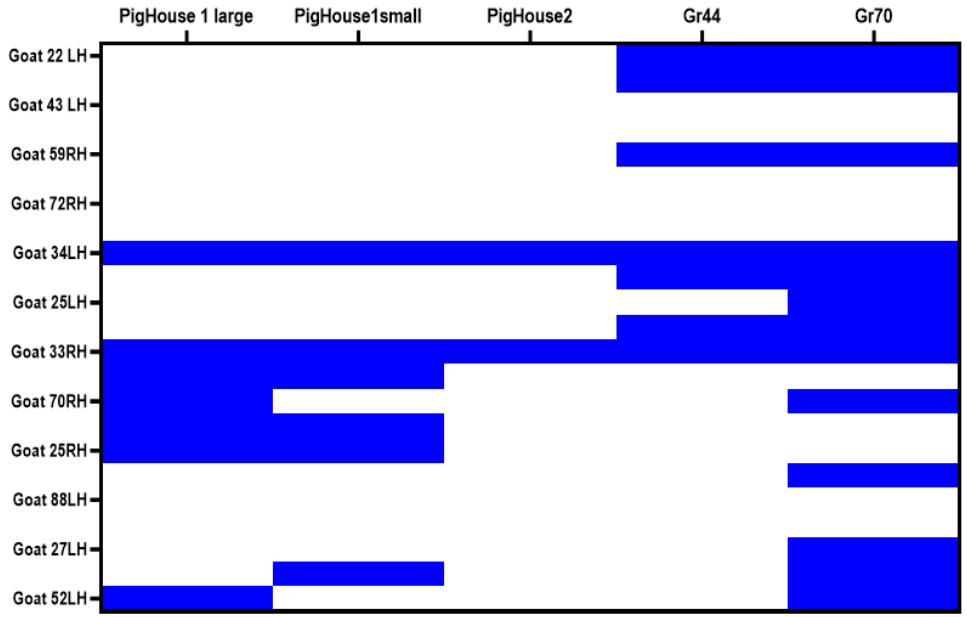




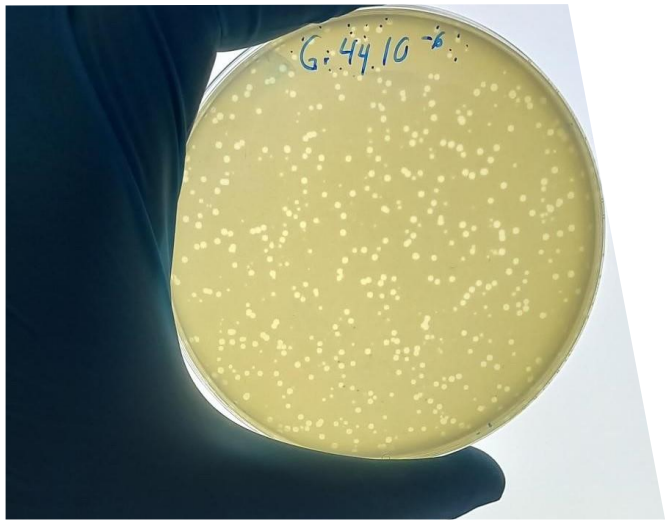


Newly Isolated Kenyan *Staphylococcus*- Specific Phages

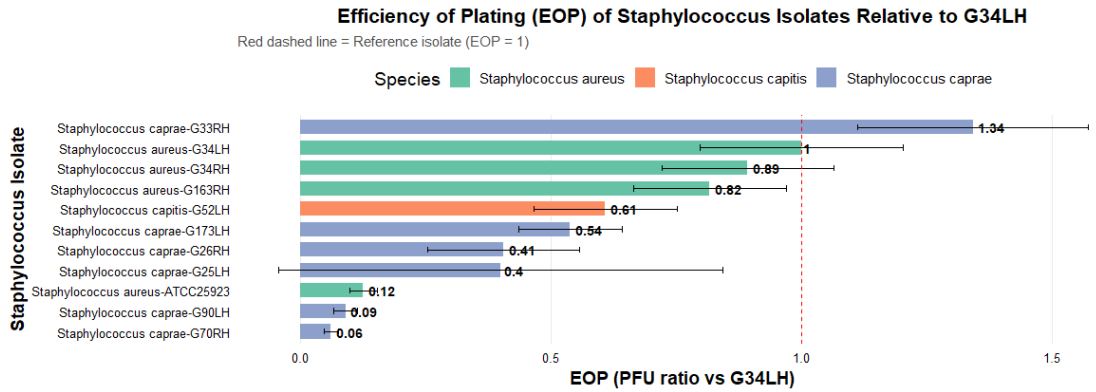
Phage host range on *Staphylococcus spp* from Kajiado



Goat 22 LH	*Staphylococcus chromogenes*
Goat 22RH	*Staphylococcus chromogenes*
Goat 43 LH	*Staphylococcus chromogenes*
Goat 43RH	*Staphylococcus chromogenes*
Goat 59RH	*Staphylococcus chromogenes*
Goat 72LH	*Staphylococcus chromogenes*
Goat 72RH	*Staphylococcus chromogenes*
Goat 83RH	*Staphylococcus chromogenes*
Goat 34LH	*Staphylococcus aureus*
Goat 34RH	*Staphylococcus aureus*
Goat 25LH	*Staphylococcus caprae*
Goat 26RH	*Staphylococcus caprae*
Goat 33RH	*Staphylococcus caprae*
Goat 44 LH	*Staphylococcus caprae*
Goat 70RH	*Staphylococcus caprae*
Goat 90LH	*Staphylococcus caprae*
Goat 25RH	*Staphylococcus xylosus*
Goat 30RH	*Staphylococcus xylosus*
Goat 88LH	*Staphylococcus xylosus*
Goat 15 LH	*Staphylococcus hyicus*
Goat 27LH	*Staphylococcus ureilyticus*
Goat 30LH	*Staphylococcus haemolyticus*
Goat 52LH	*Staphylococcus capitis*



Omukunda C., *et al*., in preparation.



Caleb Omukunda, MSc student

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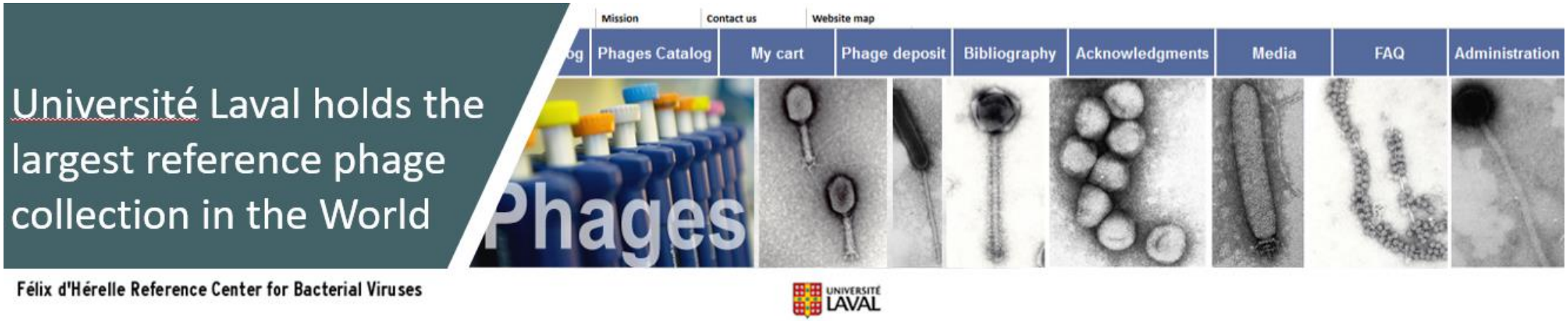
Collaborating with the Scientists at Université Laval, which holds the Félix d'Hérelle Phage Collection (largest in the world)



- ❑ Based at Laval University (Quebec).
- ❑ Founded in 1982.
- ❑ Largest reference phage collection in the world.
- ❑ More than 350 different phages.

