Microbiology TODAY

45:3 August 2018

Microbes and Food

Using microbes to influence flavour production
Microbial diversity in the digestive tract of herbivores
Mycoprotein production and food sustainability
Foodborne diseases: sequencing for answers
Bacteriophage therapy in livestock: food for thought?

MICROBIOLOGY SOCIETY

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Editorial

Welcome to the August edition of *Microbiology Today*, hopefully one you are able to enjoy in the summer sun, possibly alongside a cold drink or an ice cream. If you are enjoying this issue with a snack, it is worth stopping for a moment to consider how microbes might be impacting on your experience of that food.

Whole Picture

Microbes influence our food in an extensive range of ways, dictating whether or not you experience a delicious flavour or will be sick as a result of what you eat. They can be utilised to produce protein and can impact on the health of livestock that are an essential part of the food chain. In this edition we look at all the wonderful and not so wonderful ways in which microbes affect our food.

To start us off on our journey looking into microbes and food, Christine Dodd and Dewi Yunita explain how microbes can influence the complexity and variety of flavours and textures in the foods we eat. Covering a wide diversity of food products, they explain how microbes can direct flavour development and how using the right starter culture plays a major role in producing the desirable flavours that we come across every day.

As well as being used directly to flavour our food, microbes also impact our food choices through the role they play as an essential part of the digestive tract of herbivores. Neil McEwan describes how the relationship between host and microbe allows the host to utilise nutrients from plants that they would be unable to process alone. The microbes present in the digestive tract of ruminants reared for human consumption are of particular commercial interest, as they can impact on the energy available for the growth of those animals and can also alter greenhouse gas production.

Given that the production of the food we eat comes at a cost, both monetary and environmental, it is becoming increasingly important to look at lower-cost alternatives. Richard Harrison and Rob Johnson walk us through the production of low-carbon protein made by fungi and how it can be consumed globally as an alternative to meat. Discussing some of the reasons for the increased demand for this type of protein, they outline its origins, manufacture and the direction of research which will support an increasingly energy-efficient product in the future.

Despite the many positive roles microbes can have in food production, there are still those few microbes which can cause us distress in the form of foodborne disease. The symptoms can range from mild through to life-threatening, and some of the microbes causing these problems are considered here by Prerna Vohra. Reminding us that these microbes can impact on animal health as well as human health, Prerna explains how sequencing technology is being utilised to provide valuable information on the virulence and zoonotic potential of these microbes.

With this in mind, up next are the microbes which could have a role in helping to combat infection in livestock. Robert Atterbury turns our attention to bacteriophage and the ways in which these viruses could be used to reduce infection and antibiotic use in animals destined for the food chain, potentially creating a knock-on effect for human health.

To finish off, Gregor Reid helps us all out with his Comment piece on probiotics. Answering the questions, "what are probiotics and which one should I take?", Gregor provides us with an insight into the evidence for some of the probiotics available to the public and highlights the impact probiotics can have in clinics when used appropriately. He also describes how production of probiotics is being used to benefit human populations on a global scale.

Rowena Jenkins
Editor
r.e.jenkins@swansea.ac.uk

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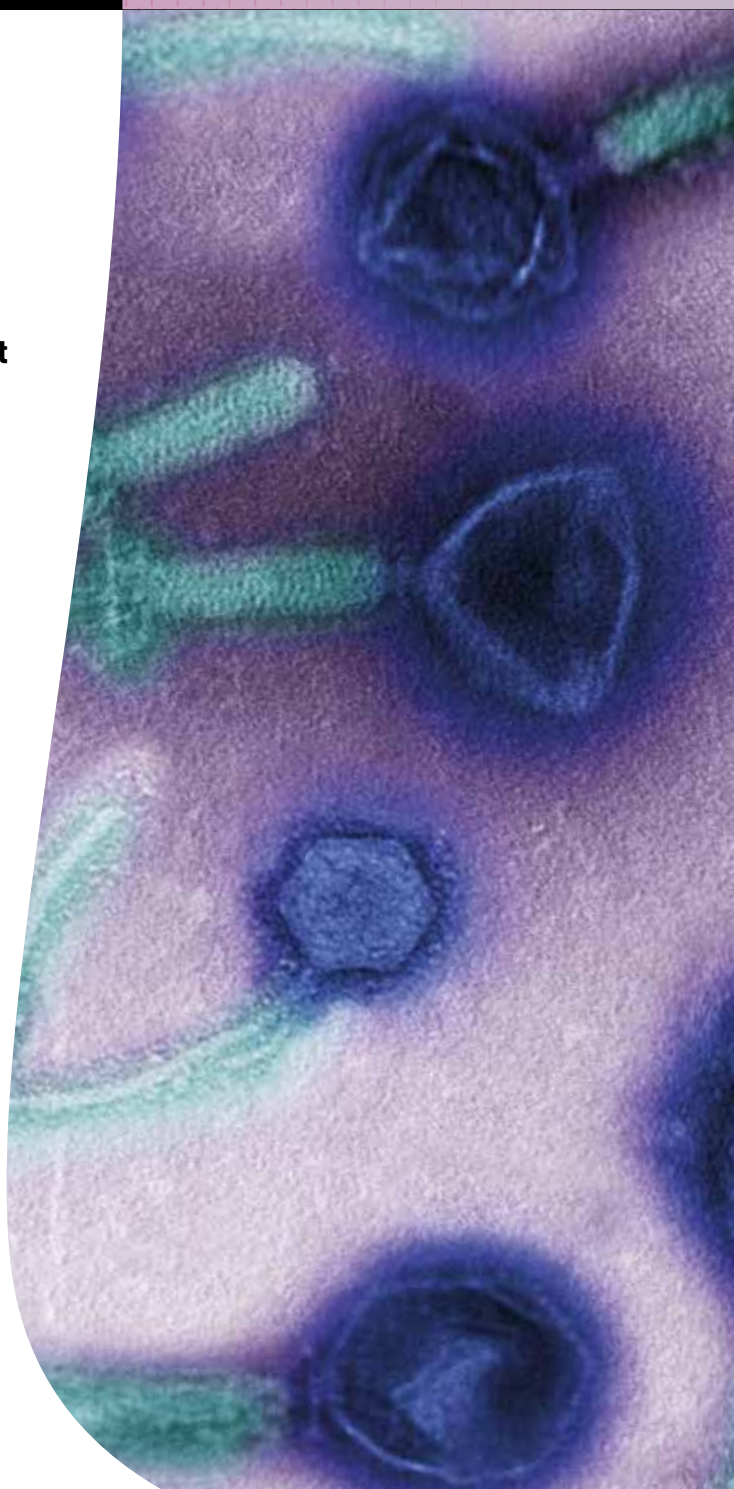

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Address **Microbiology Society, Charles Darwin House, 12 Roger Street, London WC1N 2JU** T **+44 (0)20 7685 2683** E **mtoday@microbiologysociety.org**
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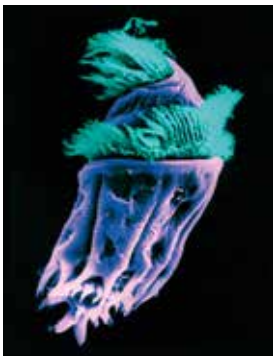

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Colour enhanced scanning electron micrograph of *Ophryoscolex* spp. ciliate, from the rumen of a cow. Biophoto Associates/Science Photo Library

MICROBIOLOGY SOCIETY

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Professor Tracy Palmer

Division of Molecular Microbiology, School of Life Sciences, University of Dundee, Dow Street, Dundee DD1 5EH; **t.palmer@dundee.ac.uk**

Professor George Salmond

Department of Biochemistry, Hopkins Building, University of Cambridge, Tennis Court Road, Cambridge CB2 1QW

Professor Nicola Stonehouse

School of Molecular and Cellular Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT; **n.j.stonehouse@leeds.ac.uk**

From the President

Our teams of professionals at Charles Darwin House are really serving our members well, and it is the teamwork of our members and professional skills of our staff that are driving us forward. In the coming months we are putting on more conferences, improving our journals platform and enhancing our impact via public engagement, scientific communication and policy work.

New infrastructure and staff investments are allowing us to further improve our game, and we have done all this while also bringing our financial balance into line with expenditure. This gives us confidence to become even more creative and adventurous with our assets in the future.

I've been to a lot of scientific meetings this year and inevitably comparing experiences, making sure our own Society meetings are competitive, innovative and exciting. In my opinion they are. Birmingham was at least as good as any other meetings I've been to in years – and, as said, I've been to a lot. But, there are no laurels to rest on, and we are already planning to make the Microbiology Society Annual Conference 2019 (Monday 8 April to Thursday 11 April) at the Belfast Waterfront better again. I've been privately checking flights and prices and, if you book plane tickets in advance, travel to Belfast may be the cheapest to any meeting you will go to next year. Before then there are many other Microbiology Society events to look forward to. The Annual General Meeting (AGM) and Showcase of the Society's Achievements event takes place in September, and three further Focused Meetings will occur in September and October. Our Conferences and Events team have acquired a reputation for putting together very slick, well-organised events – for example, we have even been asked to take over the running of a major biannual meeting in the USA that was looking for a new home. Notably, I am also delighted that our ECM Forum is already proving transformational in our Society and had its inaugural conference between 14 and 15 June.

I would like to bring your attention to a new journal we are launching, called *Access Microbiology* (page 109). This journal will introduce a new service to members of our community, allowing the publication of valuable work that sometimes can be sacrificed at the altar of journals whose ambits restrict any report that is not first in field. Also, research has often been excluded for publication unless it displays only positive outcomes to the hypotheses of the day. As a result, studies that replicate and reinforce key observations, including negative or null results, or work that describes research proposals, data management plans, additions to established methods, and interdisciplinary work can be squeezed out. Our new journal will have a more inclusive policy that will welcome such work and will cover the full spectrum of microscopic life forms, from bacteria and viruses to fungi, protists, archaea and algae. Scientists have been criticised for failing to report such work – and we can now offer a home to work that has struggled in the past to get a proper airing. This journal is the result of in-depth and extensive consultations and analyses by our Publishing Committee and journal editors, whose critically important work not only supplies the bulk of our income, but also provides a service to microbiologists and a shop window for the Society.

Successful societies not only communicate with their members, but enlist, engage and incorporate their skills. As I pass through the last year of my Presidency, I can already see how deep and rich a resource our membership is. I would like to say thank you to everybody who has put themselves forward for our recent calls for nominees for Officer and Committee Members. I hope you feel confident that we remain, above all, a members' organisation with a clear understanding of our role, responsibilities and values. The sum of talent that exists in our membership and our staff at Charles Darwin House make quite a team and this issue of *Microbiology Today* is full of the evidence of this assertion.

Neil Gow
President
president@microbiologysociety.org

From the Chief Executive

The launch of *Access Microbiology*, described on page 109, marks a seminal moment in the Microbiology Society's publishing activities. Ever since our founders decided that it was crucial for the Society to disseminate the best research as widely as possible, we have seen the development and growth of a thriving stable of scientific journals. Over the years, it is notable how many world-leading microbiologists have published important work in the Society's journals, especially early on in their careers.

When Sir David Baulcombe won the Society's Prize Medal in 2015 for his prestigious work on plant viruses, he was asked about the period in his life when he first started working in virology. What he said reveals how important our journals are: "We published some of our first papers in the *Journal of General Virology*," he said, "and the Society meetings introduced me to the virology community. To get an award from a Society that has helped me so much means an awful lot".

The governments of England, Wales, Northern Ireland and Scotland recently announced the names of the people who will sit on the panels for the next Research Excellence Framework. This exercise will decide the distribution of many billions of pounds of public money. So, it is vital that the individuals command the respect of the community and have rock-solid judgement about the immediate value and future potential of a wide range of research. The Society nominated and supported four of the individuals who were appointed: Hilary Lappin-Scott, Neil Gow, Mark Harris and Ian Henderson. Between them, these people have published at least 71 papers in the Society's journals. Put simply, the people trusted to assess the quality of the UK's research have over their careers chosen to submit important work to the journals published by the Microbiology Society.

And Geoff Smith, whose Marjory Stephenson Lecture at this year's Annual Conference was a brilliant demonstration of the power and importance of his field of virology, has published even more papers in the *Journal of General Virology*.

For the Microbiology Society's 70th birthday a couple of years ago, we asked leading researchers to choose some of the most interesting papers from our journals across the decades. Robin Weiss picked what he called "remarkable papers" from the *Journal of General Virology*, with over 2,000 citations each. He also highlighted just how relevant microbiology research can be to real lives, by selecting "the first thorough analysis of Ebola virus proteins". Stephen Gordon, who had the unenviable job of selecting highlights from *Microbiology*, which has been publishing since 1947, opted for "seminal work", acknowledging that there was not enough space to write about "many outstanding contributions" to the journals.

But as well as seeking to publish the best science, the staff and the editors of the Society's journals work extremely hard to make sure that authors who submit their work to us have a positive experience. It's nerve-wracking waiting for peer-reviewers' comments; not just for early career researchers – even well-established professors check their email every few minutes when they're waiting to hear from journal editors. So we pride ourselves on fast and rigorous review. And because we're a Society, not a commercial company, we invest in supporting early-career researchers to navigate the publishing process – for example, by holding workshops during the Annual Conference. And the icing on the cake is that any financial surplus generated by our publishing activities is ploughed back into activities that support the careers of the Microbiology Society's membership.

I was struck at a recent Editorial Board meeting of the *Journal of Medical Microbiology* how much energy and enthusiasm there was among the editors to attract the most interesting papers and make them as widely available as possible to the broadest possible community.

Please let me know which your favourite paper in any of our journals is: *Microbiology*, *Journal of General Virology*, *Journal of Medical Microbiology*, *Microbial Genomics* and the *International Journal of Systematic and Evolutionary Microbiology*. I look forward to hearing from you.

Peter Cotgreave
Chief Executive
p.cotgreave@microbiologysociety.org

News

New Microbiology Society President announced

We are delighted to announce that, as of January 2019, our new President will be **Professor Judith Armitage FRS** from the University of Oxford. The official announcement will take place at our Annual General Meeting (AGM) and Showcase, on Thursday 6 September. See the website for more details: **microb.io/2zswRbX**.

Society informs Parliamentary inquiries

The Society has informed several important policy consultations with members' expertise. Professor Paul Kellam gave oral evidence to the Lords Science and Technology Committee's 'Life Sciences and the Industrial Strategy' inquiry, and was quoted in their report. The Society submitted members' views on the impacts of Brexit for science and innovation, and plant and animal biosecurity, and was invited to a Brexit Summit by the Commons Science and Technology Committee. More information can be found on our website: **microbiologysociety.org/consultationresponses**. Contact **policy@microbiologysociety.org** to get involved in our policy work.

Publish in X-AMR and be part of the AMR community

Antimicrobial resistance (AMR) is a cross-disciplinary, global issue. Only through collaboration can scientists from different disciplines and countries find solutions to prevent the spread of AMR. WHO has called for a coordinated call to action by all countries. The Microbiology Society is, thus, providing such a home and invites all scientists from any discipline to publish in X-AMR. For more information, see our website: **microb.io/2Mmqokh**.

Annual General Meeting and Showcase of the Society's Achievements

The Society is pleased to confirm that this year's Society Showcase and Annual General Meeting will take place on 6 September 2018, at its headquarters, Charles Darwin House, London. Check the website for the latest details: **microb.io/207sW7r**.

Annual Conference Poster Prize winners

We are delighted to announce the following winners of Microbiology Society poster prizes at the Annual Conference.

People's Choice Poster Prize

André Antunes, Edgehill University, for his poster:

Innovative Assessments in Microbiology: The Bio-animation Project Experience

Early Career Microbiologists' (ECM) Forum Poster Prize

Stephen Thorpe, University of York, for his poster:

Electrophotonics: Multimodal sensors for bacterial identification and phenotyping.

The ECM Forum Executive Committee also identified the following *highly commended* poster by **Eleanor Furness**, Aberystwyth University:

Harry Smith Vacation Studentship Summer 2017 Research. How can the revival of dormant Actinobacteria unlock their potential?

If you missed these posters, they will be on display again at the Annual General Meeting in September.

Full events listing

If you are organising or hosting a microbiological meeting, the Society can help spread the word. Complete the online form **microbiologysociety.org/submitevent**, available on the Microbiology Society website.

Grant deadlines

Date	Grant
1 September 2018	Travel Grants – for eligible members wishing to present at conferences or attend training events on or after 1 October.
	Careers Conference Grant – to support Undergraduate Student members wishing to attend the Royal Society of Biology Bioscience Careers Day.
30 September 2018	ECM Forum Event Fund – for ECM members requiring sponsorship for local events.
1 October 2018	Education and Outreach Grants – for eligible members requiring support for projects to communicate or teach microbiology.
	Research Visit Grants – for eligible members wishing to make a research visit to a collaborator.
	International Development Fund – for eligible members wishing to contribute to the development of microbiology in low- and lower-middle-income countries.

Check the website for details about applying for grants: **microbiologysociety.org/grants**.

Get in touch

Are you running any outreach activities at local science festivals or Big Bang events this summer? Are you attending or presenting at a conference or simply attending an exhibition over the coming months? ***If the answer is yes, then we want to hear from you.***

We are currently looking for members to get more involved with activities across the Society. If you are interested in finding out more about the various opportunities, contact Erin Taylor, our recently appointed Member Engagement Manager, at **e.taylor@microbiologysociety.org** for more information.

New partnership with the American Society for Virology

We are pleased to announce that the *Journal of General Virology* is now affiliated with the American Society for Virology.

Founded in 1981, the American Society for Virology (ASV) promotes the exchange of information and aims to stimulate discussion and collaboration among virologists. ASV members will now receive a 10% discount off Article Processing Charges for publishing open access articles in the *Journal of General Virology*.

Microbiology Society members are reminded that they also receive a discount for Article Processing Charges. Please contact the Editorial Office at **jgv@microbiologysociety.org** for more information.

Deaths

We are sad to announce the passing of Professor **Stanley Falkow**, who was awarded the Marjory Stephenson Prize in 2004. You can read an overview of his career in a previous article in *Microbial Genomics*: **microb.io/2GwMAVp**.

Please contact **mtoday@microbiologysociety.org** if you wish to notify the Society of the death of a member whose details can be included in this section.

Society supports new curriculum for the use of animal research

A new curriculum for the use of research animals has just been launched by the British Pharmacological Society (BPS) and supported by a range of life sciences organisations, including the Microbiology Society. The curriculum is available on the BPS website: **www.bps.ac.uk**. You can read our full position statement on our website: **microb.io/2KtWKw4**.