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Staph-Specific Phages from the Félix d'Hérelle Phage Collection

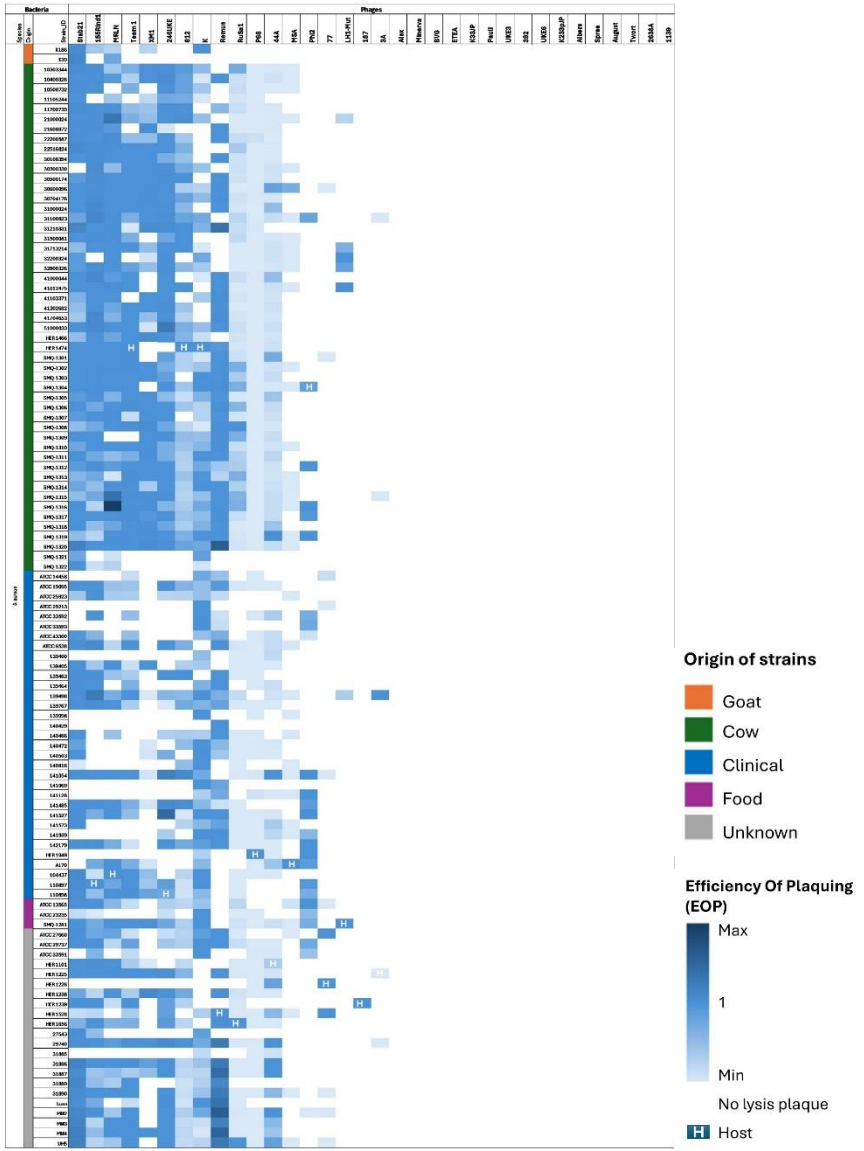

Fig: Host range of 34 phages over 111 *S. aureus* strains

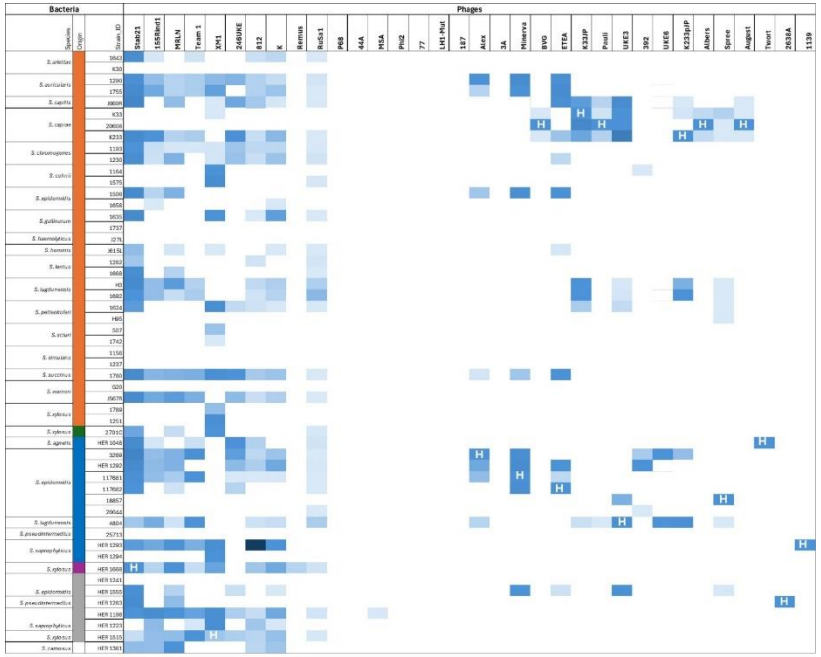

Fig: Host range of 34 phages over 53 non-*aureus* strains

- **50% of *S. aureus*** strains are lysed by **12/34** phages (mostly, myo and podophages).
- **> 15 %** of non-aureus strains are lysed by **14/34** phages (Myo and Podophages).

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Phages are Stable in Goat Milk

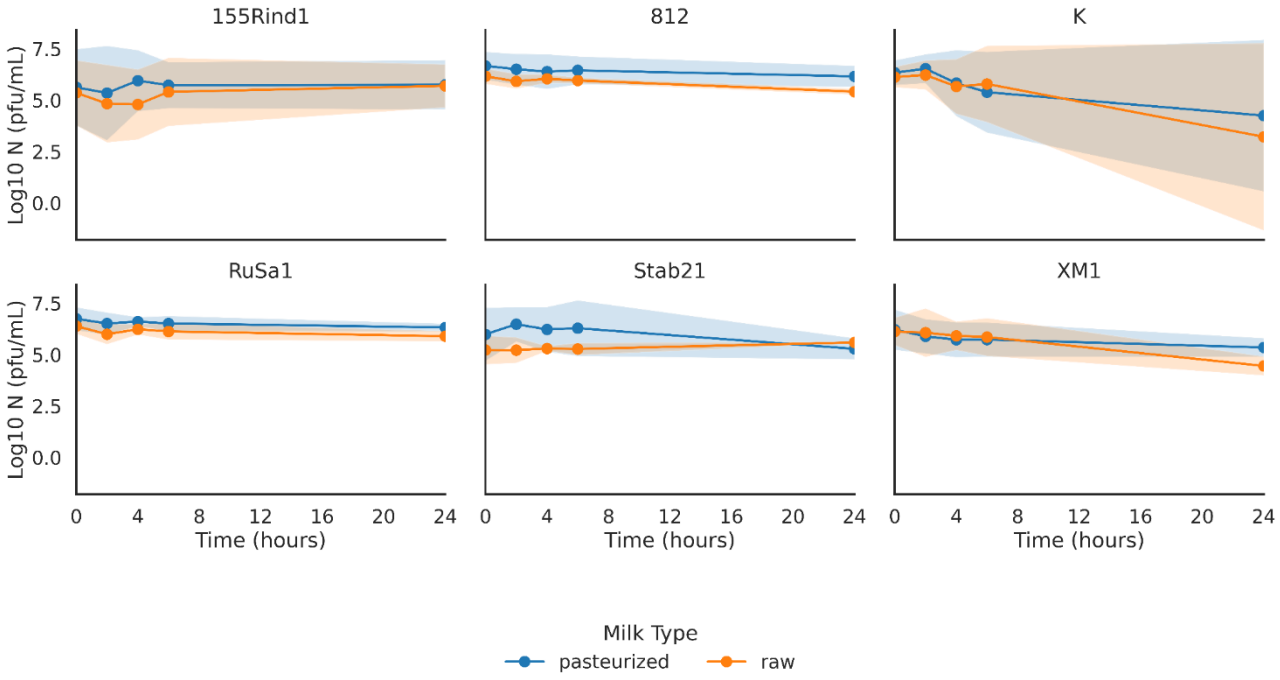
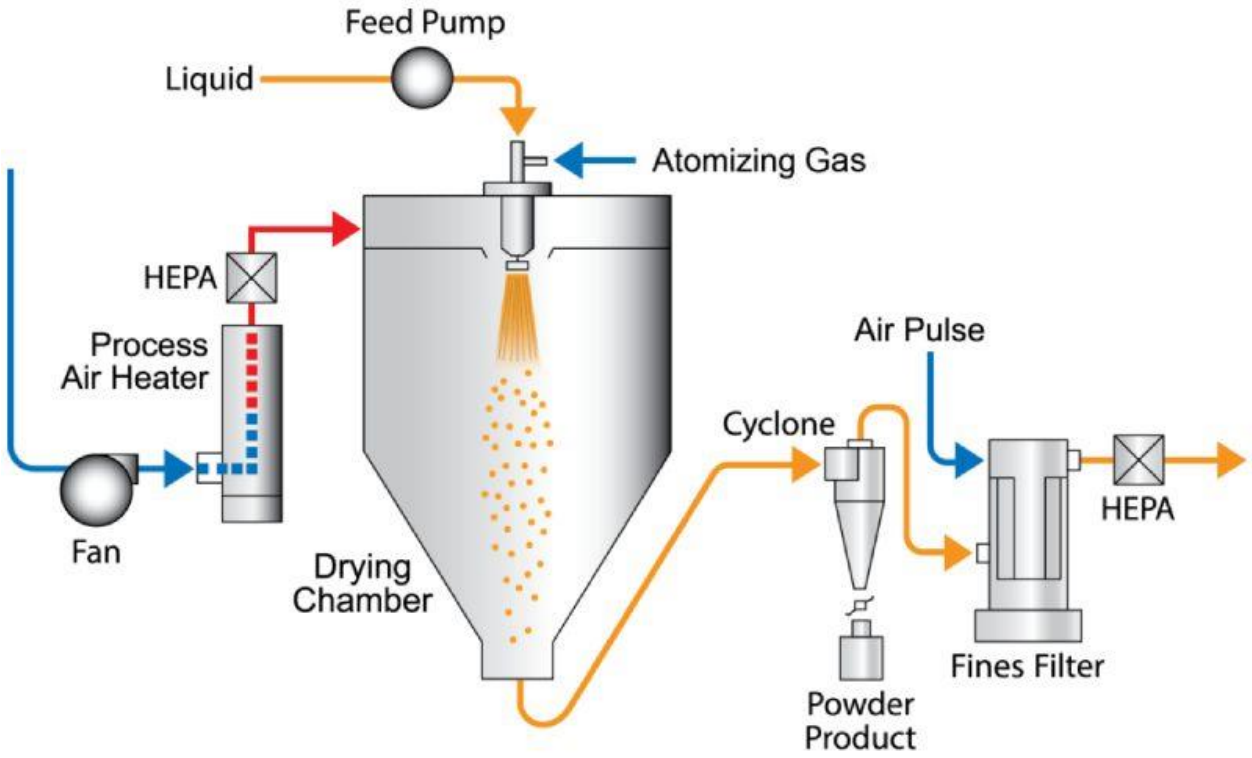


Fig: Phage are relatively stable in goat milk over 24h.
Mean+SD of phage titer. Stats: Two-way ANOVA with Tukey test.

- Phages stable in:
  - Both types of milk (raw vs pasteurized)
  - Over time.
- Slight decrease in titer after 24 h, but generally < 2 log PFU/ml
- More pronounced decrease with phage K (complete loss of activity after 24 h, in some assays).

Large Scale Production & Spray-Drying of Phages

SyntBioLab
L'alternative aux antibiotiques



- Testing different coating materials;
- Testing phages surviving the process;
- Identifying the best bacterial strain to propagate the selected phages.
- 5 or 6 phages for cost benefits.

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Next Steps – Examples from our Previous Phage Project (IDRC # 109049)

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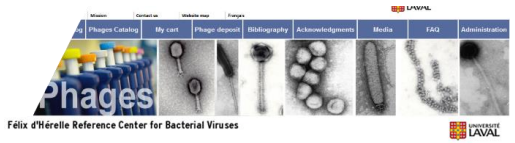
New *Salmonella* Phages!

- 59 new phages (out of 67)
- 17 clusters phages
- 4 Major Groups (Genera)
- *Similar to other known phages*
- No virulence or AMR genes

+

32

www.phage.ulaval.ca



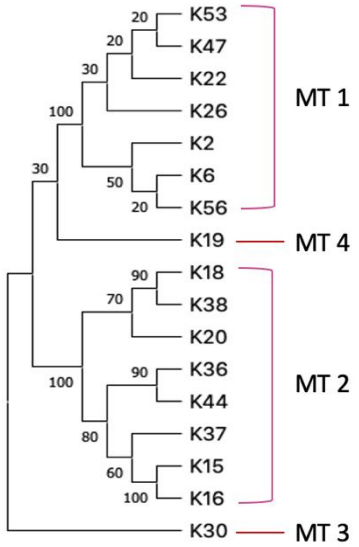
AMERICAN SOCIETY FOR MICROBIOLOGY | Microbiology Spectrum

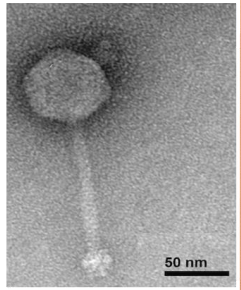
Check for updates

| Bacteriophages | Research Article

Diversity of *Salmonella enterica* phages isolated from chicken farms in Kenya

K. M. Damitha Gunathilake,[1] Angela Makumi,[2] Stéphanie Loignon,[1] Denise Tremblay,[3] Simon Labrie,[4] Nicholas Svitek,[2] Sylvain Moineau[1,3]