Contributions and feedback

The Society welcomes contributions and feedback from members. Please contact **mtoday@microbiologysociety.org** with your ideas.

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Announcing
ACCESS MICROBIOLOGY

Those who attended Annual Conference this year may have noticed a competition being run from the main Society stand to name our new journal. In running the competition, we offered two name options – *Access Microbiology* and *The Microbe Hub* – and received some other excellent suggestions, including *Microbiology Unlocked* and *Discover Microbiology*. However, *Access Microbiology* was the clear winner and the publishing team have now registered that name.

Wladimir Bulgar/Science Photo Library

Access Microbiology will introduce a new service to members of our community, allowing the publication of replication studies, negative or null results, research proposals, data management plans, additions to established methods, and interdisciplinary work in a broad journal covering the full spectrum of microscopic life forms, from bacteria and viruses to fungi, protists, archaea, and algae. We believe that too many of these valuable research outputs have been lost because they are not seen as 'high-impact', creating a situation in which research is re-done in multiple labs for no gain. *Access Microbiology* aims to reduce this kind of research waste, so our publication criteria will be based on methodological rigor rather than novelty, and the journal will be fully Open Access with a policy of encouraging authors to make their data and methods available through initiatives such as data repositories.

One of the Society's objectives under the new strategy is to enable you, our members, to strengthen your networks and gain access to new opportunities, so we are taking a novel approach to building the Editorial Board for *Access Microbiology*. We're seeking to partner more experienced editors with individuals earlier in their career, helping them to develop editorial skills and advance their careers. If you are interested in joining the journal's Editorial Board, please email the team at **accessm@microbiologysociety.org**.

We are keen to engage with the whole community in launching the journal, so even if you aren't interested in joining the Editorial Board, please get in touch with the team at **accessm@microbiologysociety.org** to share your feedback and thoughts on the journal.

The competition winner was **Daniel Morse** from Cardiff University, whose slip was first out of the box.

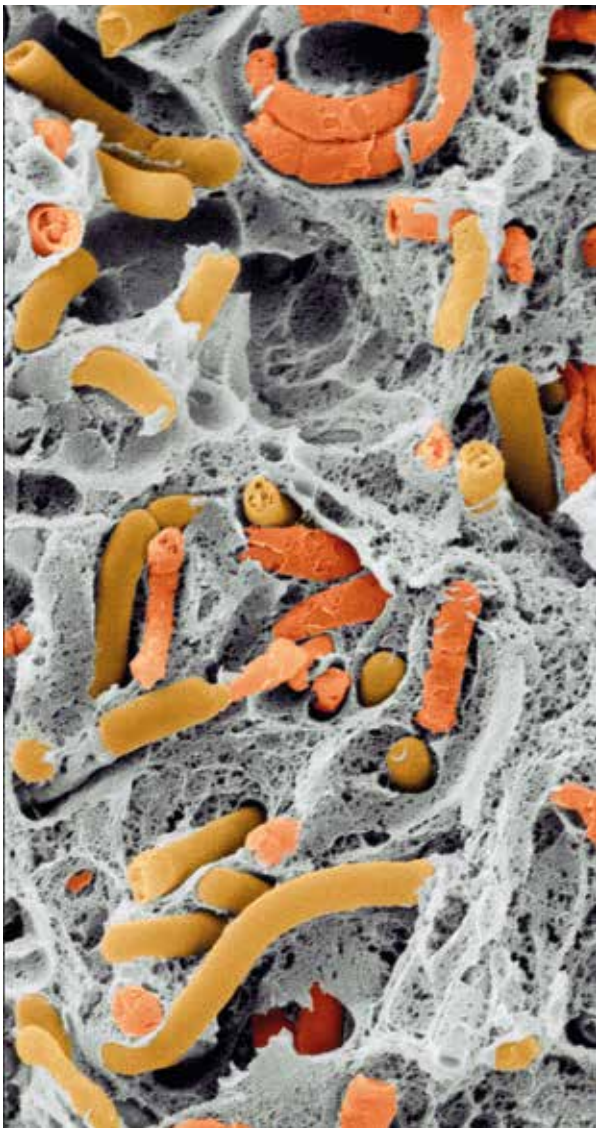
A matter of taste: using microbes to influence flavour production

Christine Dodd & Dewi Yunita

Flavour is a major component of the sensory characteristics of food and drink, and is integral to the choice of what we consume. The development of flavour is a multifaceted process as it depends on the combination of ingredients used in a product and how our sensory perception of these delivers our flavour experience.

Flavour components can include non-volatile compounds which are detected by taste and aroma volatiles which are detected by smell; the combination of these develop the full flavour experience. Some of these compounds are intrinsic to the key ingredients but, for certain food products, the involvement of micro-organisms is essential in producing their characteristic flavours and can deliver complexity and variety.

The diversity of products that involve micro-organisms in their production is high. Obvious everyday examples such a bread, yogurt, cheese, salami, wine and beer are well recognised as fermented products, as are products such as kimchi, sauerkraut and kefir, but chocolate, coffee, tea and olives also require the involvement of micro-organisms in their production. Internationally there are many fermented dairy, cereal, meat and vegetable products eaten as an everyday staple, many of which are indigenous to that country and produced traditionally at the household level by natural fermentation. Typical examples of this are *ogi,* a naturally fermented maize or sorghum product from Nigeria,

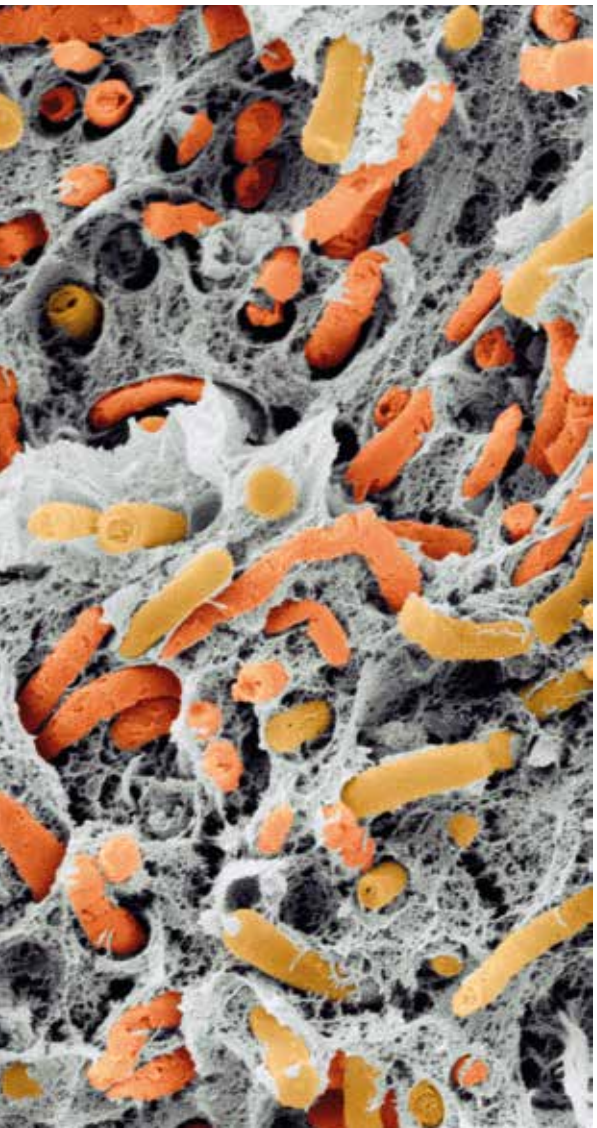


Colour-enhanced scanning electron micrograph (SEM) of a freeze-fractured kefir grain, showing bacteria in the interior. Scimat/Science Photo Library

gari, a fermented cassava product made across West Africa, and Pliek U, a naturally fermented grated coconut which is usually used as food seasoning in Aceh, Indonesia. Micro-organisms change the texture and nutritional properties of the base material and are a major contributor to the development of flavour. There are some foods which are just micro-organisms: well-known brands of mycoprotein and yeast extract are household names.

Flavour development

Flavour compounds develop when micro-organisms grow and their enzymes break down the components of the basal materials such as carbohydrates, proteins and lipids. The end products of metabolism can be elements such as amino acids, fatty acids and nucleotides, which impart particular flavour characteristics. For example, hydrophobic amino acids (e.g. phenylalanine, leucine, isoleucine, methionine) produced by the action of proteolytic enzymes on the milk protein casein result in bitterness. However, further metabolism of these can result in a diversity of flavour/aroma compounds: these can be sulphurous/cabbagey as produced from the conversion of phenylalanine to methanethiol; sweet honey-like, which results when phenylacetic acid is produced from phenylalanine; and fruity/banana/malty characteristics produced by the conversion of leucine to isovaleric acid, 3-methyl-1-butanol or 3-methyl butanal, respectively. The breakdown of sugars (e.g. lactose) typically results in organic acid end products which produce sour notes but also alcohols and diacetyl, which gives a buttery aroma, or acetoin which gives a fruity flavour. Methyl ketones and their associated secondary alcohols are produced from fatty acids and give 'blue notes' to cheeses. All of these characteristics have been described in blue cheeses and while individually they may not always sound appealing, in combination, these give products their desired characteristics. For example, the production of the three volatile sulphur compounds methanethiol, dimethyl disulphide and dimethyl trisulphide are related to a desirable flavour in Cheddar cheese.

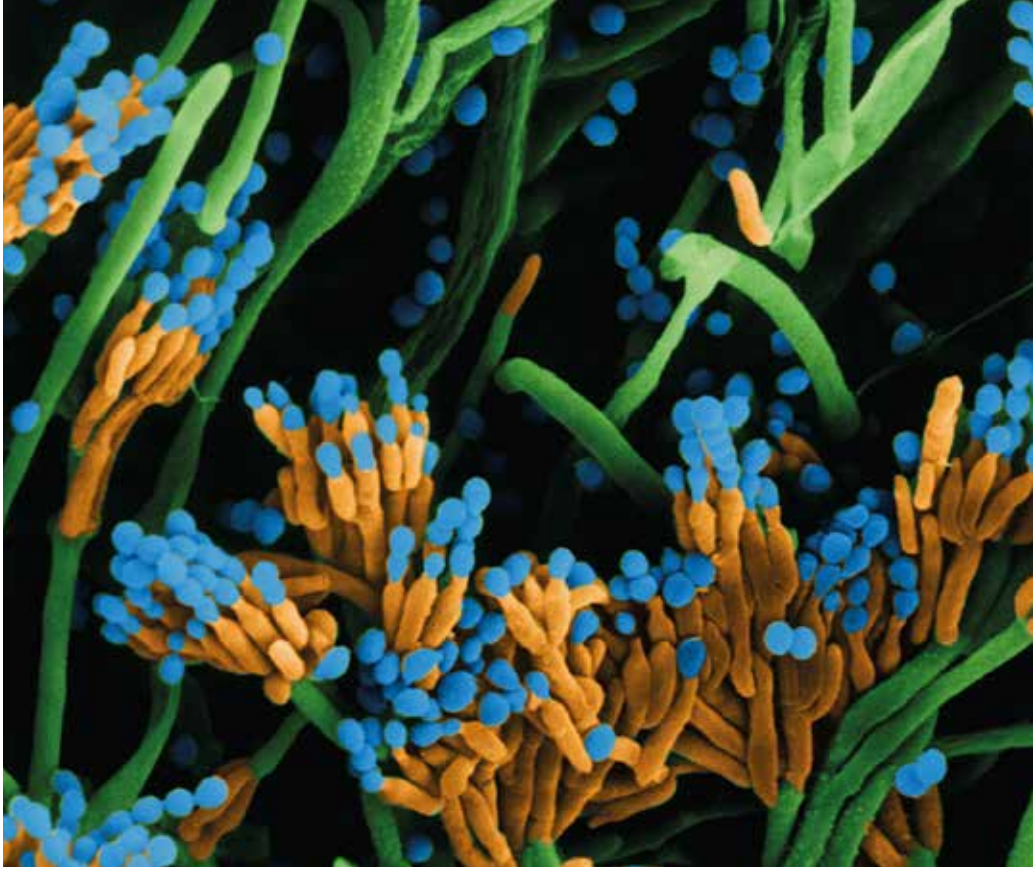


The composition of the microbial population

Which flavour/aroma compounds are produced and in what quantities is thus dependent not only on the composition of the food but also on the composition of the microbial population. Each micro-organism produces characteristic end products of metabolism, but these may then be used in turn by other micro-organisms, which results in further end products. The conditions of production determine the extent to which particular groups will continue to metabolise and produce their associated end products. In natural fermentations, the fermentation relies on the indigenous micro-organisms introduced by the components, but this can result in poor product quality or even production failure if the right species are not present to impart a particular desirable characteristic. 'Back slopping' (using a fermented product as an inoculum) can overcome this but can also perpetuate undesirable groups. The use of commercially produced starter cultures with known metabolic characteristics to initiate fermentations is widespread, and bacteria, yeasts and moulds are widely used in the food and beverage fermentation industries. These make a more uniform product but may not always be the key species influencing flavour generation.

Lactic acid bacteria such as *Lactococcus lactis* and *Lactobacillus* are an important group of bacteria used in the dairy, fermented meat and fermented vegetable industries. These produce lactic acid as an end product from glucose but, depending on the subspecies of *L. lactis* or species of *Lactobacillus,* other end products contributing to flavour can arise such as ethanol, diacetyl and acetoin. In some products, specific species are used together to produce desirable product characteristics. In yogurt, *Streptococcus thermophilus* and *Lactobacillus*

bulgaricus are inoculated together. Both produce lactic acid, but together this is improved in comparison to each alone as the *Lactobacillus* liberates valine through proteolysis, which stimulates growth of the streptococci, and the *Streptococcus* produces formate needed by the lactobacilli. Acetaldehyde and diacetyl are the important flavour volatiles produced giving the typical yogurt flavour, with the *Lactobacillus* being the primary producer of the former. The absence of an enzyme (alcohol dehydrogenase) in both species, which would convert the acetaldehyde to ethanol, means the final product is yogurt flavoured rather than being alcoholic!



Coloured scanning electron micrograph (SEM) of *Penicillium roqueforti.*
Dennis Kunkel Microscopy/Science Photo Library

Starter cultures

In fermented meats like salami, *Staphylococcus carnosus* and *Staphylococcus xylosus* are often added with the lactic acid-producing starter culture. Unusually, these organisms are not very acid tolerant and so do not grow once the pH starts to drop. However, the enzymes they produce are more tolerant and so essentially the bacteria act as bags of enzymes which contribute to fat and protein breakdown, and hence the production of flavour compounds.

The other main groups important in flavour production are yeasts and moulds. Yeasts are of course well known for their alcohol production, but the proteolytic and lipolytic activities of particular species produce a range of flavour compounds. The yeast *Yarrowia lipolytica* breaks down tributyrin, resulting in butanoic acid which has a cheese-like odour, and this is believed to be an important part of the flavour development in a number of cheese varieties. Moulds similarly have proteolytic and lipolytic activity which impart particular characteristics; *Penicillium roqueforti* gives the 'blue' flavour characteristics to cheeses like Stilton and Roquefort.

Cheeses are a good example of a product where the development of sensory characteristics is very dependent on the balance of micro-organisms present. Following the initial fermentation by a starter culture, cheeses undergo a ripening period, the length of which varies with cheese variety. It is during this period that cheeses become complex dynamic ecosystems with the growth of a variety of different micro-organisms contributing to the product's flavour development. For example, in Stilton cheese, *Lactococcus lactis* and *P. roqueforti* are the two starters added by the manufacturer but the final microbiota of a mature cheese after 12 weeks contains many other bacteria and yeasts, some of which have been shown to influence flavour characteristics. As indicated above, *Penicillium* is added to allow development of typical blue cheese flavours, mainly through the production of methyl ketones. In model cheese studies using controlled flora composition, the inclusion of *Y. lipolytica* with *P. roqueforti* has been shown to increase the development of blue cheese aroma through an increased production of ketones, in comparison to using *P. roqueforti* alone, and resulted in sensory characteristics equivalent to a mature cheese which the mould alone did not. This may result from the yeast's highly lipolytic activity releasing free fatty acids which the mould could then convert to ketones. Thus, the full product characteristics desired by the consumer may rely on this yeast being present. However, this is a species which is present only through chance introduction during processing and hence its presence could be variable from batch to batch, leading to variability in the product.

Many micro-organisms are thus beneficial in contributing to the production of flavour characteristics in many products we consume. However,

it should always be remembered that context is key; diacetyl production in dairy products is desirable: in beer it is an off-flavour! One producer's starter culture is another's spoilage agent. That well-known yeast extract product effect!

Further reading

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Christine Dodd

Division of Food Sciences , School of Biosciences, Sutton Bonington Campus, University of Nottingham, Nr Loughborough LE12 5RD

e **christine.dodd@nottingham.ac.uk**

www.nottingham.ac.uk/research/groups/rpas/antimicrobials/people/christine.dodd

Christine Dodd joined the University of Nottingham in 1985 as a postdoctoral researcher and was awarded the Chair in Food Microbiology in 2007. She works on various areas in food microbiology including transfer of pathogens and antimicrobial resistance in the food chain and the contribution of non-starter micro-organisms to food fermentations.

Dewi Yunita

Universitas Syiah Kuala, Fakultas Pertanian, Jurusan Teknologi Hasil Pertanian, Jl. Tgk. Hasan, Krueng Kalee No.3, Darussalam, Banda Aceh – 23111, Indonesia

e **dewi_yunita@unsyiah.ac.id**

dewi.yunita.37

www.linkedin.com/in/dewi-yunita-88413145

Dewi Yunita has worked in Syiah Kuala University, Banda Aceh, Indonesia since 2006. She completed her MRes (2008–2010) and PhD (2011–2016) at the University of Nottingham, UK. Her PhD research was about microbial dynamics of raw-milk cheese ripening. Now, her research projects focus on fermentation of coconut, cacao and coffee beans.

What advice would you give to someone starting out in this field?

Christine: My advice to new research students would be to join one or more of the learned societies associated with microbiology, and to engage in the opportunities for receiving funding, attending conferences and networking which being a member affords.

Dewi: I strongly agree with Christine for this question. That's what I did when I was a student at the University of Nottingham. I got funding from this Society when I attended a conference in Torino, Italy in 2013. Thanks! Subscribing or following societies on social media is also important to keep us up-to-date with any news or hot issues related to microbiology around the world.

On a typical day (week) in your position, what do you do?

Christine: I am now working only one day a week for the university, and so my day is very structured to delivering the teaching needed for that day, preparing lectures for the following week and getting updates on my shared research.