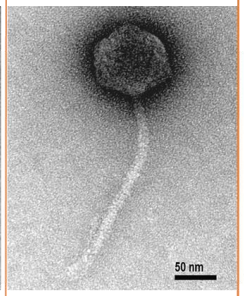
MG1 (K47)

Siphophages

Capsid diameter ~ 50 nm

Tail length ~ 125 nm

Jerseyvirus



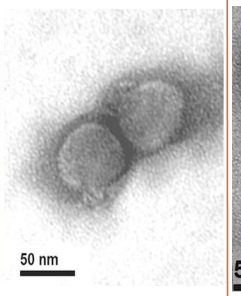
MG2 (K37)

Siphophages

Capsid diameter ~ 75 nm

Tail length ~ 150-200 nm

Tequintavirus



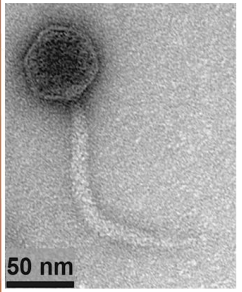
MG3 (K30)

Podophage

Capsid diameter ~ 50 nm

Short tail

Zindervirus



MG4 (K19)

Siphophages

Capsid diameter ~ 60 nm

Tail length ~ 150 nm

Dhillonvirus

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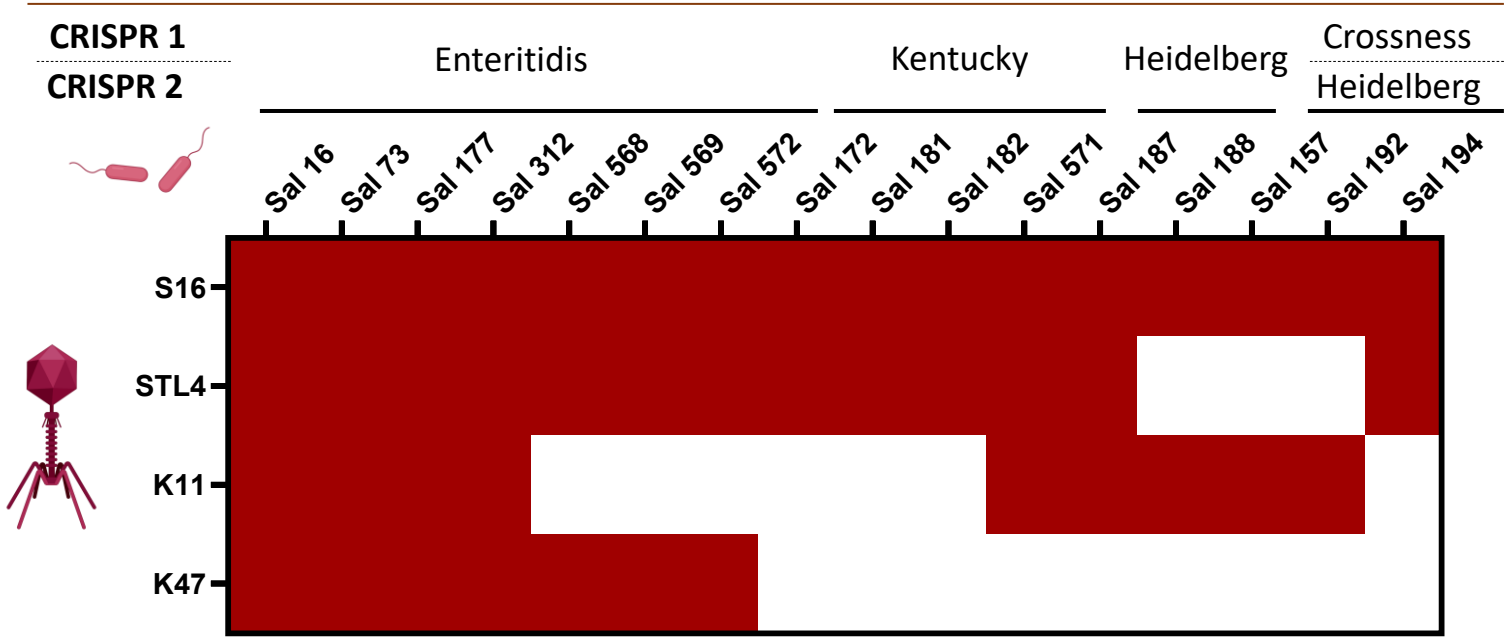
Our **4 Phage Champions** Part of the Cocktail…:
2 From Université Laval & 2 From ILRI



S16: Myophage, Gelderlandvirus
STL4: Siphophage, *Epseptimavirus*
K11: Podophage, *Zindervirus*
K47: Siphophage, *Jerseyvirus*

- ❑ Able to infect all *Salmonella* strains;
- ❑ At least two phages per strain;
- ❑ Phages easy to spray dry and produce at large scale;
- ❑ Cocktail able to control the emergence of BIMs effectively;
- ❑ Phages that have a higher survivability score.

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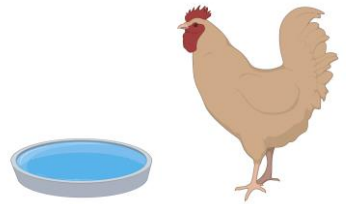
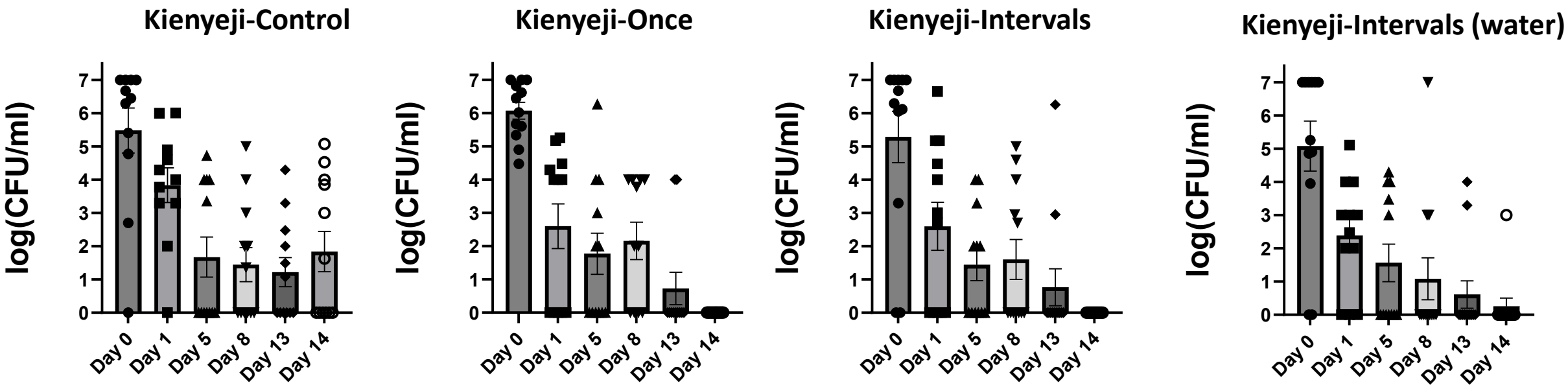
Phage Delivery Through the Oral Route and Through the Drinking Water is Effective in Reducing *Salmonella In Vivo*





Days post-phage treatment

Makumi A., et al., in preparation.

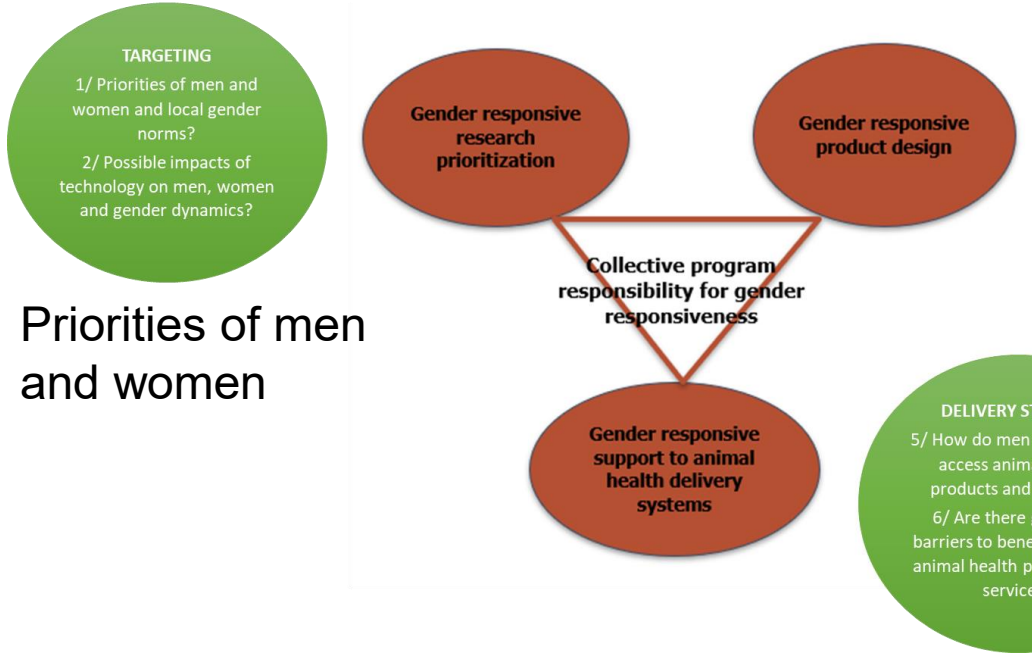
Target Users

Field veterinarians

Livestock keepers

GENDER - Assessing the Impact of Phage Technology & Adoption by Women and Men Goat Farmers

Animal health and gender framework



Priorities of men and women

Product design that promotes gender-equal access

Best delivery strategy

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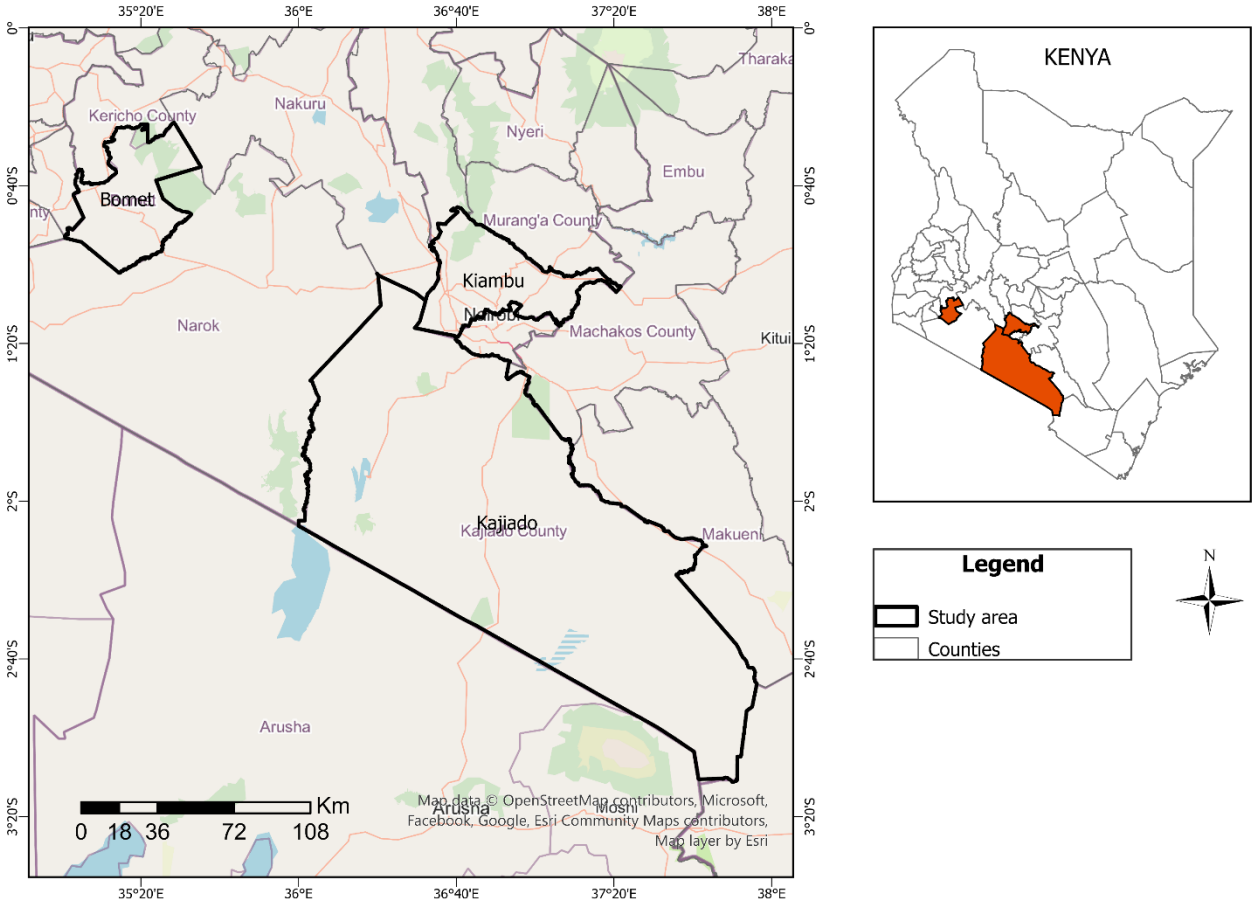
GENDER - Assessing the Impact of Phage Technology & Adoption by Women Goat Farmers



<u>Target Groups and Stakeholders in Dairy Goat Health Management</u>

- Men, women, and youth dairy goat farmers in Bomet, Kajiado, and Kiambu Counties.
- Veterinarians, animal health assistants, agrovet attendants/owners, livestock reporting officers, the chiefs, village and religious leaders who deal directly with dairy goat farmers.