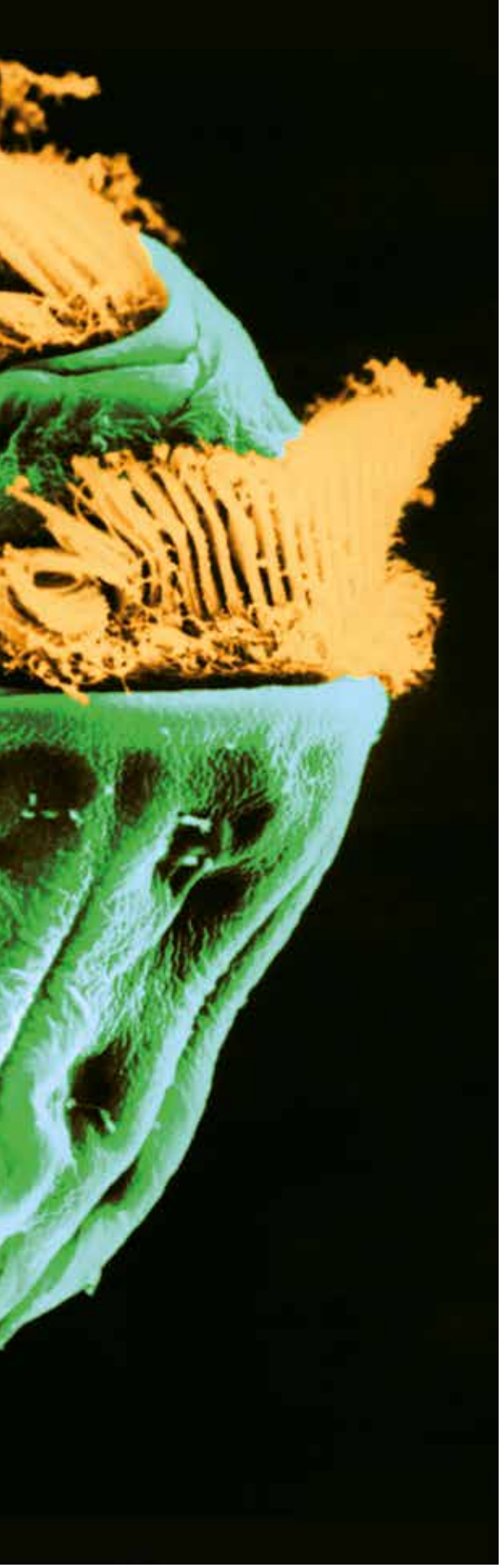
Dewi: I work five days a week full time for Syiah Kuala University as a head of the Food and Industrial Microbiology Laboratory. My main duties are teaching, conducting research and delivering knowledge to community services. Currently, I am involved in organising committees for the Annual International Conference of the University. I am also one of the editors of a scientific journal for the students.

Microbial diversity in the digestive tract of herbivores

Many mammalian species survive on a diet composed solely of plant material. This is despite mammals not encoding the enzymes necessary to fully digest the plants, particularly the plant cell wall. Instead, the animals depend on microbes present in their digestive tract. This is a symbiotic relationship, as the microbes are provided with a regular supply of nutrients and a thermostable environment. In return, the host animal uses many of the metabolites produced by the microbes as sources of energy.

Neil McEwan

Colour-enhanced scanning electron micrograph (SEM) of *Ophryoscolex* spp. ciliate, from the rumen of a cow.
Biophoto Associates/Science Photo Library



It is also known that in some animals (e.g. ruminants and horses) there is also a considerable eukaryotic community found in the digestive tract; mainly anaerobic fungi and ciliated protozoa.

The exact nature of this relationship varies between different host animals, both in terms of the microbes involved, but also in terms of organs, which are the principal sites of microbial digestion. Some animals have their major source of microbial digestion, or fermentation, in the foregut (e.g. ruminants and camelids) while others are hindgut fermenters (e.g. horses and rabbits). In terms of the microbial community present, all of these mammals have bacteria as the most abundant organisms. However, it is also known that in some animals (e.g. ruminants and horses) there is also a considerable eukaryotic community found in the digestive tract; mainly anaerobic fungi and ciliated protozoa.

The fungi and protozoa

The fungal population was the last of these to be described, partly because it had previously been believed that all fungi were aerobic, and partly because the fungal spores were thought to be forms of protozoa. Moreover, there are relatively few (around 10–12) species of fungi found within the rumen, meaning they are the least diverse group of organisms, and they continue to be most poorly studied. These fungi are widely distributed across ruminant species and many hindgut-fermenting species such as horses and elephants, but are absent from organisms such as rabbits. Where they are present it is thought that they play a role in the early colonisation of plant material, and help to produce weaknesses in the plant cell wall, which

allows other microbes to gain access to, and start to digest the plant cells.

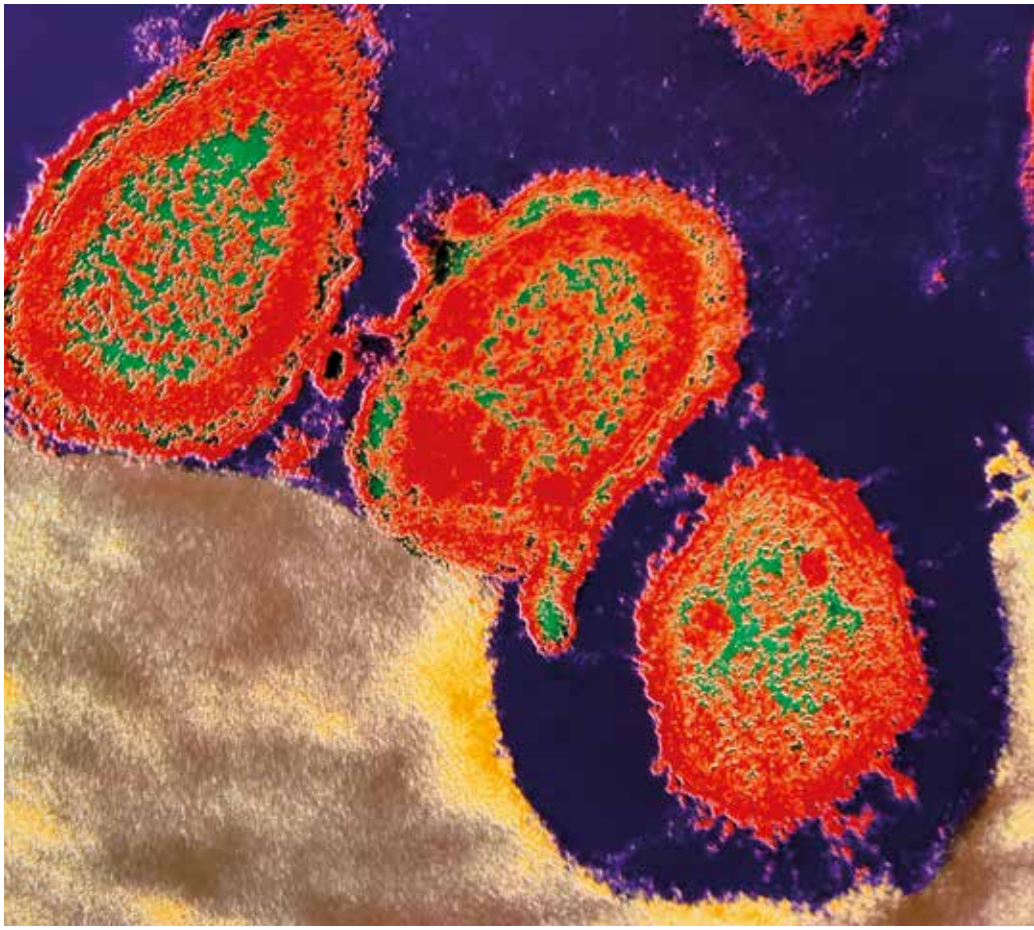
The other group of eukaryotes present are protozoa, almost exclusively ciliated protozoa. This group of organisms was first described in the mid-19th century, when they were first observed in rumen fluid studied by microscopy. Since their discovery, they have also been observed in the foregut of other foregut fermenters (e.g. kangaroos) as well as in faecal samples from hindgut fermenters such as horses and elephants – although, as with the anaerobic fungi, they are absent from other species such as rabbits. Although found in different gut regions in the different species, these ciliated protozoa are known to have come from a single genetic origin.

Despite being less abundant than bacteria, due to being considerably larger, the protozoa can account for anything up to 50% of the microbial biomass. Normally their abundance varies within the digestive tract in accordance with the diet of the animal, but is typically in excess of 10^5 cells ml^{-1}. However, at least in ruminants, these organisms are not essential, and it is well documented that both cattle and sheep which have been reared to avoid infection with protozoa (ciliate-free animals) function normally.

Therefore, the nutritional benefits of the host animal having protozoa are still unclear. As with other protozoa, these organisms are able to 'graze' on bacteria, and it is thought that they can help to digest some of the bacterial pathogens of the digestive tract, thereby potentially reducing the pathogen burden on the tract. Moreover, at least some of the protozoa are known to have genes for fibre digestion and can make at least some contribution to plant cell digestion, albeit on a scale smaller than that of the bacteria. These fibre-digesting genes, as with many other genes in the rumen protozoa, have been acquired from bacterial sources via lateral gene transfer, a feature which makes their biology interesting beyond purely nutritional studies.

The archaea and bacteria

In the case of ruminants, the presence of methanogenic archaea in the rumen has attracted environmental attention due to enteric methane production being implicated as a contributor to greenhouse gas production. Many, although not all, of these methanogens have been shown to have an association with rumen ciliates. In addition to posing an environmental concern, production of methane within the rumen has also been implicated as leading to reduced efficiency in terms of usage of available energy in livestock. However, in the rumen, production of methane is now known to act as a channel for removal of hydrogen. Failure to use methane as a hydrogen outlet means that alternative



Coloured transmission electron micrograph (TEM) of unidentified bacteria in the rumen of a cow. A number of anaerobic bacteria are visible (red), sectioned through to show the cell wall and cell contents. At lower frame (grey) is cellulose plant material which is in the process of being digested by these bacteria. Dr Kari Lounatmaa/ Science Photo Library

> The microbial community of the herbivore's digestive tract is complex and contains a diverse range of species, which varies from species to species, and can adapt in response to the host animal's diet.

pathways would have to be used as hydrogen sinks within the rumen. Such pathways are already used by many rumen microbes, although methane production is still regarded as the major approach as a hydrogen sink, meaning it is currently a highly active area of research.

However, the majority of organisms in the digestive tract of animals, both in terms of species diversity and also numbers of cells, are bacteria. Due to the commercial importance of ruminants as a source of meat and milk, the microbial community of the rumen was the first to be studied and continues to be the most extensively studied group of bacteria in the digestive tract of any herbivores, mainly to enhance nutrition and productivity. The number of bacterial species in the rumen is still unknown as, with the application of next-generation sequencing, new sequences are constantly being reported. However, there are probably several thousand species present, with different species showing specialisation of roles. For example, some species play a major role in digestion of plant fibrous materials, while others play a role in digestion of proteins, peptides and amino acids.

Roles and functions

Irrespective of the host organism, the roles played by the microbes of the herbivore's digestive tract show similar functions. For this reason, it was originally thought that the bacteria of the rumen and the bacteria of the large intestine of the hindgut fermenters might be relatively similar. Having been the first to be studied in detail, with many bacteria already isolated from it, the bacterial community of the ruminant served as an initial reference point. However, after the first research to identify bacterial species from the hindgut of the horse, it was soon clear that although a number of bacterial taxa were common to both sources, there were also a number of organisms in the hindgut of the horse which had not been reported in the rumen. In a similar way, based on DNA sequence analysis, the first reports of the bacterial community in the caecum of the rabbit suggested that around half of the sequences identified were from organisms which were unrelated (probably at the phylum level) to anything described previously.

In addition to interspecies variation in the microbial communities present in the digestive tract, there is also variation within individual animals, depending on the organ of the digestive tract being investigated. This is a reflection of physiological differences in terms of the digestive contents (e.g. moisture levels, pH, etc.). Moreover, temporal variation in the microbial content is well-documented as the microbiome changes in response to factors such as dietary composition and time since last feed.

In summary, the microbial community of the herbivore's digestive tract is complex and contains a diverse range of species, which varies from species to species, and can adapt in response to the host animal's diet.

Neil McEwan

School of Pharmacy and Life Sciences, Robert Gordon University, Aberdeen AB10 7GJ, Scotland

e **n.mcewan@rgu.ac.uk**

neil.mcewan

@NeilRossMcEwan

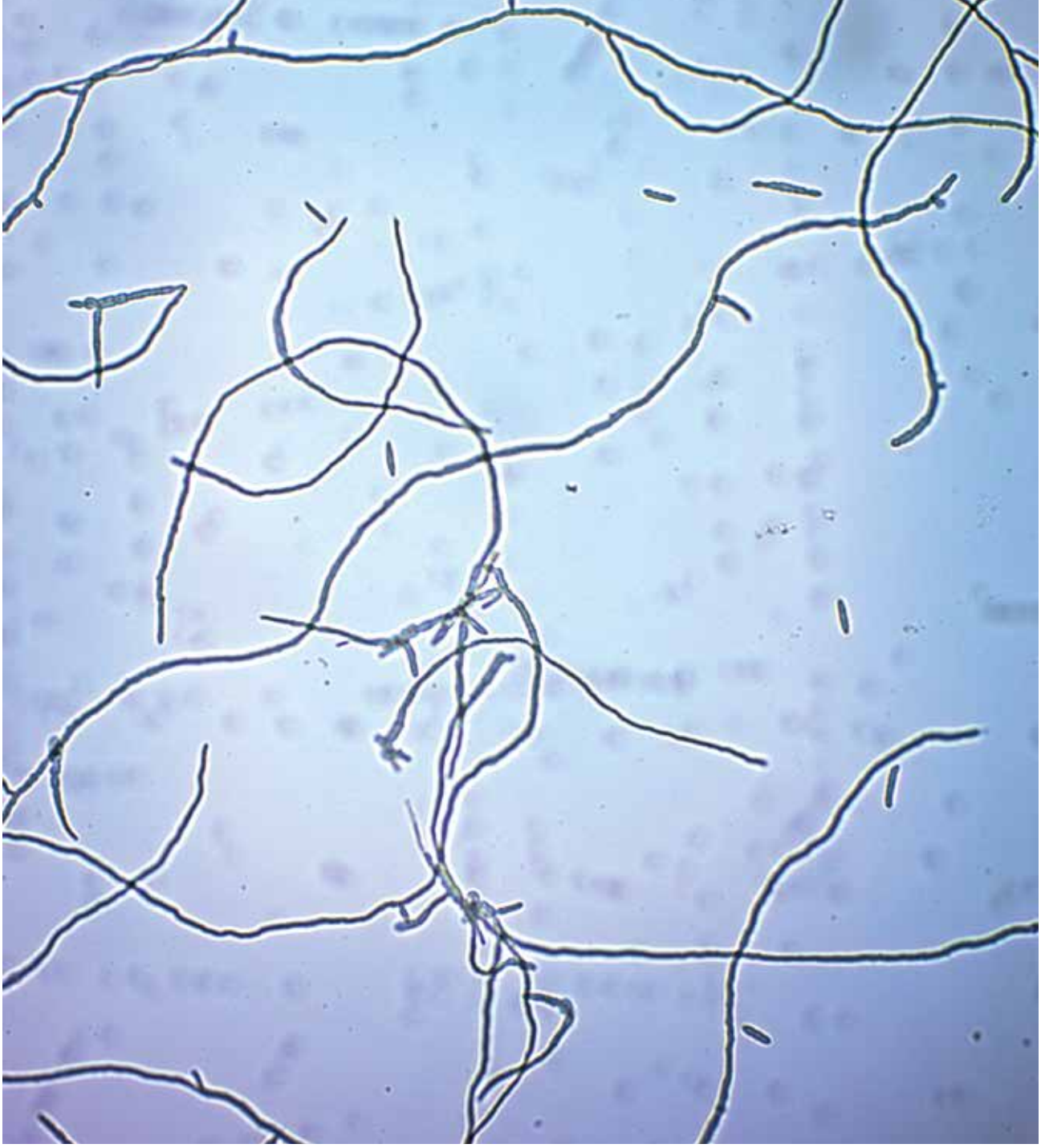
Neil McEwan is a lecturer in microbiology at Robert Gordon University in Aberdeen. His first degree is in Genetics from the University of Glasgow, and he has a PhD in Biology from the University of Stirling. Although interested in a number of areas of microbiology, his main research topic is the microbes found in the digestive tract of herbivores.

What do you love most about your job?

Being a lecturer combines the opportunity to perform research and learn new information, and to then teach this information to students.

What skills are required in your position on a day to day basis?

Teaching and researching across a range of topics and undertaking different research themes requires an adaptable attitude and an enquiring mind.



Mycoprotein production and food sustainability

Richard Harrison & Rob Johnson

Above *Fusarium venenatum.* Marlow Foods Ltd

Global consumption of protein is driving many of the major changes that we see in land use throughout the globe. We now produce somewhere between four to five times more meat than we did just 50 years ago, and in order to feed livestock, production of protein-rich pulses, such as soy, have also grown by about 10-fold in the same time, to a current high of 300 million tonnes per year.

As well as being responsible for about 14% of total human-associated greenhouse gas emissions, animals are responsible for 40% of global methane production and 65% of nitrous oxide. The inevitable conclusion, re-iterated only a couple of months ago by the United Nations' Food and Agriculture Organization (FAO) director general José Graziano da Silva, is that we must reduce meat consumption and in turn reduce global demand for animals and animal feed. Only 65 years ago, the FAO were grappling with the opposite problem, an impending predicted global shortage of protein foods and the spectre of malnutrition. Ironically, the solution proposed then, may be the same as it is now: alternative low-carbon protein derived from fungi.

History

The development of mycoprotein is a fascinating story; having decided that there was a need for a protein source, the British company Rank Hovis McDougall (RHM) set about screening thousands of strains of fungus for their suitability for growth on glucose, finally hitting upon *Fusarium venenatum*. After 15 years of research, partnering with Imperial Chemical Industries (ICI) to scale fermentation, approval was given in 1984 by the UK Government for sale as a food by the newly formed Marlow Foods. The total investment was over £1 billion in current terms and progressed even after a few false starts had to be abandoned. Mycoprotein was first sold under the brand name Quorn™ in 1985, in the form of a savoury pie by Sainsbury's. The company is now worth over £500 million (part of the Filipino company Monde Nissin), sells Quorn™ in 19 countries and aims to be a billion dollar business within 10 years.