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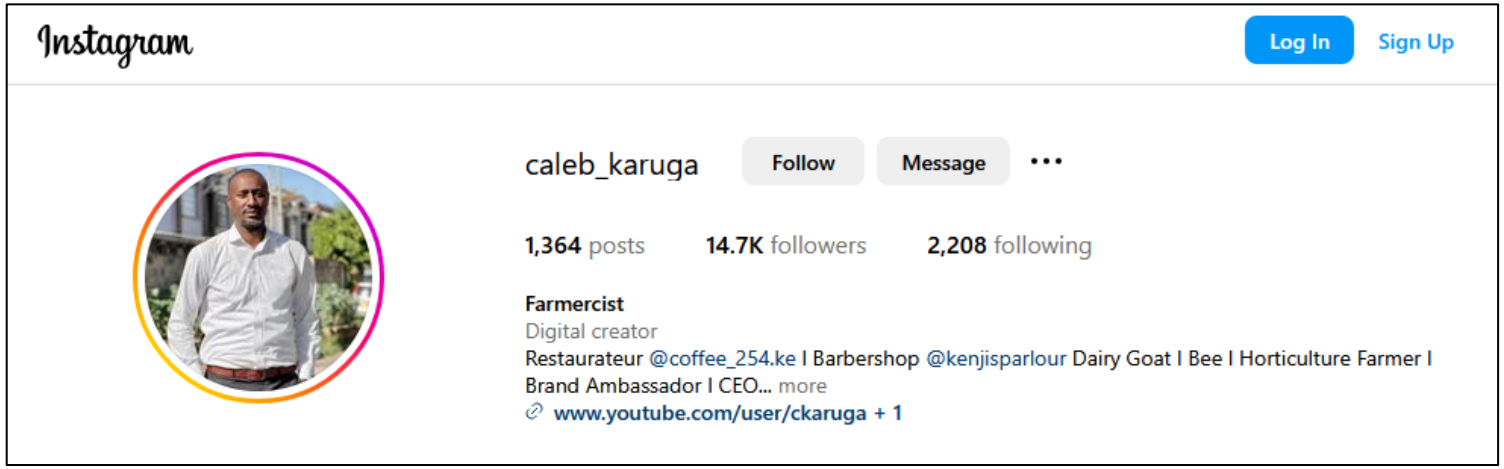
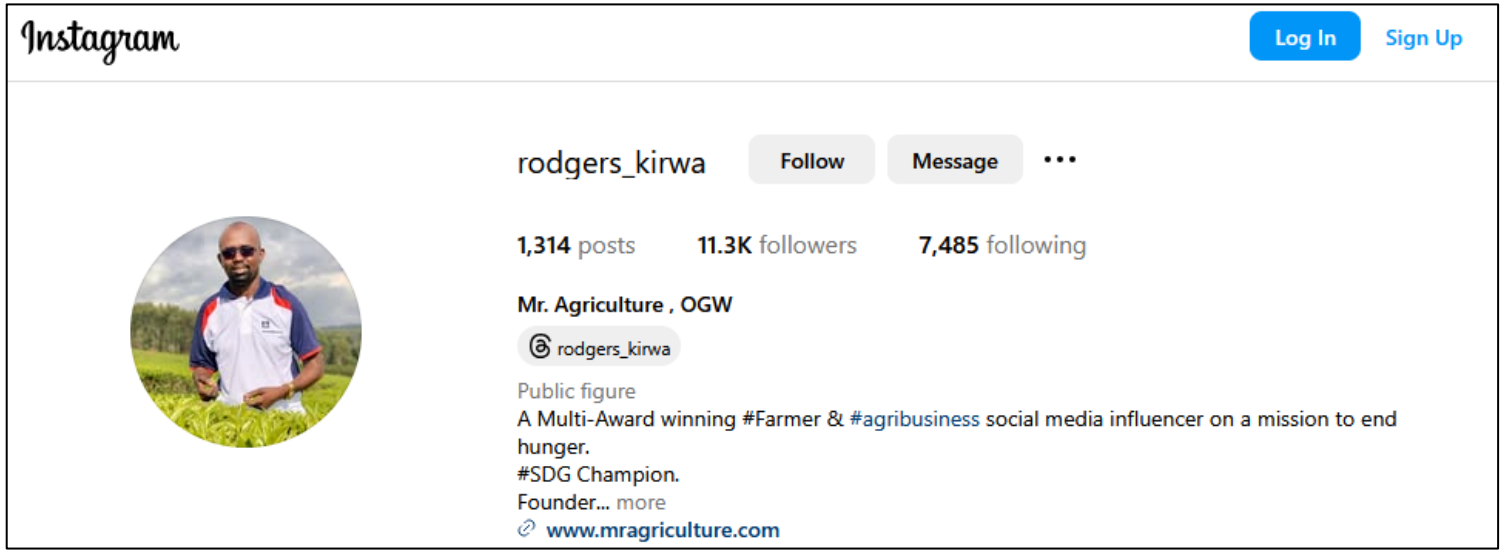
Collaborating with Local Influencers to Educate & Promote Phage Products





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Regulatory Guidelines of Phage Products by Veterinary Medicines Directorates (VMDs)