At the same time as Quorn™ was being developed, RHM and ICI were also developing another single-celled protein for animal feed, Pruteen™. Pruteen™ was made from *Methylophilus methylotrophus*, an aerobic organism that was fed methanol in one of the largest fermenters that has ever been built, at over 1,500 tons working volume. The 80-metre high fermenter dominated the skyline at Billingham in Teesside, along with the associated cooling tower for a few years in the mid 1980s, before being demolished as the rise in oil prices and increased efficiency of traditional farming made it uncompetitive.

Throughout its history, the development of Quorn™ has always drawn heavily on microbiologists in the university sector. Perhaps the most fundamental insights into the biology of *F. venenatum* have been gained through the work of Marilyn Weibe, Geoff Robson, Steve Oliver and Tony Trinci in the 1990s, while in Manchester. Moving into the post-genomic era, work is now taking place at National Institute of Agricultural Botany (NIAB), University of Nottingham and Northumbria University into the growth and metabolism of *F. venenatum* at the molecular level, in research supported by Biotechnology and Biological Sciences Research Council (BBSRC), Innovate UK (NIAB), and Marlow Foods directly (University of Nottingham and Northumbria University).

Process

The towers containing the Quorn™ fermenters stand over 40 m high, and the fermenters themselves are over 30 m high within the towers. The fermentation process is a pressure cycle airlift, where the entire circulation is caused by the differential density between the aerated medium in the main body of the fermenter and the higher density, unaerated medium in a return pipe. No impellers are used, making these 150,000 l fermenters remarkably energy efficient. The medium used is a minimal salts medium using high purity – almost research grade – salts, pure glucose and ammonia fed in through the airline. Small amounts of biotin and choline are added to aid growth and morphology. The fermentations are continuous, running for about a month before the accumulation of short, hyperbranched mutants affects the quality to the point

that the process must be stopped and restarted. The broth is heat treated as it leaves the fermenter to reduce the RNA content. It is then pasteurised and the liquid is removed by centrifugation, leaving a paste that resembles bread dough.

The paste from the fermentation is mixed with a protein (usually egg white) to align the hyphae and cross link them. Flavourings are also included at this stage. The mixed paste is then heated to set the dough into a solid billet, which is then cooled, cut into shapes or minced and then frozen. The freezing allows ice crystals to form that force the hyphae into bundles that closely resemble the fibres seen in muscle.

Footprints

There are a number of different greenhouse gases, but greenhouse gas footprints tend to be expressed as carbon dioxide equivalent (CO_2e); this is known as the carbon footprint. Mycoprotein production produces 1.14 kg CO_2e per kg, a finished product e.g. Quorn Mince™ = 1.72 kg CO_2e per kg at the factory gate. This is lower than the most intensively produced broiler chicken (at 2.4 kg CO_2e) and is clearly below the lower end of the spectrum of animal-derived protein sources (beef can be anywhere between 12 and 60 kg CO_2e depending upon how and where it is produced).

The water footprint of mycoprotein is around one tenth of that of beef and around half that of chicken, taking about 2,000 kg to produce 1 kg of protein. This is still high in comparison to plant-based protein and work is underway to reduce this significantly, through reuse of water in production.

Feed conversion ratios are also favourable, with under 2 kg of wheat needed to produce 1 kg of mycoprotein – in comparison to beef (taking 12–24 kg). Because of the fermentation process, Quorn™ contains more protein than there was in the original grain, unlike animal proteins which can only concentrate what was in the grain (with some losses).

The towers containing the Quorn™ fermenters, two in the tower on the left and one in the right.
Marlow Foods Ltd

Benefits

Over the years, a significant amount of work has been done on the health benefits of Quorn™ mycoprotein. Research has shown that it aids satiety, can help control blood sugar levels by increasing sensitivity to insulin and can reduce blood lipids. It has been shown to aid gut health and current research indicates that it is a good source of anabolic protein.

Future targets

Some of the key future targets for production of mycoprotein aim to turn the production process into a more cyclical one, utilising waste water and reusing some of the waste streams (such as the 'broth' left over from fermentation). These waste sources have the potential to be of some value, as well

as reducing the ecological footprint of mycoprotein.

One key target for future research is the use of alternative carbon sources. Currently, production relies on wheat-derived glucose, which is plentiful in the UK. However, looking beyond this into other sources of carbohydrate, there may be opportunities to develop new recipes for fermentation using either plentiful carbon sources or indeed other waste streams such as lignocellulose. The diversity harboured within the population of *F. venenatum* has not yet been explored and may offer some significant potential for novel bioprocesses that are not present within the current production strain. Ongoing BBSRC-funded research at NIAB is beginning to explore some aspects of this challenge.

Finally, if fermentations could be carried on for longer, the overall energy required to produce mycoprotein would decrease. Some ongoing work at NIAB is investigating the genetic basis of a 'colonial variant'– a short-branched mutation of the production strain that arises during fermentation. This is one of the primary barriers to continuous production. Understanding the genetic basis of the means by which this arises may allow work-arounds to be designed into the production process, allowing operational costs to be lowered.

Taken together, the evidence suggests that with the combination of shifting dietary habits in the under-25s towards a flexitarian or vegetarian diet, the lower carbon and water footprints and the huge potential to further refine production, mycoprotein could well be a part of the transition to a more sustainable and circular economy and, while never replacing the role of animals in our diet, it may offer a palatable, clean and green alternative for many.

Dedication

This article is dedicated to Geoff Robson, who passed away suddenly in May 2018. Our condolences are with his family, his many colleagues and friends.

Richard Harrison

Genetics, Genomics and Breeding, NIAB-EMR, New Road, East Malling, Kent ME19 6BJ

e **richard.harrison@emr.ac.uk**

Richard Harrison leads the Genetics, Genomics and Breeding department at NIAB EMR and is supported by BBSRC through BB/P020364/1.

Rob Johnson

Quorn Foods, Station Road, Stokesley, North Yorks TS9 7BR

e **rob.johnson@quornfoods.com**

Rob Johnson is Science Manager (Fermentation Specialist) at Marlow Foods.

What advice would you give to someone starting out in this field?

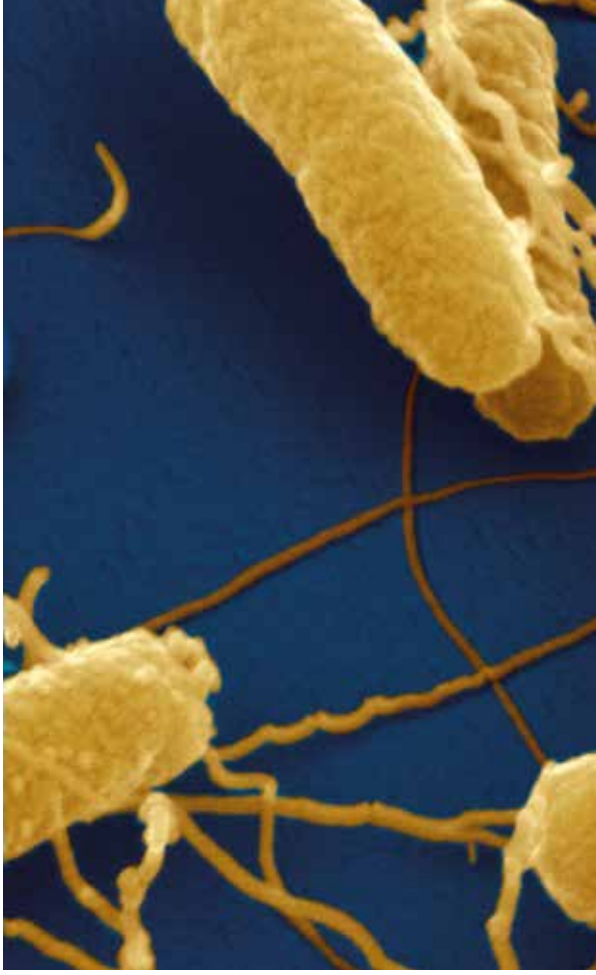
Richard: Microbiology is a fascinating and diverse area of research, which can lead in many different directions, so it's very hard to give specific advice. If you are interested in gaining an enhanced microbiology 'experience' at the undergraduate level, try to combine microbiology and molecular biology modules with some more quantitative modules, such as metabolic modelling and informatics, and try not to specialise only on human-associated microbes. If you're looking for PhDs in the area of industrial biotechnology with microbes, again try to select an institution with a great track record (University of Nottingham, Imperial College London and The University of Manchester are all strong in this area) at which you can learn both the molecular biology skills and the modelling/informatics that's needed for most cutting-edge research. Joining a society often allows you to mingle with relevant industries as well as other academics; after all, two-thirds of postgraduates go into industry.

What is the most rewarding part of your job?

Richard: By far the most rewarding parts of the job are discovering new biological phenomena (and sharing them with the research community) and getting work out into practice. Both these elements of my work are what keep me going, despite the struggles of the funding cycles and the general daily grind. I am a firm believer in the fact that you can do high-quality curiosity-driven research with the dual aim of getting work into practice and advancing the field. If you can manage both simultaneously, then it's twice the reward!

Foodborne diseases: sequencing for answers

Prerna Vohra



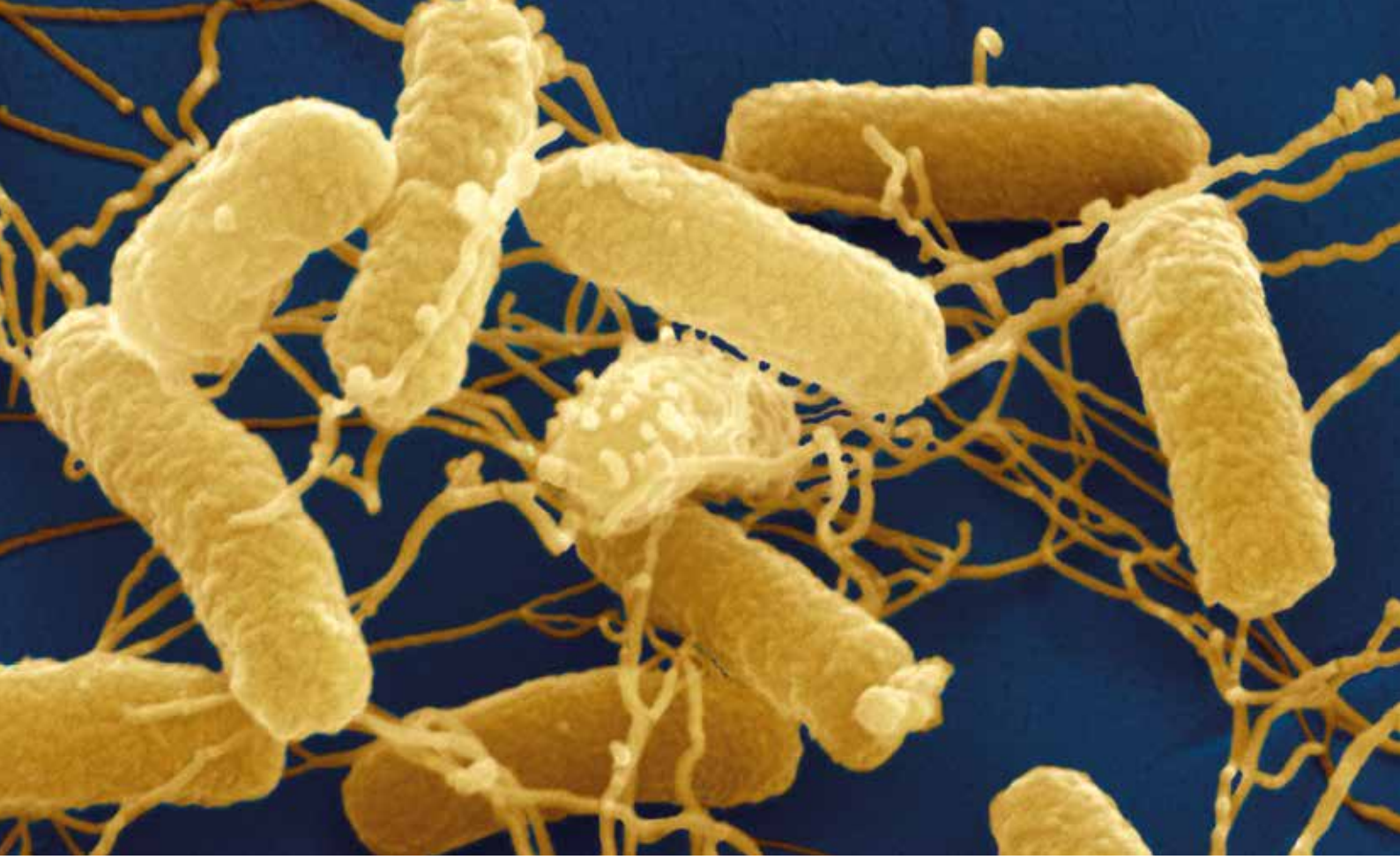
***Salmonella typhimurium* bacteria, coloured scanning electron micrograph (SEM).** Juergen Berger/Science Photo Library

'Food poisoning', 'stomach bug' and 'gastroenteritis' are some of the ways in which we commonly refer to foodborne diseases, which are a constant challenge for humans. We are all susceptible to the bacteria that cause foodborne diseases, but the more vulnerable in society – the young, old, immunocompromised and those with limited resources and infrastructure – often suffer the gravest consequences.

While most of us experience mild and self-resolving diarrhoea with some nausea and vomiting for a few days, foodborne diseases can lead to severe, life-threatening conditions such as kidney failure and neurological disorders. Foodborne diseases affect lives and economies.

Be smart, be safe

Among the most common causes of foodborne diseases are *Salmonella*, *Escherichia coli* and *Campylobacter*. These bacteria are ubiquitous in the environment and typically reside within the intestines of farmed animals like cows, pigs and chickens and within unmanaged wildlife. During slaughter and processing, bacteria can contaminate equipment and carcasses. A good example of this is the topical contamination of chicken by *Campylobacter*. Other bacteria are found deep in tissues; for example, *Salmonella* can survive within the peripheral lymph nodes of cows and pigs. These lymph



nodes are small and challenging to remove during processing and often get incorporated into minced meat. Improper handling and consumption of contaminated food leads to food poisoning but simple measures, such as not washing raw chicken to prevent *Campylobacter* contamination of our kitchens and thorough cooking of mince to eliminate *Salmonella,* can be highly effective in reducing our risk. The Food Standards Agency ensures that products are appropriately labelled with storage and handling advice to make food safer for consumers. However, we can also be exposed to zoonotic bacteria via direct contact with infected people and animals, so proper handwashing is an essential part of preventing infection.

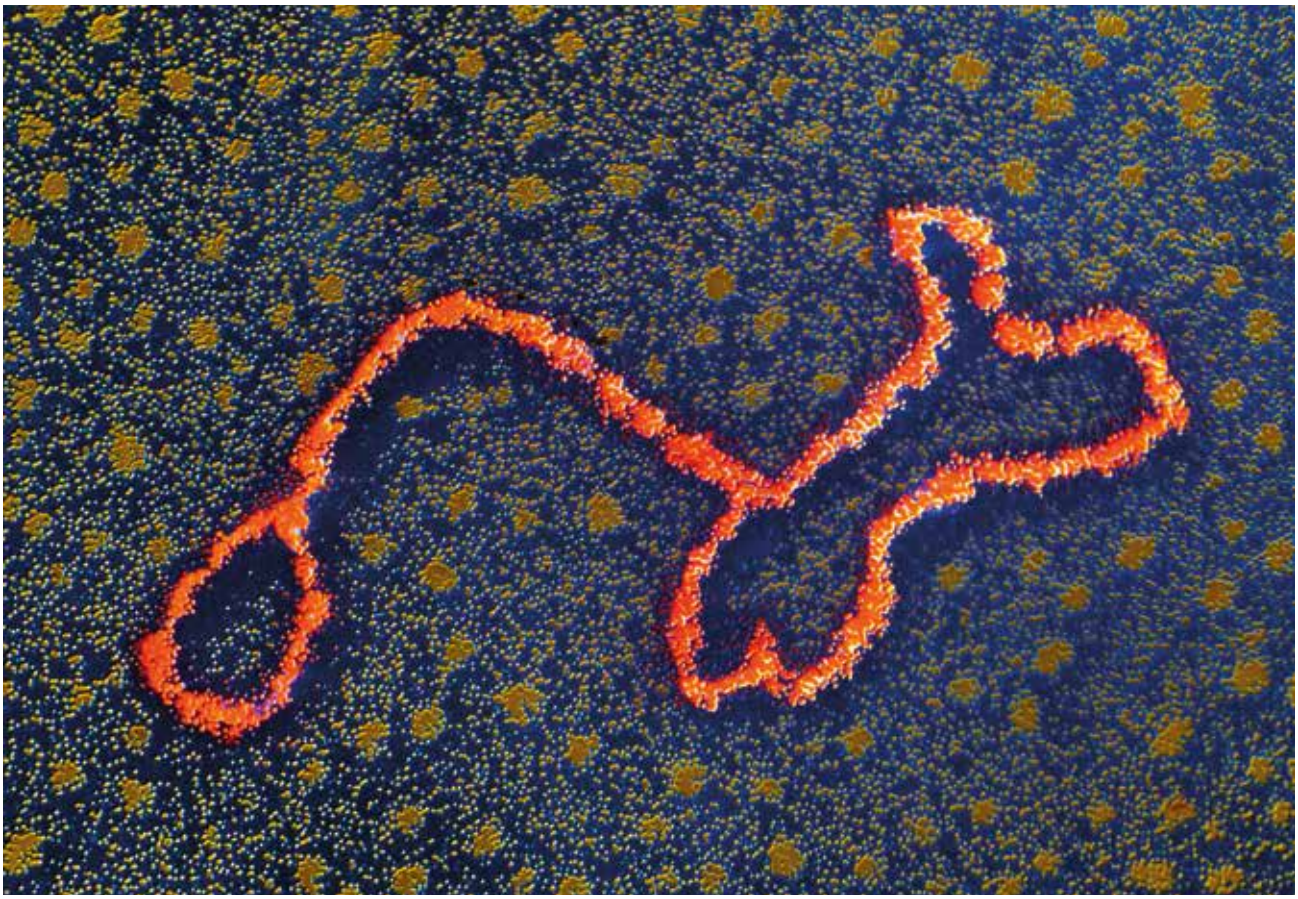
Animals can suffer too

There is a common perception that foodborne pathogens are harmless to their animal reservoirs, but this is not necessarily true. Some types of *Salmonella* cause transient diarrhoea in cows and pigs, while others can cause typhoid-like disease and lead to abortion. Even *Campylobacter*, which was long-regarded as a harmless commensal of chickens, has been associated with disease and pathology in some broiler lines. Vaccination is an attractive option to reduce the burden of foodborne diseases. However, there are currently no licensed vaccines for *Campylobacter* in chickens or Shiga toxin-producing *E. coli* in cattle. Some *Salmonella* vaccines are available for farmed animals, but how they confer protection is not well understood. In concert with vaccines, better hygiene and changes in farm practices can also help to limit foodborne pathogens, as evidenced by the National Control Plan for *Salmonella* in poultry in the UK. Given the rise of drug-resistant superbugs, we cannot simply eradicate foodborne pathogens with antimicrobials. How then can we make food safer and improve animal welfare?

From sequence to infection

Researchers have had access to the genetic blueprints of key foodborne pathogens for decades, but bacterial genomes are complex. It can be difficult to predict which genes contribute to disease, the impact of sequence variation and which genes would make good targets for vaccines and other interventions. Due to advances in sequencing technologies, the number of bacterial genome sequences in databases is increasing exponentially, but relatively few studies have sought to link bacterial genotype and phenotype during infection.

Foodborne bacteria are relatively easy to study. We can grow them in large numbers in the laboratory and have numerous molecular methods to genetically manipulate them. For example, we can knock-out genes to study their function, or knock-in nucleotide markers to make bacteria trackable, and we are constantly



False-colour transmission electron micrograph of a DNA transposable genetic element or 'transposon', seen here forming a characteristic stem-and-loop structure.
Professor Stanley Cohen/Science Photo Library

developing more sophisticated ways to study them. However, it is still unrealistic to study bacterial pathogenesis gene-by-gene or strain-by-strain, especially in relevant animal species, owing to the large number of animals, time and costs involved. To overcome these obstacles, researchers have developed clever approaches to study foodborne diseases with minimal animal use.

Sequencing approaches have been invaluable to the study of all aspects of foodborne diseases, from outbreak investigations and epidemiology, to pathogenesis and evolution. The prediction of virulence and zoonotic risk of foodborne pathogens remains a key challenge of the post-genomic era, but novel methods are aiming to tackle these. A method called transposon directed insertion sequencing (TraDIS) combines bacterial mutagenesis with deep sequencing, to identify genes which are essential for pathogen survival. By encouraging a mobile genetic element called a transposon to insert into genes, gene function is disrupted. Then, using sequencing, disrupted genes can be identified, and the number of bacteria with a defined disruption present in a population can be quantified. If a gene disruption leads to reduced bacterial survival, we can infer that that gene is important for survival. In this way, we have found out which genes *Salmonella* needs for bile tolerance, a requirement for intestinal bacteria. We also studied the roles of over half the genes of *Salmonella* during colonisation of intestines of chickens, pigs and calves. Interestingly, some genes were essential to colonise all the reservoir hosts, which would make them good targets for vaccines, but others were host-specific, suggesting that *Salmonella* uses different strategies to survive in them. Similar studies have also now defined conditional essential genes of *E. coli* and *Campylobacter*.

Along with understanding gene function during infection, it is also important to know which bacterial strains pose greater risk, but this is difficult. There are over 2,600 serovars (distinct variations within a species distinguished by their cell surface antigens) of *Salmonella*: some cause disease in humans, some in animals and some in both. So how do we decide which are high-risk? To try to answer this, a new method to simultaneously test multiple serovars was developed. All *Salmonella* serovars share genes which vary in their sequence between serovars. These variations are stable, serovar-specific and can be identified by

sequencing, to determine which serovars are present in a mixed population and at what abundance. From the presence or absence and abundance of serovars under different conditions, we can infer serovar fitness. Using this method, we studied 11 serovars in 10 tissues of cows simultaneously and found that all of them could survive within peripheral lymph nodes, despite varying in their capacity to colonise the intestines, providing valuable information for vaccine design. Sequence analysis can also be used to predict whether some bacterial strains are more zoonotic than others. Using machine-learning algorithms to analyse genome sequences of hundreds and thousands of bacterial isolates from humans and animals, computers can be trained to differentiate between them and group them based on their genetic traits. When this was applied to *E. coli* and *Salmonella*, a subset of bovine strains with human-like traits and vice versa were identified, suggesting that they pose a risk of zoonosis. Different sequencing-based approaches are also being used to link the presence of bacterial genes with traits of interest and show promise in identifying bacterial genes that may influence zoonosis.

Closing the gap

Bacterial foodborne pathogens remain a major threat to humans and animals alike, but using different sequencing and computational methods, we are slowly beginning to unravel the mysteries of these masters of misery. We now need to use the knowledge we have acquired, to develop effective drugs and vaccines to control these pathogens and reduce the burden of foodborne diseases. Long-term research is required to bring such strategies to fruition. In the meantime, we must remain cautious. Surveillance and prevention are essential while we await solutions.

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Prerna Vohra

The Roslin Institute & Royal (Dick) School of Veterinary Studies, University of Edinburgh, Easter Bush, Midlothian EH25 9RG

e **prerna.vohra@roslin.ed.ac.uk**

@DrPrernaVohra

Prerna Vohra is a postdoctoral researcher with a keen interest in enteric pathogens and how they interact with their hosts. She began her research career by studying *Clostridium difficile* during her MSc and PhD. She then moved on to vaccine-related projects, first looking at *Bacteroides fragilis* as a delivery system for vaccines for diarrhoeal diseases, and later trying to develop novel glycoconjugate vaccines for veterinary pathogens. Her current research focuses on understanding the pathogenesis of *Salmonella* and *Campylobacter* in cattle and chickens, respectively, to inform the design of vaccines or control strategies. She has been a member of the Microbiology Society since 2007 and is an ECM Forum member.

What do you love most about your job?

I love learning new things and my job gives me ample opportunities for this. I love that I can be creative to find new ways to solve problems. I also love the diversity of my day-to-day work. It can be challenging, but that's what makes it fun.

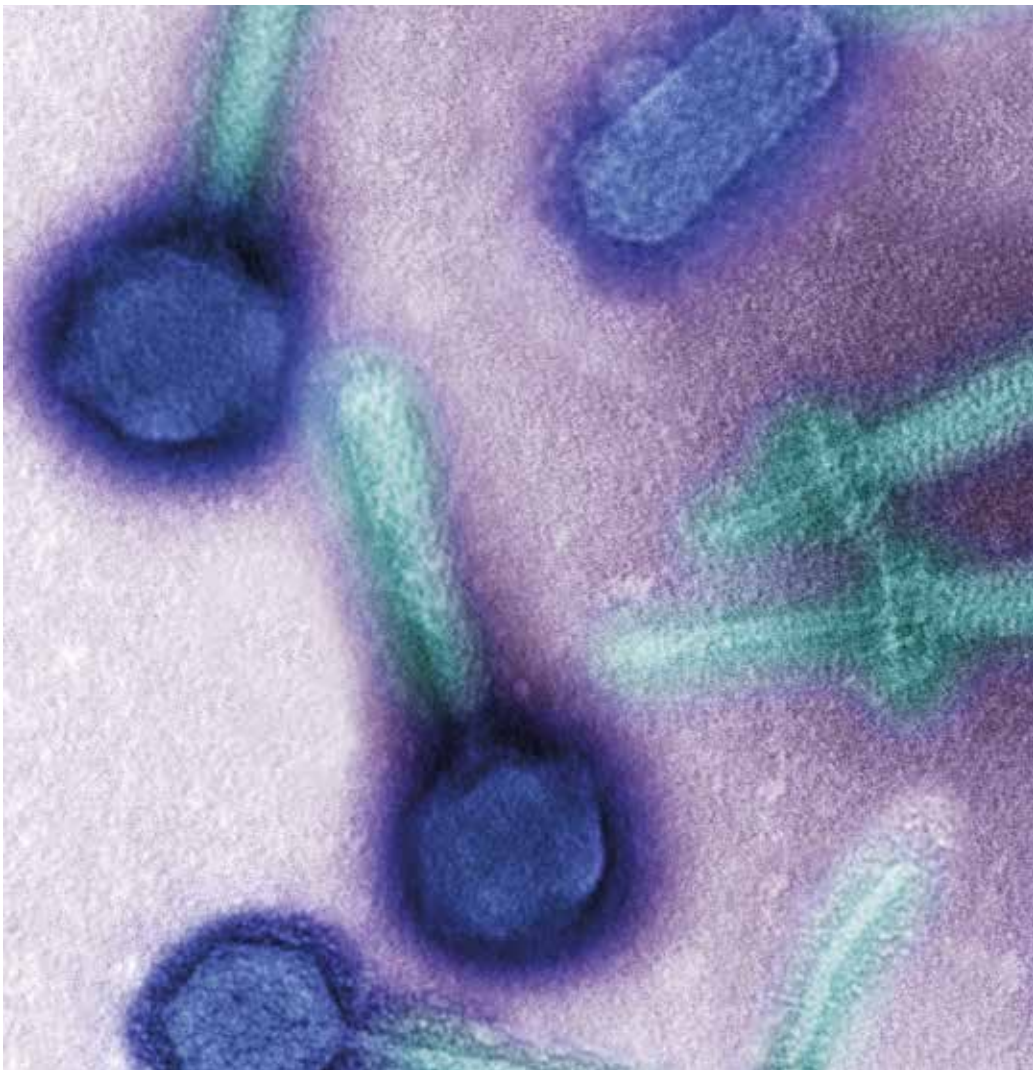
What skills are required in your position on a day to day basis?

I use my lab skills – bacteriology, molecular microbiology, immunology and *in vivo* skills – to do my research; computational skills – data organisation, bioinformatics and statistical analysis – to understand the results; and writing and presentation skills to communicate the outcomes, along with project planning and time management of course!

Bacteriophage therapy in livestock: food for thought?

Robert Atterbury

In 2014, UK Prime Minister David Cameron commissioned a major review on antimicrobial resistance. The review, led by Jim O'Neill, aimed to "Analyse the global problem of rising drug resistance and propose concrete actions to tackle it internationally". The findings of the review made for sober reading.

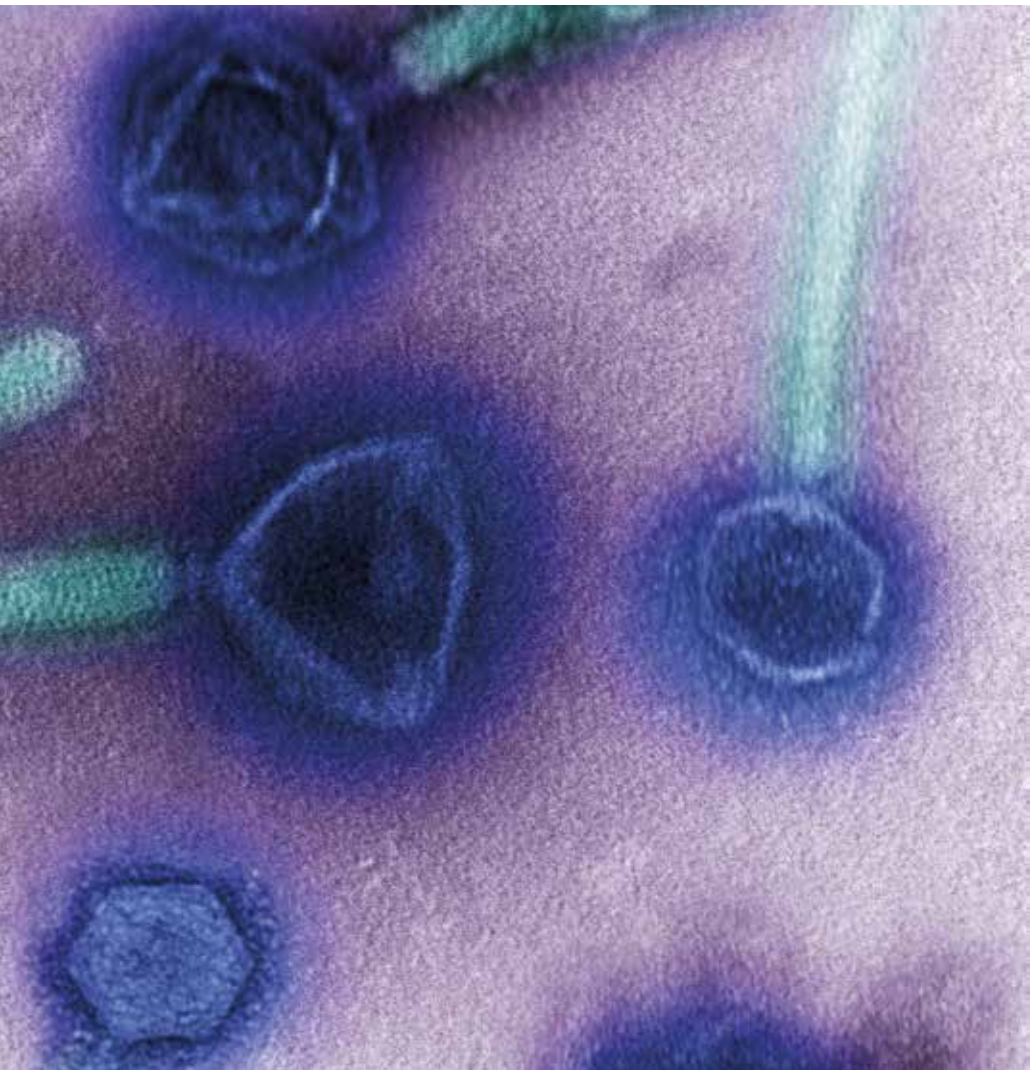


Phage therapy. Transmission electron micrograph (TEM) of various bacteriophages from a mixed phage theraputic sample. Steve Gschmeissner/Science Photo Library

Without policies to stop the spread of antimicrobial resistance (AMR), by 2050 up to 10 million lives could be lost per year to untreatable infections. Dire as this projection is, it gets even worse when you consider that much of global food production is directly or indirectly reliant on antimicrobials. The quantity of antimicrobials used in food production is estimated to at least equal that used for human medicine. Furthermore, in some countries more than 70% of medically important antibiotics are also used in livestock. Add to this the lack of financial incentives for pharmaceutical companies to develop new antimicrobials and you have a dysfunctional system unfit to meet our needs.

Alternative approaches

The O'Neill report highlighted the need to reduce our reliance on antimicrobials by developing alternative therapies.



This was echoed by a recent *The Lancet Infectious Diseases* report, jointly funded by the Wellcome Trust and UK Department of Health and Social Care, which recommended a broader-based approach, including 'non-compound' therapies. Of the 10 most promising technologies they identified, three were based on bacteriophage, and all of these were categorised as 'Tier 1' treatments which were sufficiently advanced to warrant clinical trials.

Bacteriophage (often abbreviated to 'phage') are viruses which infect and kill bacteria. The idea of using them to treat infections (aka 'phage therapy') is not new, and predates the discovery of antibiotics by approximately 10 years. Early in the 20th century, Félix d'Hérelle, who co-discovered bacteriophage, conducted several phage therapy experiments in animals and humans, successfully treating bacterial dysentery, bubonic plague, cholera and *Salmonella* infections among others. Phage therapy fell out of favour in the West during the 1930s and 1940s, due partly to a poor understanding of bacteriophage biology, and also the rise of antibiotics, which was seen as more promising. The resurgent interest in phage in the West in recent years is chiefly a consequence of AMR.

Why phage?

Phage have many potential advantages as antimicrobials. They are self-replicating and self-limiting; multiplying only when susceptible bacteria are available. Unlike antibiotics, they are specific to a genus, species or strain of bacteria and can precisely target bacterial subpopulations. This reduces the possibility of imbalances of microbiota (dysbiosis) which have been linked to disorders such as inflammatory bowel disease, coeliac disease, asthma and

metabolic syndrome. Few side effects have been reported for phage therapy, so they could be useful substitutes for patients who are allergic to antibiotics. They can be prepared inexpensively, and locally, which facilitates their use in underserved populations (e.g. in developing countries). They can also be targeted towards receptors on the bacterial cell surface which are involved in virulence. The loss or modification of these receptors by the bacterium often leads to attenuated virulence.

Applications of phage in livestock

Interest in phage therapy in livestock was rekindled during the 1980s with some exquisitely designed experiments by H. Williams Smith. This work, initially performed in mice, then in cattle, demonstrated that a single dose of phage was as effective as multiple doses of antibiotics when treating systemic *Escherichia coli* infections. Subsequent experiments demonstrated that phage can be used both prophylactically and therapeutically to treat intestinal and systemic diseases in a range of livestock, including chickens, pigs, cattle, sheep and fish.

Phage therapy in livestock has been largely directed towards foodborne zoonoses, chiefly those caused by *Campylobacter*, *Salmonella*, *E. coli* and *Listeria*. The phage used for this purpose are often characterised as exclusively lytic, i.e. their infection cycle does not involve integration in the bacterium's chromosome (a property of 'temperate' bacteriophage). The use of lytic phage arguably improves the predictability of phage therapy, and also reduces the possibility of phage-mediated transfer of DNA between bacteria. More recently, it has become commonplace to sequence and annotate the genomes of candidate therapeutic phage to ensure they do not carry potentially harmful genes associated with virulence or AMR.