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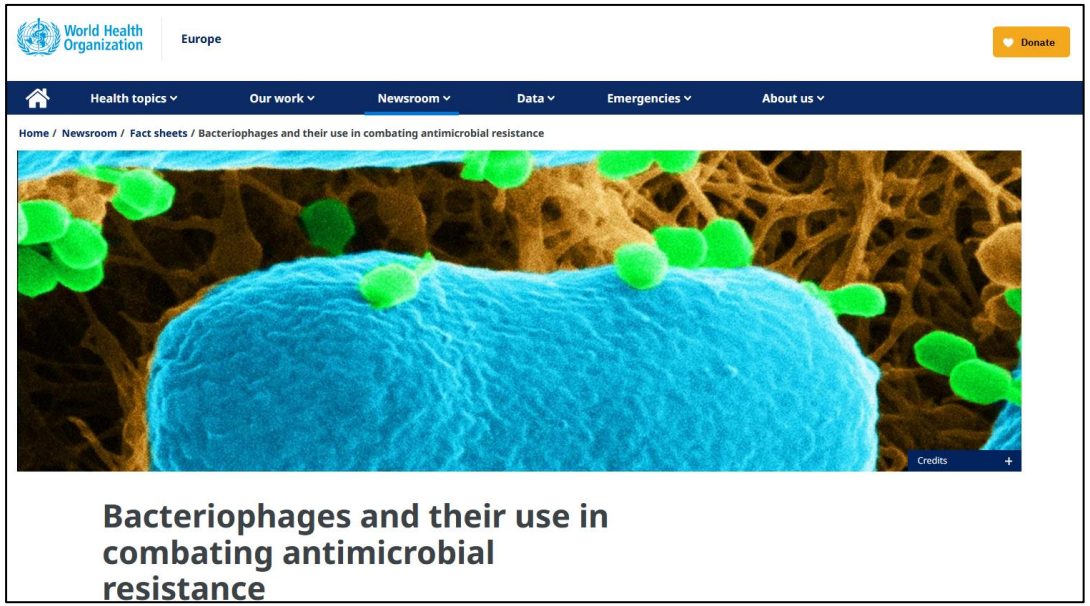
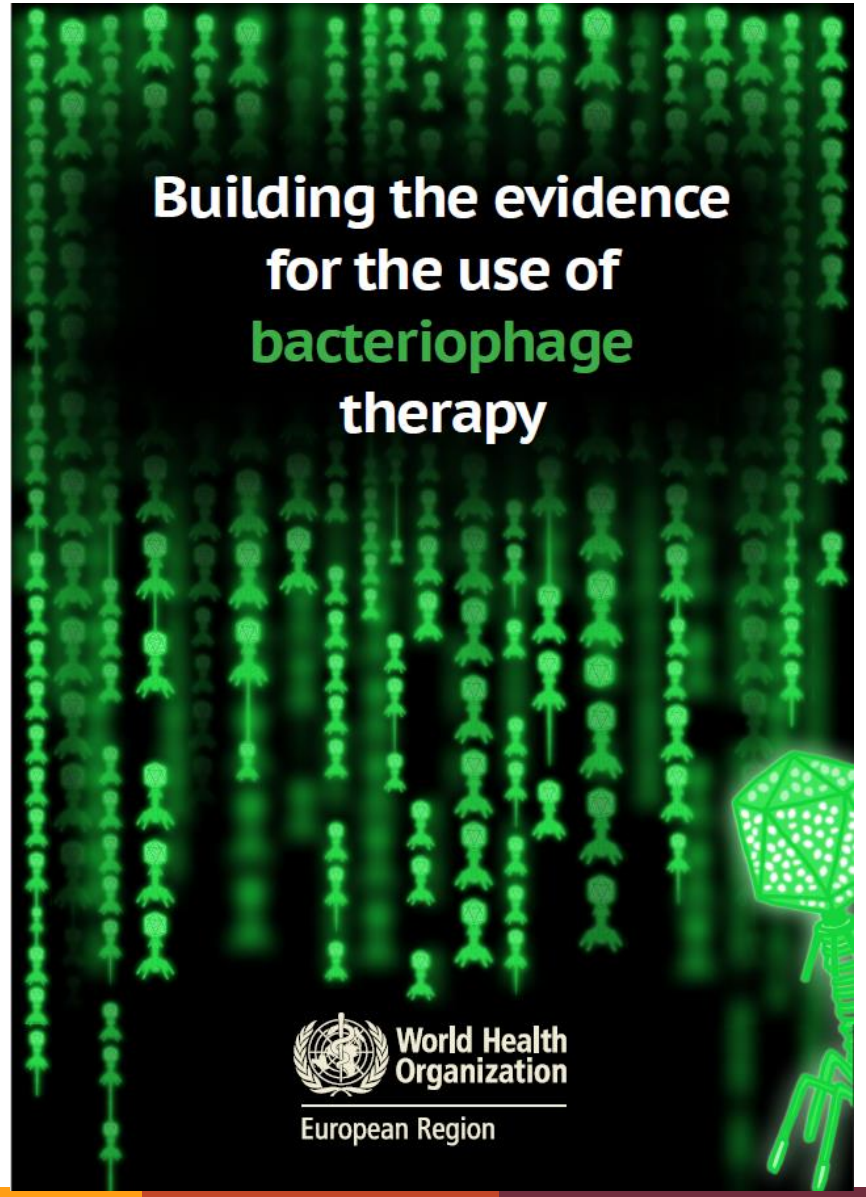
WHO - Building the Evidence for the Use of Bacteriophage Therapy

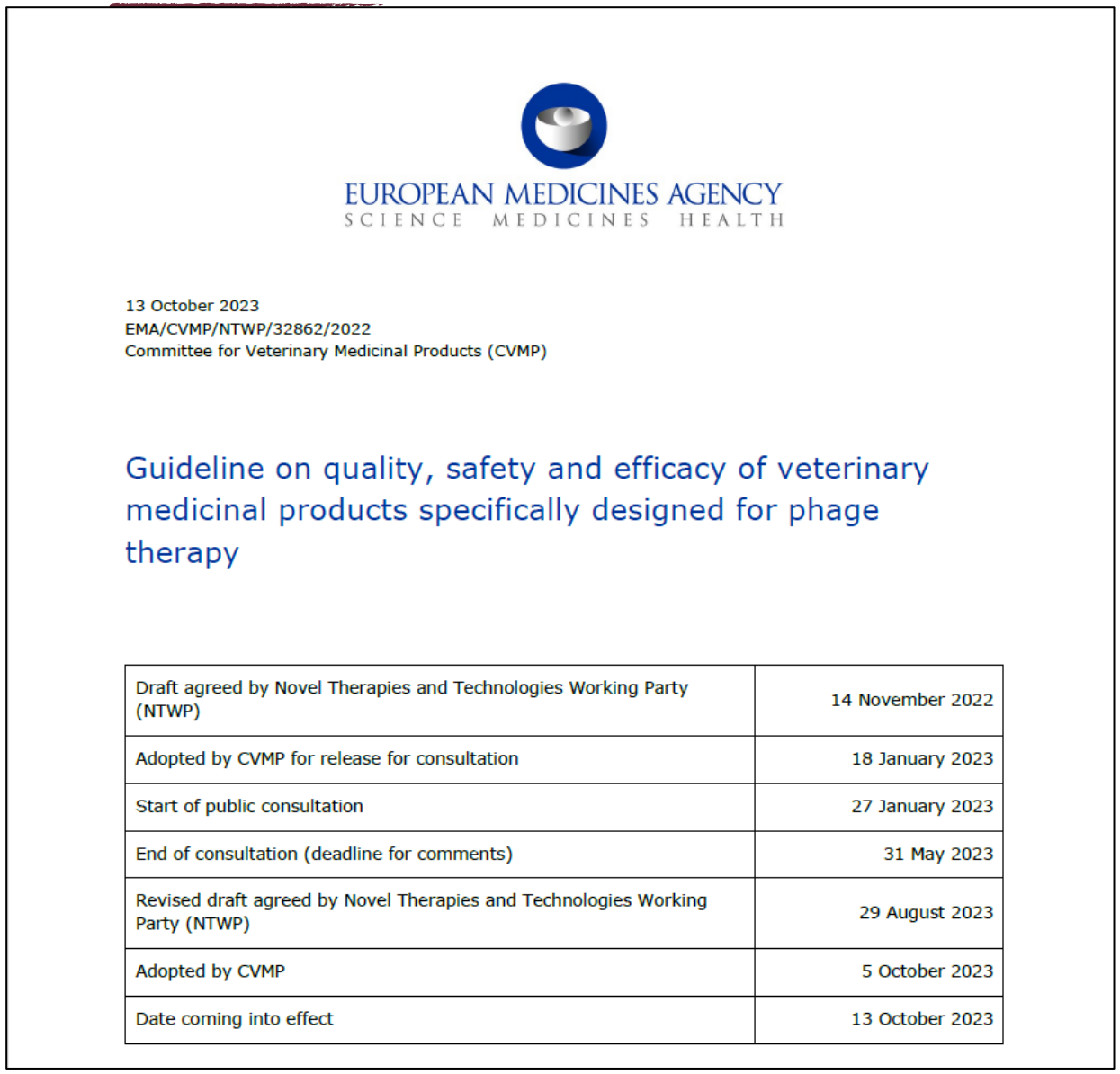


*"**Phages** could offer an **alternative to** traditional **antibiotics** or be **used in combination with them** to enhance treatment efficacy.*

*In the case of drug-resistant bacteria, **phages** provide a **biologically innovative approach** to **treating infections** that can **no longer be treated** with traditional **antibiotics**."*



Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline



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SCIENCE MEDICINES HEALTH

13 October 2023
EMA/CVMP/NTWP/32862/2022
Committee for Veterinary Medicinal Products (CVMP)

Guideline on quality, safety and efficacy of veterinary medicinal products specifically designed for phage therapy

Draft agreed by Novel Therapies and Technologies Working Party (NTWP)	14 November 2022
Adopted by CVMP for release for consultation	18 January 2023
Start of public consultation	27 January 2023
End of consultation (deadline for comments)	31 May 2023
Revised draft agreed by Novel Therapies and Technologies Working Party (NTWP)	29 August 2023
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Home > Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline

Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline

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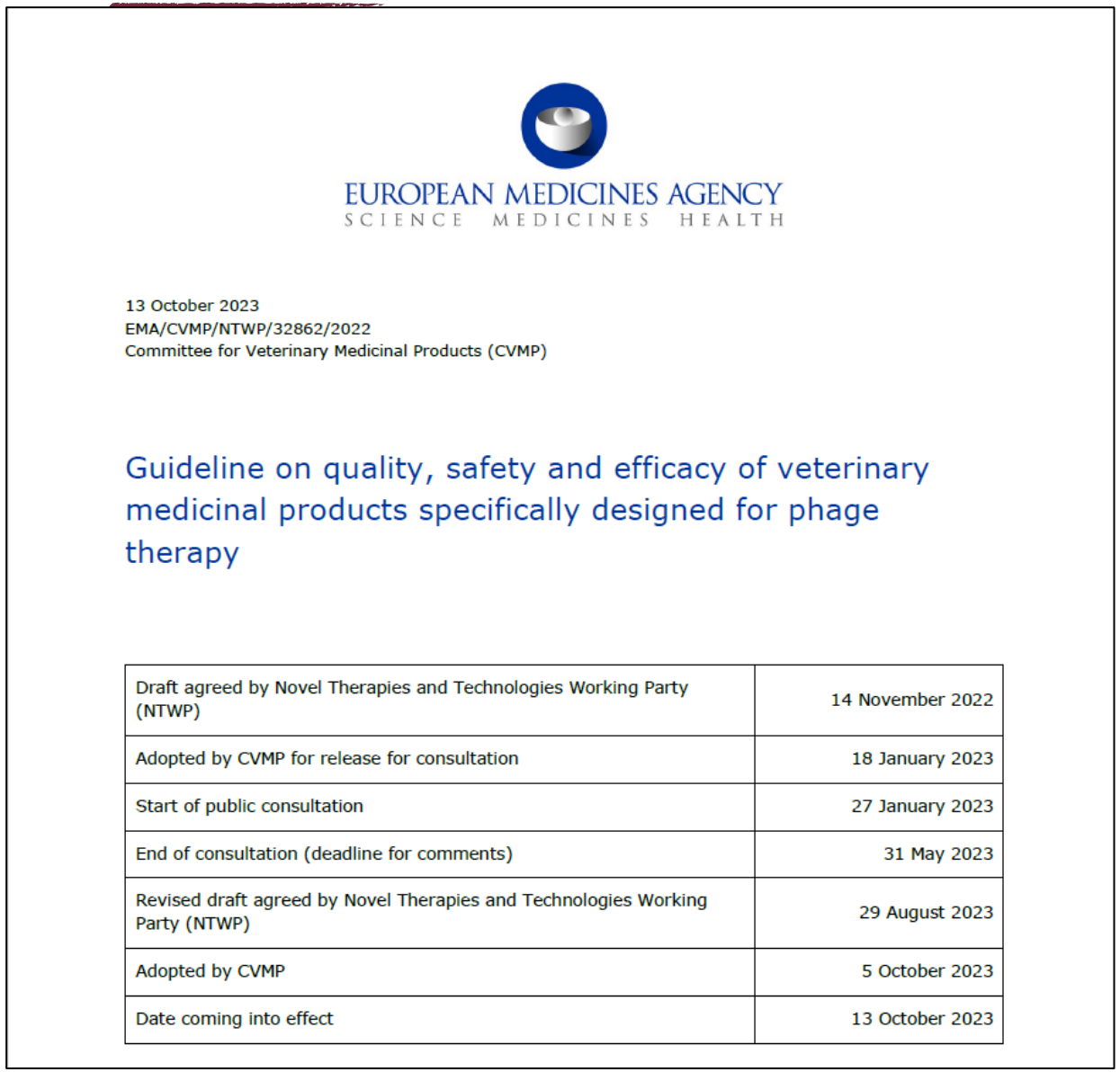
Veterinary | Scientific guidelines

- The product's qualitative and quantitative composition must list all monophages it contains.
- **The host bacterial species for each monophage must be specified.**
- The intended use is generally for prophylactic and/or therapeutic purposes against specific bacterial infections or dysbiosis.
- **Although phage therapy can be an alternative to antibiotics, combined use with antibiotics may be appropriate in some cases. If such use is intended, it must be supported by data and clearly defined in the product dossier and information.**

Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline



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Home > Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline

Quality, safety and efficacy of bacteriophages as veterinary medicines - Scientific guideline

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Veterinary | Scientific guidelines

- Safety concerns: Bacteriophage products may contain microbiological contaminants, including endotoxins or exotoxins, which must be controlled during manufacturing.
- **Environmental impact: Applicants must assess how the product may affect soil bacteria and soil functions.**
- Pharmacokinetics (ADME): Traditional ADME studies may not apply, but applicants should still provide data on:
  - Absorption at the administration site
  - Dissemination within the body
  - Degradation pathways
- **Usage contexts: Information should cover both scenarios—use in animals without bacterial infection and use in animals with the target bacterial infection.**

Discussion with the VMD of Kenya (2019)

VETERINARY MEDICINES DIRECTORATE

- VMD's role at the manufacturing step;
- Important to demonstrate efficacy, safety, stability [good quality of product];
- Batch-to-batch consistency;
- Better to have Kenyan phages, or demonstrate the safety of "foreign" phages;
- Combining phages with antibiotics for synergistic activity is not a problem for the Kenyan VMD.

A Few Take-Home Points for Phage Therapy

1. Phage will likely not be an appropriate therapeutic for all infections (intracellular bacteria).
2. **Neutralizing antibodies against certain phages typically associated with the microbiome may be a general obstacle for phage therapy.**
3. Unlike antibiotics, phages are self-dosing and self-limiting, and the formation of resistance is typically lower.
4. **A mixed therapy of phages & antibiotics might be the ideal strategy to treat MDR bacteria.**
5. VMP based on bacteriophages are expected to require frequent changes in composition for the bacteriophage strain(s) in order to maintain efficacy/circumvent resistance development in relation to the intended indication.

Acknowledgments – Phage Therapy Projects

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ILRI
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SyntBioLab
L'alternative aux antibiotiques

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Nicolas Lemire

Republic of Kenya
Ministry of Agriculture, Livestock, Fisheries and Irrigation

Samuel Njuguna
Jane Githinji

IDRC | CRDI
International Development Research Centre
Centre de recherches pour le développement international

UKaid
from the British people

Department of Health & Social Care

CGIAR
RESEARCH PROGRAM ON Livestock

Acknowledgements

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Canada

UKaid
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Department of Health & Social Care

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MARS
NAIMA
HAVE
FUN!
EVERYONE

Asante Sana!