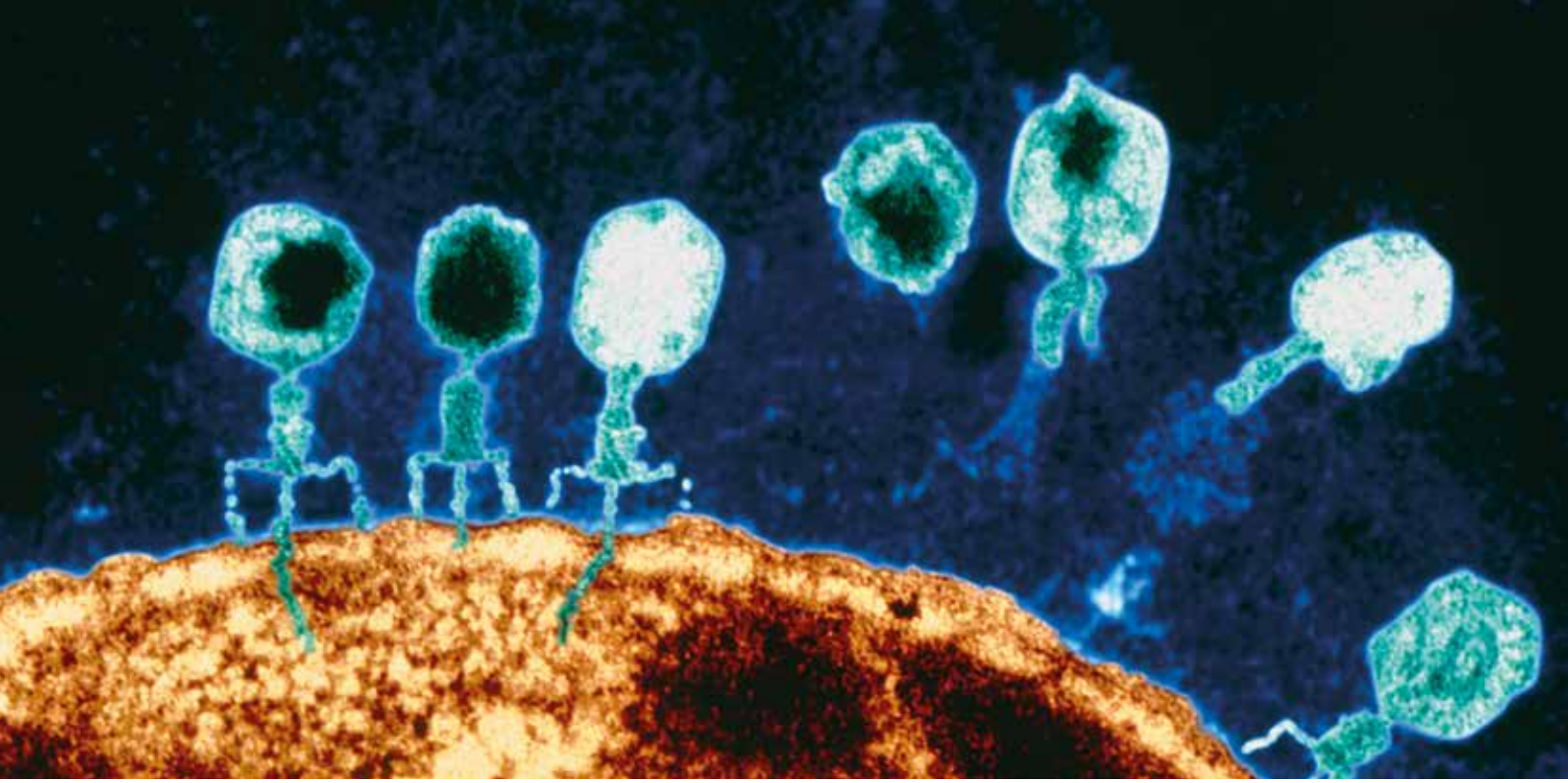
Phage treatment of systemic infections in animals is usually by intravenous or intramuscular injections whereas gastrointestinal infection or colonisation is usually treated by phage supplementation of feed or water. Experimental phage therapy trials typically report a 90 to 99% reduction in the targeted bacterial population, and sometimes much greater. However, the phage do not usually eliminate their targets. Once the bacterial population falls below a critical level (sometimes called the 'phage proliferation threshold') it becomes less likely that the phage will come into direct contact with the bacteria and initiate an infection. This scenario is perhaps more likely in the guts of animals than other environments because phage may attach to particles of food or non-host 'decoy' bacteria, which will further reduce the available pool of phage. In addition, the host bacteria are not evenly distributed throughout the animal gut, but exist in localised populations and particular environmental niches which may not always be accessible to the phage.

While phage are unlikely to be a panacea, they clearly have significant potential to control bacterial infections which may no longer be amenable to antibiotic chemotherapy.

A 99% reduction in bacterial pathogens has been shown to significantly improve clinical outcomes in many experimental livestock infections, including cattle, pigs and chickens, and is comparable to reductions seen with therapeutic levels of antibiotics such as enrofloxacin in poultry. Selectively reducing bacterial populations to this degree may also result in appreciable public health benefits. For example, some estimates suggest a 99% reduction in the level of *Campylobacter* on retail chickens would reduce the number of human campylobacteriosis cases by more than 30-fold.

Limitations and barriers

Despite impressive results in experimental infections, there are some important limitations on the useful scope of phage therapy. Phage are unlikely to be effective for the treatment of tuberculosis, brucellosis or other diseases involving intracellular pathogens. The specificity of phage also makes them less useful in the treatment of polymicrobial infections. The emergence of phage-resistant pathogens is also a concern, but can be addressed by using 'cocktails' of phage, targeting different receptors. In addition to these technical limitations, there are practical considerations, such as where phage fit into national and international regulatory frameworks which are not designed to deal with 'living' antibiotics. Also, like antibiotics, there is no financial incentive for pharmaceutical companies to develop phage-based therapeutic products. Finally, there are concerns about the public acceptability of food, or food animals, deliberately treated with viruses.



Coloured TEM of T-bacteriophage viruses attacking a bacterial cell of *E. coli*. Eye of Science/Science Photo Library

Future prospects

The rise of antimicrobial resistance has forced us to reappraise phage therapy as an alternative or adjunct to antibiotic treatments. While phage are unlikely to be a panacea, they clearly have significant potential to control bacterial infections which may no longer be amenable to antibiotic chemotherapy. As such, phage therapy promises to be a valuable tool in the fight against antimicrobial resistance.

Further reading

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Sulakvelidze A. & Barrow P. (2005). Phage therapy in animals and agribusiness. In: *Bacteriophages: Biology and Applications,* pp. 335–380. Edited by E. Kutter & A. Sulakvelidze. CRC Press **doi:10.1201/9780203491751.ch13**

Robert Atterbury

Robert Atterbury

School of Veterinary Medicine and Science, Sutton Bonington Campus, Sutton Bonington, Leicestershire LE12 5RD

e **robert.atterbury@nottingham.ac.uk**

@RobAtterbury1

Robert Atterbury is a lecturer in Veterinary Microbiology and Public Health at the School of Veterinary Medicine and Science, University of Nottingham. His research themes include the epidemiology and control of bacterial pathogens, with a focus on utilising biological controls such as bacteriophage to treat antimicrobial-resistant infections.

What inspired you to become a microbiologist?

I have been interested in microbiology since primary school, when I opted to do a research project on fungi. During my undergraduate degree at the University of Nottingham, I was very lucky to have a number of inspirational and talented lecturers. My microbiology lecturer, (now Professor) Liz Sockett, is a brilliant science communicator and ambassador, and was particularly inspiring for me as an undergraduate – so much so that I ended up working in her lab as a postdoc! Liz's final year undergraduate course in pathogens cemented my interest in this area, and set me on course for a microbiology PhD, using bacteriophage to control *Campylobacter*.

How do you see this field changing in the future?

Interest in phage has grown considerably since I entered this field in the early 2000s, largely because of their potential as biocontrol agents. Relatively few bacteriophage have been well-characterised genetically, and this will have to change (and it is) if we are serious about using them for larger-scale therapeutic applications. This information will feed into the growing area of phage engineering and synthetic biology, which may help to address some of the limitations of classical phage therapy.

Annual Conference **2019** #Microbio19

8–11 April 2019
Belfast Waterfront

The Annual Conference is currently in production and work continues on programme development and confirmation of its global speaker line-up of expert microbiologists.

This flagship event will take place in Belfast over four days, between 8 and 11 April 2019, and consists of symposia, workshops, forums, poster sessions and a trade exhibition. It is designed to offer ample opportunities for formal and informal networking for both early career and established microbiologists.

Destination Belfast

Belfast is the capital of Northern Ireland and home to the conference venue – the Belfast Waterfront. This landmark city stages the best in arts and entertainment as well as hosting major conferences and business events.

Belfast itself is a city rich in culture and history, so whether you're looking to visit its historic landmarks and attractions or experience new culinary delights, there's a lot waiting to be discovered.

There are many things to see and do in the city's Cathedral Quarter, which is packed full of interesting architecture and has a host of fabulous pubs, bars and restaurants.

If you're planning on extending your stay after the Conference, there are plenty of attractions you could visit, such as the Titanic Museum, the Alexandra Graving Dock or Belfast City Hall, one of Belfast's most iconic buildings. Learn more about this city and its attractions at **www.visitbelfast.com**.

Belfast Waterfront

Annual Conference 2019 will be held at the Belfast Waterfront, which was awarded Best Event Space 2017 and is one of Europe's most exciting conference destinations.

With 7,000 m^2 of multi-purpose event space designed to accommodate events for up to 2,000 delegates, this venue offers the perfect space for the microbiology community to come together in Northern Ireland.

Annual Conference works to reflect the broad geographic representation of its national and international membership that is based in universities, industry, hospitals, research institutes and schools.

Crèche

Following positive feedback from this year's Conference in Birmingham, the Society is again teaming up with Nipperbout to provide a free crèche at the Annual Conference 2019. The crèche will be available to all children between the ages of 0 to 12 years.

All registered delegates will be offered the opportunity to make use of these free childcare services, which will be offered on a first come, first served basis.

In addition, the event will also be providing a nursing room, cloakroom and prayer room to help support the attendance of our diverse microbiological community.


surangaw/Thinkstock

Keep up-to-date with events, follow the Society on Twitter: **@MicrobioSoc**

Accommodation and travel

Belfast is a popular destination city whose hotels fill up quickly. So, if you're planning on joining us for next year's Conference, we highly recommend you secure your accommodation and make your travel plans as early as possible.

To support you in securing your accommodation you can visit our website where we provide links to our booking and accommodation services via Reservation Highway (**www.reservation-highway.co.uk**). This travel and venue agency has secured negotiated rates at hotels to suit a broad range of budgets. You can make your reservation today or, alternatively, search online travel agencies or visit the local tourist board. Whatever you choose to do, avoid delay to ensure you're able to join us.

Travel to Belfast is easy and fast. The city is well connected by road, rail and sea transport and with two local airports the city is accessible by air from both Great Britain and overseas destinations.

Belfast Waterfront is conveniently located within a 10-minute walk of the city centre. Its address is 2 Lanyon Place, Belfast BT1 3WH.

Air: George Best Belfast City Airport is only a 10-minute drive away, whilst from Belfast International it takes only 25 minutes to reach the heart of the city and conference centre.

Train: The nearest train station is Central Station, which is on East Bridge Street, around five minutes' walk from the venue. There is a regular train service from Dublin and the average journey time is approx. two hours**.**

Road: The venue is located on Lanyon Place, just off Oxford Street in the city centre. If you are travelling on a major road into the city, follow signs for the city centre and Belfast Waterfront, via East Bridge Street or Oxford Street.

Visit the Society website to view all the information about the Annual Conference (**microbiologysociety.org/events**) and follow the Twitter hashtag **#Microbio19** for regular updates.

Conference Programme 2019

Annual Conference 2019 opens for delegate registration and abstract submissions this month. Here is a list of the scientific sessions for 2019:

Main symposia*:

- 3Rs
- Biobased circular economy & bioremediation
- Bioinformatics workshop
- Extremophiles: living life at the edge
- Global food security: the challenges for microbiology
- Intra- and interspecies metabolic networks: you are what you eat
- Irish Fungal Society clinical case studies
- Microbial dark matter
- Missing microbes and the hygiene hypothesis: new challenges and perspectives
- Natural products and *Streptomyces* microbiology
- Non-human pathogens
- Offence/defence
- The Microbial Pangenome
- The origin and diversity of the eukaryotes
- Vaccines (for prokaryotic pathogens)
- Viruses in the central nervous system – neurotrope niche
- Virus Olympics: jumping the host range barrier

Virus workshops:

- Antivirals and vaccines
- Clinical virology
- Gene expression and replication
- Innate immunity
- Morphogenesis, egress and entry
- Pathogenesis

Forums:

- Environmental & Applied Microbiology Forum
- Genetics & Genomics Forum
- Infection Forum
- Microbial Physiology, Metabolism and Molecular Biology Forum

**Titles subject to change*

Focused Meetings 2018

The Conferences and Events team have now delivered three successful Focused Meetings from this year's programme. The Microbes and Mucosal Surfaces meeting took place on 21–22 June in Dublin, Ireland. The second event, British Yeast Group: Embracing Variation, was on 27–29 June in Leicester, UK, while the latter, Emerging Zoonoses and AMR: A Global Threat, took place on 2 July in Guildford, UK.

Collectively, we welcomed over **260** attendees, **37** invited speakers, over **40** offered talks and **75** posters. Thank you to all the session organisers and those who attended these events.

Top left: **Delegates at the Microbes and Mucosal Surfaces Focused Meeting in Dublin, June 2018.**

Middle right: **Delegates at the British Yeast Group: Embracing Variation Focused Meeting in Leicester, June 2018.**

Bottom left: **Delegates at the Emerging Zoonoses and AMR: A Global Threat Focused Meeting at the University of Surrey, July 2018.**

Keep up-to-date with events, follow the Society on Twitter: **@MicrobioSoc**

You can still register for the following Focused Meetings, which will be taking place all around the UK and Ireland during September and October. Places at these meetings are limited, so we advise you to secure your place as soon as possible and please share the dates with relevant networks and colleagues.

Molecular Biology and Pathogenesis of Avian Viruses

#Avian18

St Catherine's College, University of Oxford, UK
Monday 3 to Tuesday 4 September

Key topics:

- Emerging and variant viruses
- Host antiviral responses and virus immunomodulation
- Molecular biology and genetics of avian virus replication
- New and improved approaches to the control of avian viruses
- Pathogenesis of avian viruses
- Tropism and host range restriction

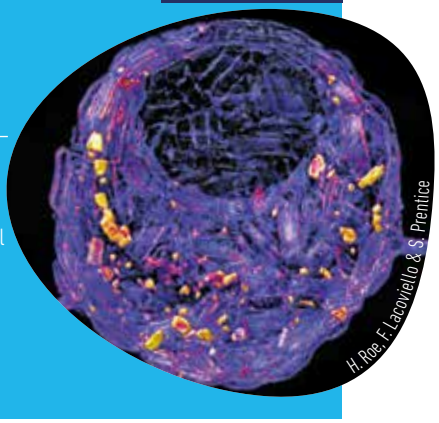
Early bird deadline: 5 August 2018

microb.io/avian18

9th International Symposium on Testate Amoebae (ISTA9): Recent Advances and Future Research Priorities

#ISTA9

Riddel Hall, Belfast, UK
Monday 10 to Friday 14 September



Key topics:

- Ecology and bioindication
- Functional traits, morphometics and novel analytical approaches
- Palaeoecology and palaeoclimatology
- Phylogeny and biogeography
- Role of testate amoebae in microbial food webs and nutrient cycling
- Taxonomic advances

Early bird deadline: 12 August 2018

microb.io/ISTA2018

Microbiomes Underpinning Agriculture

#MUAFM18

Rochestown Park Hotel, Cork, Ireland
Monday 1 to Tuesday 2 October

Key topics:

- Animal microbiomes underpinning agriculture
- Plant microbiomes underpinning agriculture
- Methods for exploring microbiomes in agriculture
- Soil microbiomes underpinning agriculture

Grants deadline: 10 September 2018*

Early bird deadline: 21 September 2018

microb.io/MUAFM18 **Subject to change. Please check the website for details.*

When a civil servant met a microbiologist

The Royal Society's Pairing Scheme connects scientists with UK Parliamentarians and Civil Servants, to learn about each other's work by spending time together in Westminster and the researcher's institutions. Microbiology Society member Dr Paul Hoskisson took part in the 2017 Scheme with Javier Igartua, an Economic Advisor at the Department for Environment, Food and Rural Affairs (Defra). We spoke to them about the experience.

Javier, can you tell us about your role at Defra?

"I lead on evidence on waste management and the environmental impact of waste, such as recycling facilities, incinerators or landfill, and food waste.

Day to day, I provide evidence support to policy colleagues and Ministers by recommending what policies are best to minimise the environmental impact of waste, and quantify the environmental impacts of our proposed policies. Pulling my advice together entails desk-based research on the subject, modelling predicted impacts of policies, coordinating research projects and consulting with colleagues to ensure my advice and analysis take a well-rounded view of the issues."

What was your prior knowledge of each other's fields?

Javier Igartua: "Pretty minimal! Despite having grown up in a scientist household (my mother is a microbiologist by degree and my father works in research in agriculture)."

Paul Hoskisson: "One of my main reasons for signing up for the Scheme was to find out more about how policy is implemented as I knew very little about the area and also, as I'm naturally cynical, to see how much of policy is actually evidence-based – which is surprisingly a lot!"

What were the highlights for you?

JI: "Getting to clone a gene and actually being successful! Also, seeing waste being disposed of properly."

PH: "The time spent with Javier seeing how policy is formed and implemented from the government departments following a parliamentary/ministerial decision. The mock select committee, run as part of the Scheme, was an excellent way to understand how Parliament functions."

What were the main take homes?

JI: "There are plenty of synergies between areas that may, on paper, look unrelated. I was impressed with some of the work on valorising waste materials.

Javier Igartua and Paul Hoskisson at the Royal Society Pairing Scheme launch. Roya Ziaie

Javier tries his hand at gene cloning during his time in Paul's lab. Paul Hoskisson

Also, despite Paul and I having very different jobs, our day to day issues were quite similar!"

PH: "I agree with Javier, the same issues crop up in every job and our day to day work is much more similar than one would expect. Also, I was impressed by how hard the civil service works for the people of the UK and how much influence they have on Ministers to make policy workable. I can certainly now see how my work can be framed in terms of its wider impact going forward. I learned a lot about the kind of language used to develop policy and can use this to widen access to my work."

What could be done to bridge the gap between science and policy?

JI: "Yes. Policy-makers need to be better at taking stock of what evidence is out there already and scientists need to proactively communicate it. There is a lot to gain on both sides!"

PH: "This scheme really helps break down the barriers between scientists and policy-makers. I think this is mainly related to the jargon and language we both use, but like multidisciplinary science projects, it becomes easier to communicate and reach common goals with a little bit of attention and thought. There is a little bit of inertia on both sides to engage, but once we do, it will benefit all parties and it can be a lot of fun. There are lots of opportunities to do this, we just need to take them."

What's your advice for scientists looking to engage with government?

JI: "Engage with the Government Office for Science, take part in government consultations, look out for stakeholder workshops and conferences, and, of course, the Pairing Scheme!"

PH: "The Microbiology Society's Policy Committee is a good introduction to this area, as well as the Royal Society Pairing Scheme. There are lots of consultations to get involved in, either via learned societies or directly yourself. I think we have a huge amount of untapped expertise at the Society that could be of great benefit to Government. My work is publicly funded so I feel I have a responsibility to make my work as accessible as possible, to as many people as possible."

Javier, would Paul make a good civil servant?

JI: "Absolutely, although I'm not sure he'd be willing to trade the lab coat for a suit jacket!"

...and Paul, how would you rate Javier's pipetting skills?

PH: "Javier was really good in the lab, although I think he may have cheated and got some tips from his scientific parents! He managed to clone a gene and get a PCR to work, so if economics doesn't work out, I'm sure he could work in a lab!"

To find out more about the Pairing Scheme visit ***www.royalsociety.org/grants-schemes-awards/pairing-scheme****.*

Applications for 2019 will open in late February.

Further information:

Policy at the Microbiology Society
microbiologysociety.org/policy.html

Government Office for Science
www.gov.uk/government/organisations/government-office-for-science

Roya Ziaie
Policy Officer
policy@microbiologysociety.org

DNA fingerprinting algae

The Culture Collection of Algae and Protozoa (CCAP) is the largest collection of marine and freshwater algae, protists and seaweed in Europe. Housing over 3,000 living strains, it is the most diverse collection of its kind in the world and is used as a source of genetic material and natural products for medical and life sciences research, as well as for industry.

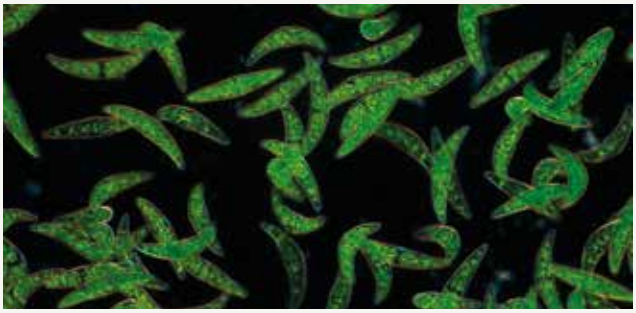
As an International Depository Authority (IDA), the facility accepts and stores some strains under cryopreservation for the Purposes of Patent Procedures and Regulations, as well as preparing cultures to order for research, education and industry (cyanobacterial, protistan and macro-algal). To commercialise a strain or start a patent application, it is necessary to know the identity of the strain. To this end, CCAP now carries out molecular identification of algae and cyanobacteria through sequencing DNA barcode regions (typically 18S rDNA for eukaryotes and 16S rDNA for prokaryotes). By pairing sequencing data with algal taxonomy expertise, CCAP aims to determine the identity of strains to genus and, if possible, species level. The scientists at CCAP also provide high-quality genomic DNA from pure strains in the collection.

Humble beginnings

For a cutting-edge facility, now pushing the boundaries of microbial genetics, CCAP had remarkably humble beginnings. It started out as a collection of vials, smuggled into the UK by Professor Ernst Georg Pringsheim, who fled from Nazi Germany in 1938. The war refugee professor smuggled his algal collection to England in his luggage, leaving behind all his other belongings.

On arrival in the UK, Professor Pringsheim brought the vials to Cambridge University, where he further developed his research and his collection of microalgae and protozoa. Much later, in 1986, the marine cultures were relocated to the Scottish Association for Marine Science (SAMS) near Oban on the west coast of Scotland; home of CCAP. The freshwater samples were also relocated here in 2004, and together these cultures formed the basis of the modern CCAP collection. CCAP is now funded by the Natural Environment Research Council (NERC) and is one of eight microbial national biological resource centres (BRC's) within the UK.

Professor Pringsheim retired at the ripe old age of 86, having isolated 438 strains – many of which are still available at CCAP today!



Freshwater Desmid. Scottish Association for Marine Science (SAMS)

Supplying the scientific community

CCAP provides services and support to the scientific community, as well as to businesses, supplying strains for ecotoxicology and biocide testing and for aquaculture feeds. The national facility also delivers training courses for scientists and students, teaching them to isolate and culture algae from their own water samples. The long history of the centre means that the scientists at CCAP have accumulated a wealth of resources about the strains they maintain, including information on their provenance, properties and images, as well as references from the scientific literature about where each of the strains has been used. The facility even supports the next generation of microbiologists by producing an Algal Culture Kit for schools.

For more information on molecular taxonomy or cultures from CCAP, visit **www.ccap.ac.uk**.

Acknowledgement

SAMS is supported by the NERC, which provides £430,000 of funding for the CCAP facility each year.

Keri Wallace

Scottish Association for Marine Science (SAMS), Oban, Argyll.
keri.wallace@sams.ac.uk

Teaching Microbiology in Higher Education Symposium satellite meeting

The Microbiology Society held its first Teaching Microbiology in Higher Education Symposium as a satellite meeting before the Annual Conference 2018. We were delighted that the event, a result of our members asking for more support for teaching-active individuals, was a great success, bringing delegates together to discuss and share teaching practices and starting a network of microbiology lecturers.

The symposium began with a poster session over lunch, to create a space for the exchange of ideas and to start an interactive day where knowledge flowed between delegates. Posters were also available during the Annual Conference.

As the ever-changing landscape of teaching is affected by many factors, including the Teaching Education Framework, Dr Tadhg Ó Cróinín, Chair of the Society's Professional Development Committee which organised the symposium, began the day in conversation with Rachel Lambert-Forsyth, Royal Society of Biology, and Professor Jeremy Pritchard, University of Birmingham. The discussion ranged from topics such as the future of university teaching, to the way pedagogy is taught in various courses.

New teaching methods often involve finding inventive ways to engage students. During the first session (Using digital platforms for teaching in higher education), Dr Helen Gadegaard, University of Glasgow, explained how *Labster*, a virtual lab simulator, can teach students just as well as conventional wet-lab sessions, showing the cost efficiency of using online teaching resources for large groups.

Ian Turner, University of Derby, Lecture Theatre Pantomime.

Dr Stephen McClean, Ulster University, demonstrated his use of the interactive cloud-based audience response tool, *Nearpod*, exploiting gamification to help students benefit from peer interaction. Dr Alison Graham, Newcastle University, showed how she involved undergraduate students in the assessment process using the electronic platform *Grademark*, with the aim of improving the clarity of marking criteria, leading to the creation of a library of feedback comments to improve marker consistency. Discussion on how to engage students who do not look at their feedback, showed that this remains a challenge for many lecturers.

In the cases presented, digital platforms have enabled better access to, and engagement with, large groups of students as well as better use of time spent teaching.

Dr Ian Turner, University of Derby, began the Novel Techniques in the Lecture Theatre session with his unique approach to lectures: using pantomime. He described a creative and interactive method for enabling students to understand the fundamental elements of biology. By using props for visual representation, a mental association was created and students learned basic interactions.

As well as invited speakers, the symposium allowed delegates to present their work as posters and we also heard insightful offered oral presentations. Talks on a flipped classroom approach, the use of role-play-based workshops, and cultivating student creative self-efficacy all stimulated conversation and allowed delegates to consider alternative approaches to their current teaching methods.

The success of the Society's first Teaching Microbiology in Higher Education Symposium would not be without fantastic contributors, so we would like to thank our invited speakers, offered oral and poster presenters. The exchange of knowledge was invaluable; so much so that we are delighted to announce that the second Teaching Symposium will take place in 2019.

Rachel Asiedu
Professional Development Officer
r.asiedu@microbiologysociety.org

Schoolzone

Microscopes – peering into the invisible world

An activity for year 5 children

Lindsay Stimson

In February, a team of volunteers from the Sir William Dunn School of Pathology (SWDSP), University of Oxford spent a day with year 5 children at Pegasus Primary School, Oxford. The theme of the event was 'Microscopes' and how they enable us to better understand the world around us.

In designing this event, we considered not only what children would learn and understand, but also how the activities would contribute to the development of scientific skills relevant for key stage 2. We sought input and advice from the teachers to ensure our activities were suitable and safe, and worked closely with the school to fully risk assess the project. To ensure our activities were suitable and safe, we worked closely with the school to fully risk assess the project. We were fortunate to be awarded an Education and Outreach Grant from the Microbiology Society for the purchase of microscopes and we received helpful guidance from Brunel Microscopes Ltd. We also found the Royal Microscopical Society and 'Microscopes 4 Schools' websites useful resources to identify suitable models for the age group.

During a two-hour session, the children had the opportunity to look at posters illustrating the fascinating detail of micro-organisms that we made using images from our Electron Microscopy facility and from online resources such as the Wellcome Trust and Public Health Image Library. The children also attended three workstations. At workstation 1, the children learned how Antonie van Leeuwenhoek crafted lenses and used them to observe micro-organisms, and how Robert Hooke visualised 'cells', the basic units of life. At workstation 2, volunteers explained how microscopes work; the children used lenses to magnify images and labelled the parts of a microscope on worksheets. Finally, workstation 3 was a practical 'observation station' at which the children were able to use microscopes themselves to observe a range of everyday objects and fixed biological specimens using monocular compound and stereomicroscopes.

The children were given tasks to complete, such as to describe and illustrate their observations. The groups were also encouraged to discuss their findings to promote teamwork and communication. The feedback from the children, volunteers and teachers indicated that the event was a success and, from our perspective, seeing the children so engaged with science and their delight when using the microscopes to 'peer into an invisible world' was a very rewarding and enjoyable experience.

This event was the second of three events taking place this year, as a strategic partnership with Pegasus Primary School. Our aim is to help year 5 children develop a keen interest in research and science, and to teach them key concepts of microbiology. We also aim to inspire children by discussing how the achievements of scientists' impact on their daily lives, and hope that meeting and engaging with current researchers may encourage them to pursue the study of science. Our longer-term plan is to foster similar partnerships between scientists from the SWDSP and local primary schools, and to repeat and develop these activities.

Further information

Royal Microscopical Society **www.rms.org.uk**
Microscopes4Schools **www2.mrc-lmb.cam.ac.uk/microscopes4schools**
Wellcome Collection Image Library **www.wellcomecollection.org/works**
Public Health Image Library (PHIL) **phil.cdc.gov**

Christoph Tang, Lindsay Stimson and Rachel Exley

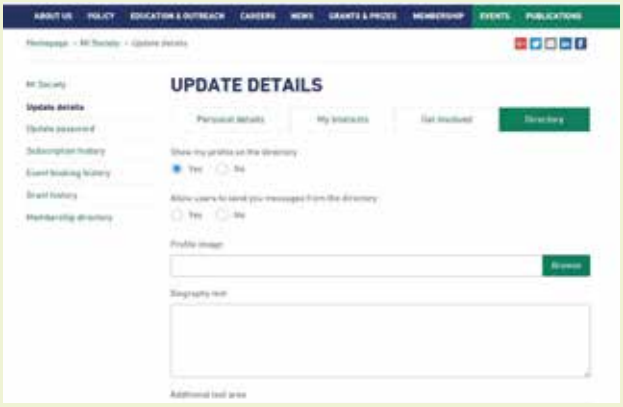
Sir William Dunn School of Pathology (SWDSP), University of Oxford, South Parks Road, Oxford OX1 3RE

The new Membership Directory – as easy as one, two, three!

You may have recently read about the introduction of the new Membership Directory. It allows members to search for and contact others by location, expertise and special interests. It's very easy to use. Here's all you need to do to get started...

1

Register for Mi Society – the online area of the Society's website.

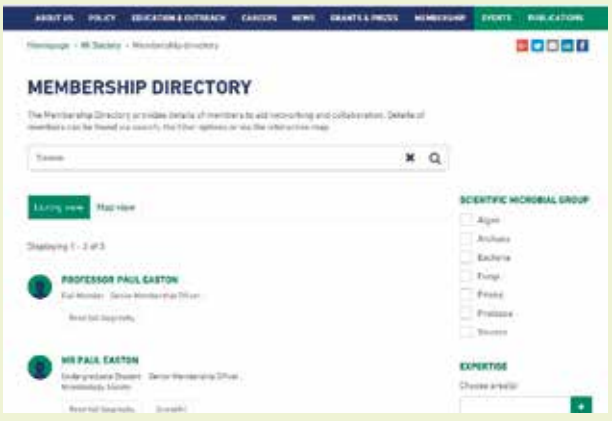


2

To update your own record, click on 'Update Details', then 'Directory' and enter the details you'd like to make available to share.

3

To look for other members simply enter your search criteria or use the map. Once found, you can send a message (to those who have consented) by clicking the email icon.



The Membership Directory will become an increasingly useful tool, helping to bring members together. Make the most of it by ensuring your entry is up-to-date and reflects what you want it to say about yourself.

Journals update

Congratulations to the 2018 Annual Conference Poster Prize winners

Microbiology Society Journals gave poster prizes at the Annual Conference 2018. *Microbiology*, *Journal of General Virology*, *Journal of Medical Microbiology* and *Microbial Genomics* awarded prizes to one poster each. We would like to thank Editors who volunteered to talk to the poster presenters and select winners. Below are the winners with the titles of their award-winning posters.

Microbiology

Gal Horesh
'The diversity and mobility of toxin antitoxin systems in a large dataset of *Klebsiella* spp.'

The following posters were highly commended:

Cadi Davies 'Investigating the biogenesis of *Campylobacter jejuni* outer membrane vesicle production'

Rebecca Hall 'Pretty fly for a Tsetse: flux balance analysis of the tsetse symbiont *Sodalis glossinidius*'

Roger Klein 'Protein interactions facilitated by CsgE are vital to amyloid fiber assembly in *E. coli*'

Nizar Saeedi 'Metabolic adaptation in *Escherichia coli* isolates during transition from UTI to bloodstream infection'

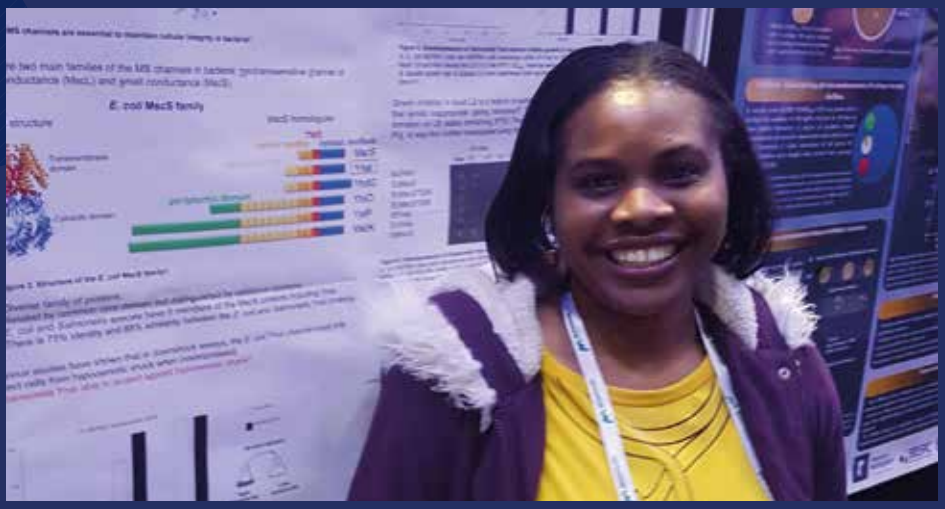
Aaron Ming Zhi Tan 'Host niche environments play a critical role in dictating the motility phenotype of *Escherichia coli*'

Nizar Saeedi explaining his highly commended poster, 'Metabolic adaptation in *Escherichia coli* isolates during transition from UTI to bloodstream infection'.

Journal of General Virology

Elizabeth Elder
'Human cytomegalovirus US28 antagonises PYHIN proteins: effects on interferon and apoptosis during latency'

The following posters were highly commended:
Valeria Lulla 'Functional characterization of human astrovirus ORFx'
Ibrahim Al-Masoud 'Comparative analysis of rabies virus glycoproteins from pathogenic and non-pathogenic strains'
Emer O'Byrne 'High degree of genetic variability in respiratory syncytial virus strains circulating in Ireland'
Yasser Tatawi 'Immunogenecity evaluation of seasonal influenza vaccine in COPD patients'



Mimi Asogwa, with her prize-winning poster, 'Investigating the role of the bacterial mechanosensitive channel YnaI in *Salmonella* pathogenesis'.

Journal of Medical Microbiology

Mimi Asogwa
'Investigating the role of the bacterial mechanosensitive channel YnaI in *Salmonella* pathogenesis'

The following posters were highly commended:
Oliver Creese 'Fluorescent artificial cellular environments to interfere with bacterial adhesion'
Sophie Irving 'Functional characterisation of (p)ppGpp synthetases: enzymes required for bacterial stress adaptation and survival'

Microbial Genomics

Imogen Johnston-Menzies
'Investigating the differential virulence of *Salmonella enterica* serovars in livestock animals using quantitative proteomics'

The following posters were highly commended:
Blanca Perez-Sepulveda 'Sequencing of 10,000 *Salmonella* genomes: a worldwide effort to understand the epidemiology, transmission and virulence of invasive non-typhoidal Salmonellosis'

Congratulations to all those who won a Microbiology Society Journal sponsored poster prize!

Outreach

Flyers for the Multicoloured Microbiomes colouring book and Antibiotics Unearthed bugs from the Society. K. Robinson

Microbiology at the Nottingham Festival of Science and Curiosity

The 2018 Nottingham Festival of Science and Curiosity was a week-long programme, aiming to bring exciting and inspirational science, technology, engineering and maths to the general public. There were around 3,000 interactions with members of the public during the week. Of those attending, 41% were children aged 11 or younger, and 68% of people went along with their family to take part in the fun.

As part of the MRC/EPSRC-funded Nottingham Molecular Pathology Node at the University of Nottingham, with diverse interests in medicine, we displayed our science on five creative stalls at the 'Science in the Shopping Centre' event on Saturday 17 February, in partnership with Rick Hall of Ignite!, a science communication charity. Our research group, being mostly microbiologists, came up with an idea to show the public some interesting examples of 'the microbes on and around us', to demonstrate that there are infectious organisms in all sorts of places. Together with Dr Kazuyo Kaneko from the group, we manned the stall and chatted with visitors on the day. Our idea to show the public what microbial colonies look like on agar plates was extremely popular, as most had never had an opportunity to see this before (other than in photos) and they found it really fascinating.

We swabbed some commonly used items (toilet door handles, kitchen surfaces, mobile phone, shoes etc.) and applied fingertips and coins to the surface of blood agar plates. After incubation, we sealed the plates into sturdy clear autoclave bags, and securely fixed them to our display table at the event. We invited visitors to guess which plates had been grown from swabs of the gents or ladies toilets, the floor, worktop or bin in our tea room, and to look at how many colonies had grown from the other items. Apologies if this appears sexist but we recovered more colonies from the gents' toilet door handle than the ladies'. We were all horrified though to discover that the plate with the most colonies was inoculated from the worktop in our tea room, rather than the floor or the bin. Most likely due to a pretty ancient dish cloth. The visitors were amazed to find out that coins are made from metals, which kill bacteria, and to see that the colonies grown from fingertips resembled those recovered

The plates, quiz sheets, prizes and Microbiology Society resources on our stand. K. Robinson

Coins applied to a blood agar plate, prior to incubation. K. Robinson

from the mobile phone. With help from the Microbiology Society, we had some educational leaflets and comics on handwashing and antibiotics, as well as pens, fluffy bugs, badges and stickers to give away. These all disappeared very swiftly, along with huge buckets of sweets and springy 'bug' toys.

Over 280 people came to visit our stall, from all walks of life, from pensioners to young children and everything in between. We were pleasantly surprised to find many people already understood that not all bacteria are 'bad' bacteria and that the overuse of antibiotics is a big problem – this is perhaps a reflection of how well the Public Health England antimicrobial resistance (AMR) campaigns have worked. We were even more surprised when a young girl of around 10 years old knew what an agar plate was – maybe a future microbiologist in the making? On the whole people were very interested and asked questions on lots of topics, from how we had grown the bacteria to effects of the microbiome. We even had a teacher taking notes and photographs to show her class. It was exciting for us to see so many members of the general public interested in bacteria and microbiology in general.

Kazuyo Kaneko and Nikki Osborne ready to receive visitors to the stand. K. Robinson

It was a very rewarding experience to be able to speak to the general public about our work and to receive such positive responses. It emphasises why we do research when we see people outside of the science-sphere engaging with microbiology and being genuinely curious about it all. As an early career microbiologist, engaging with the public is very important. Often we get so used to using our scientific jargon that trying to explain our science in more basic layman's terms can be a real challenge, especially when talking to young children. To be able to explain your science to kids in a way that is simple enough for them to understand, but interesting enough to keep them engaged, is an art in itself. Getting involved in public engagement at the beginning of your microbiology career gives you plenty of opportunities to improve these key communication skills. It is so important for the science community to engage with the public; from keeping them informed, to inspiring children to pursue a career in science, the benefits are huge. But the personal benefits are also really important. These include learning new skills and gaining confidence, but there is also a reminder that even the most simple things in microbiology can be truly fascinating.

Further information

Nottingham Festival of Science & Curiosity website
www.nottsfosac.co.uk

Ignite! **www.ignitefutures.org.uk**

Microbiology Society resources
microb.io/2sLBO9c

Nikki Osborne

PhD student from the Wellcome Trust Doctoral Training Programme in Antimicrobials and Antimicrobial Resistance, Centre for Biomolecular Sciences, University of Nottingham, NG7 2RD
nicola.osborne@nottingham.ac.uk

Karen Robinson

Associate Professor in Infections and Immunity, Centre for Biomolecular Sciences, University of Nottingham, NG7 2RD
karen.robinson@nottingham.ac.uk

Early Career Microbiologists' Forum Update:

ECM Forum presence at the Annual Conference

One of the standout features of this year's Annual Conference was the contribution made by ECM Forum members, from co-chairing to presenting. I caught up with a few of them to find out how they felt about the whole experience.

There was a notable increase in the number of offered orals slots in comparison to previous years, opening up this opportunity to a wider selection of researchers. David Williams from the University of Dundee was selected to present his PhD research, entitled 'Linking genotype to phenotype: inter-bacterial competition in *Serratia marcescens*'.

David said that as this was his first time talking at a conference, he was "initially a little nervous about speaking, but the nerves quickly disappeared. Overall it was a really good experience, and I found it rewarding and a confidence booster." His advice for those considering applying next year? "Go for it! Keep the talk simple with a clear structure and one or two take-home points".

The ECM Forum co-chairing scheme was in its second year and received lots of applications and positive feedback. Justine Rudkin, the ECM Forum Irish Division Representative from University College Cork, decided to apply to be a co-chair because she is "trying to say yes to as many opportunities as possible", putting herself out there in terms of networking and professional development as well as adding something a bit different to her CV.

When applying, Justine recommends taking the time to consider which session is most appropriate for you, "not only in terms of the area you work in, but also which area you find most interesting. After all, you will be responsible for asking the speaker questions if the audience are feeling shy on the day." All successful applicants were supported by a senior chair which also helps to take the pressure off. This was a scheme brought in by the ECM Forum Committee and we are hoping to see even more applications next year!

Another aspect of the Annual Conference that the Society has made big progress with is the poster sessions, in particular the prizes on offer. Imogen Johnston-Menzies from the Roslin Institute was one of the worthy winners, scooping the prize awarded by the Editors of the Society's journal, *Microbial Genomics*.

It was Imogen's first time presenting her work at a conference and she enjoyed the opportunity to discuss her data with researchers from a broad spectrum of fields. She believes the key to a great poster is to "not be afraid of bright colours and white space". She also noted that telling a story with your data is important, as is keeping the text to a minimum.

If these positive anecdotes have inspired you and you want to know more, get in touch! We are always happy to answer any questions.

Rebecca Hall
Communications Representative,
ECM Forum Executive Committee

To get in touch with the ECM Forum Executive Committee, please email us on ***ecm@microbiologysociety.org*** *or tweet us using* ***#ECMForum****.*

Membership Q&A

This is a regular column to introduce our members. In this issue, we're pleased to introduce Justine Rudkin.

Conor Feehily

Where are you currently based?

I am currently based in the School of Microbiology at University College Cork, in the Republic of Ireland.

What is your area of specialism?

Antimicrobial resistance and bacterial virulence.

And more specifically?

I'm interested in the interplay between the development of antimicrobial resistance and its impact on a pathogen's ability to cause disease. The implications go beyond our inability to treat infections, affecting the way that bacterial pathogens interact with their host, changing biofilm phenotypes, toxin production and even how visible a pathogen is to the immune system.

Tell us about your education to date.

I studied for my degree in Tropical Disease Biology at The University of Liverpool. I was more of a home bird in those days and was worried that I wouldn't be able to afford living away from home. Luckily, I had such a good university on my doorstep. I moved to the University of Bath for my PhD, which I completed in 2012, before I moved on to Ireland. I have been here ever since, firstly at the National University of Ireland, Galway, and now University College Cork.

Where did your interest in microbiology come from?

I started my degree as a Zoology student, but I quickly realised that I am what they refer to as a 'glory zoologist' (only interested in the big furry animals). It was during the first semester that I was introduced to the world of microbiology and quickly switched courses. I later switched again to the Tropical Disease Biology course, which allowed me to keep all the infectious disease modules but swap out the industrial microbiology content for parasitology and vector biology – basically keeping it all about infectious disease, which is where my interests lie.

What are the professional challenges that present themselves, and how do you try to overcome them?

The biggest challenge I face is lack of job security. Working on short-term contracts, I feel that I am not being as ambitious as I would like to be with my research, constantly thinking about what can be achieved and published within the next year. It is something that hangs over you. My current contract is up in September and I have therefore directed a lot of time towards grant applications, to try to keep my research going.

What is the best part about 'doing science'?

Discovering new things and being the first person to observe phenomena. We create knowledge and I think that is pretty cool!

Who is your role model?

Is it weird that I don't have one? I have lots of people who have inspired me in one way or another, but no-one who I would call a role model, or who I look up to.

What do you do to relax?

I'm a runner and currently training for my first marathon. Whilst I am not very fast, running allows me to clear my head and gives me an energy boost. If I go more than three to four days without exercise I get a bit anxious and ratty.

What one record and luxury item would you take to a desert island?

The Arctic Monkeys are my absolute favourite band, so I would have to take their album *Whatever People Say I Am, That's What I'm Not*, along with a cosy blanket. I am forever wrapped up in a pashmina, even in the office at work. .

Tell us one thing that your work colleagues won't know about you.

We talk so much in the office I can't imagine there is much that they don't know about me! I will go with that I once auditioned for the TV soap *Brookside* – I wouldn't have told my colleagues here that as they have probably never heard of it. I was big into acting when I was at school.

If you weren't a scientist, what would you be?

The head chef at my own bistro! Cooking (and subsequently eating) is my passion and something which I have a natural flair for.

If you would like to be featured in this section or know someone who may, contact Paul Easton, Head of Membership Services, at **p.easton@microbiologysociety.org**.

Reviews

Fungi: Biology and Applications (3rd Edition)

Edited by K. Kavanagh
Wiley (2017)
£104 ISBN 978-1119374329

Fungi: Biology and Applications is in the third edition of this textbook, and maintains an excellent balance between the ease of reading of potentially complex and specific topics, while providing detail and subsequent sources of relevant information. The broad range of subject matter compiled by the editor and the internationally recognised authors makes comprehensive reading. It covers the basics of fungal physiology, through genetics and genomics/proteomics, with reference to the post-genomics era, which is particularly significant given the avalanche of information that can be generated through next-generation sequencing. The book continues by describing how fungi can be exploited by the human race, from the well-known use as a food source, to the potential production of pharmaceutical agents and chemical reagents, and the use of fungal-derived enzymes in the ever-expanding biotechnology industry.

The deleterious side of fungi is not excluded. There are chapters on fungal plant and human pathogens, with significant detail on immunity and therapy included for the latter. The chapter on fungi in the environment provides an excellent understanding on how the actions of fungi are essential to all parts of the natural environment. One topic I feel could be covered in more detail is the impact of fungal disease on animals, as the number of species at threat of extinction through relatively novel fungal disease is of global concern, and is affecting many classifications of animal life.

Overall, the book provides an excellent addition to the library of those interested in the field of mycology, whether novice or expert, and the inclusion of the colour plates certainly adds a little zest.

P. Lewis White
UKCMN Regional Mycology Reference Laboratory, Public Health Wales Microbiology Cardiff

For more reviews, please visit the online issue of *Microbiology Today* at **microbiologysociety.org/microbiologytoday**

Comment

Probiotics – a living story

Gregor Reid

What do you remember about 2001, apart from 9/11? The publication of the Human Genome Project? Thinking how good Lance Armstrong was in winning his 6th Tour de France? Sitting in your car listening to the number one selling song of the year, "It Wasn't Me," by Shaggy?

ayo888/Thinkstock

Well, in Cordoba, Argentina, I was chairing a United Nations and World Health Organization Expert Panel that was asked to define probiotics. It wasn't something that would have resulted in brownie points at my university, since nobody there had ever heard of 'probiotics'. In fact, with a few exceptions, nobody in Canada had.

Fast-forward to 2018, and while some events are now assigned to history, probiotics are writing their own in profound ways.

The big question

But, before we discuss the big question, 'what is a probiotic?', what was the outcome from Cordoba? The definition of a probiotic: 'Live micro-organisms, that when administered in adequate amounts, confer a health benefit on the host.' In lay terms, it means ingesting, inserting or applying living microbes (usually bacteria) to your body (or to an animal or other living host). These microbes must first have been shown to have certain beneficial attributes, like being able to kill a diarrhoea-causing bacterium. They are placed in a delivery vehicle (for example a dairy product or capsules) with viable numbers, even at the end of shelf-life, that are sufficient to bring about a positive response. That response should be measurable, even if it does not result in you perceiving a difference.

It might be easier to state what probiotics are NOT.

- Well, they are not in you – unless you have taken them.
- They are not fermented food – unless that specific food has been documented and tested in a human study.
- They are not prebiotics – a substrate that is selectively utilised by host

micro-organisms conferring a health benefit.

- They are not multiple strains selected by a marketer.
- *Lactobacillus* is not a probiotic, nor is *Lactobacillus acidophilus*. These are names, not specific strains with documented probiotic activity.
- They are definitely not dead – that sounds like a cool title for a crime thriller.
- Oh, and while we're at it, lactobacilli is not italicised, and *Lactobacillus rhamnosus* does not have a capital R.

By now, you're thinking I get hung up on semantics. But really, if you went to buy a car and the salesman didn't know if it had three or four wheels and an engine, wouldn't you be worried? Likewise, if he told you it was the best car on the planet, even at £1,576, you'd better find another dealership.

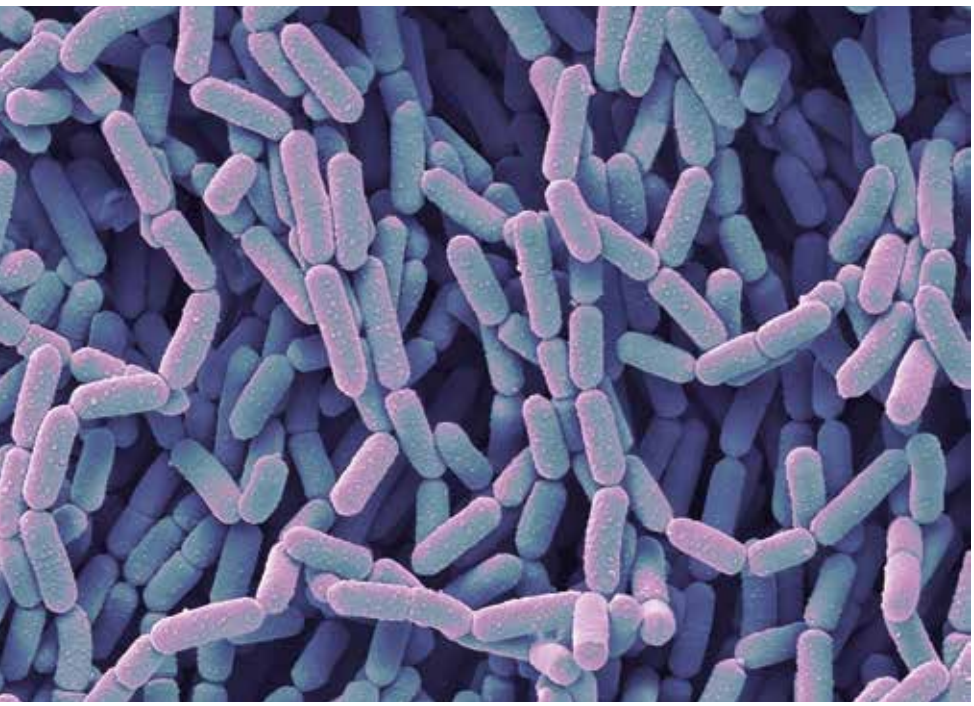
The question I'm asked the most

As a new immigrant to Canada in the early 80s, I was constantly asked, "where is your accent from?" That was easy to answer – my throat.

Now, it's, "which probiotic should I take?" Easy, but split into three replies. Firstly, "it depends on why you are taking a probiotic." Secondly, "it depends on how you prefer it, as food or dried supplement." Thirdly, "I prefer you do the homework to know the options." That may sound like a cop-out, but who am I, without an MD degree, to ask personal medical questions and then decide on someone's course of action?

Fortunately, a group of experts in Canada and the USA have made it easier for me to guide people to the place where they can get reliable information on products. In Canada, it's **www.probioticchart.ca** and in the USA it's **www.usprobioticguide.com**, but for those of you reading this from the UK or Europe, sorry, nobody has repeated this unique evaluation of every product sold in your country. It is simple really. You match the product contents, dose and formulation with human studies published and available on PubMed, and then you determine the level of evidence of the study(ies) against the health outcome.

The result is a table that says, you may have heard of *Align*, but if you are trying to prevent recurrent urinary tract infection (UTI), it's not the product for you. Then, if your fitness instructor or health food shop owner says that *Ole Ole Ole* is the best probiotic since snake oil, because it has 20 strains and 50 billion organisms, all you need to do is check the list. It won't be there, so now you have to confront your trusted advisor and tell them they are misinformed. It might be the end of your relationship, or it might make them get back to the producer and recommend they perform appropriate human studies to prove their product does indeed give you the perfect figure and help you win the Tour de France at age 76. *Yes, I'm being sarcastic*. The longer the list of documented strains, the happier we will all be.



Lactobacillus rhamnosus **bacteria, coloured scanning electron micrograph (SEM).**
Steve Gschmeissner/Science Photo Library

Probiotics are impacting life

I hope you get to visit The Loch Ness Monster Centre and Exhibition near Inverness. You enter as a cynical non-believer and exit heading straight for the loch to look for bumps hovering across the water. Okay, so it's not a great analogy, but my point is if you really look at the data, there's lots to believe about probiotics.

The evidence for preventing necrotising enterocolitis (NEC) led to

Children eating probiotic yogurt in Mwanza, Tanzania. Gregor Reid

our hospital instituting probiotics as standard therapy for premature, low birth weight newborns, and while the rate of NEC was not overly high at around 3% beforehand, it's almost zero now. The ultimate in clinical translation.

But probiotics are not a silver bullet. They may never reduce cholesterol as much as statins, but they won't cause muscle wasting and terrible side effects. They reduce colic in breast-fed babies, reduce the duration of diarrhoea and respiratory infections and recurrence of UTI. What else can enhance immunity, reduce side effects of HIV/AIDS and many other drugs, reduce stunting and improve maternal and infant health?

In the late eighties I had a grant rejected on probiotics to prevent UTI with a reviewer stating, "why are you doing this when we have antibiotics?" While we now suffer the penalties of excessive antibiotic use, my only satisfaction from rejection is seeing many of these grant panellists now studying probiotics. We must be doing something right.

Translation means to all people, not just the rich

Of the thousands of grants I have read, almost all start with stating a clinical problem their project relates to then many describe so-called 'mechanistic' experiments in mice. I suspect less than 10% of these projects ever make the slightest dent in that disease. If we truly want to understand health and prevent and treat disease, we need to direct funding to studying and replenishing beneficial microbes in humans.

Since 2004, I have been committed to giving people in Africa access to probiotics. With amazing colleagues, we are now providing the opportunity for everyday citizens in villages and towns in Tanzania, Kenya and Uganda to produce probiotic fermented food (**www.yoba4life.org**, **www.westernheadseast.ca**).

These efforts are reaching over 250,000 people, while in Argentina, a wonderful school programme is doing the same through a locally discovered probiotic yogurt.

Imagine the possibilities!

It's a microbial world, and probiotics have an important place in it. Imagine what we could do as a collective?

Gregor Reid
University of Western Ontario, Lawson Health Research Institute, Rm F3-106, 268 Grosvenor Street, London, Ontario N6A 4V2, Canada
e **gregor@uwo.ca**

Gregor Reid is Professor of Microbiology and Immunology, and Surgery at The University of Western Ontario. He has published 520 peer-reviewed papers, been awarded 28 patents and given over 600 talks in 54 countries. He has many awards, including an Honorary Doctorate from Orebro University in Sweden, and being appointed to the Royal Society of Canada and the Canadian Academy of Health Sciences.

What is the most enjoyable bit of your job?

The highs. They come in many forms (discoveries, papers accepted, grants won, awards, student successes, invitations to speak, people personally benefiting from probiotics, etc.), and you need them to offset the lows which are sadly inevitable in science.

What advice would you give to someone starting out in this field?

Find something to believe in that is real, and make it part of your life. The concept of lactobacilli being beneficial for the female urogenital tract made sense from day one, and made even more sense the more I studied it. I was relentless in its pursuit, making the data be the marker, not mythical ideas. Passion is critical if what you are passionate about has a foundation in stone, not sand.

MICROBIOLOGY SOCIETY

Annual Conference 2019

8–11 APRIL, BELFAST WATERFRONT, UK

Registration and abstract submission open August 2018

Abstract submission deadline:
10 December 2018

Grants deadline:
31 January 2019

Registration closes:
11 March 2019

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