HOUSE OF COMMONS

Science, Innovation and Technology Committee

Oral evidence: Harnessing the power of fungi, HC 544

Wednesday 7 February 2024

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Watch the meeting

Members present: Greg Clark (Chair); Dawn Butler; Chris Clarkson; Tracey Crouch; Dr James Davies; Katherine Fletcher; Rebecca Long Bailey; Stephen Metcalfe; Graham Stringer.

Questions 1 - 99

Witnesses

I: Dr Merlin Sheldrake, Biologist and Author; and Professor Irina Druzhinina, Senior Research Leader in Fungal Diversity and Systematics, Royal Botanic Gardens, Kew.

II: Professor Katie J Field, Professor of Plant-Soil Processes, University of Sheffield; and Professor Paul Dyer, Professor of Fungal Biology, University of Nottingham.

III: Professor Matthew Fisher, Professor of Fungal Disease Epidemiology, Imperial College London; and Professor Marc Stadler, Head of Microbial Drugs, Helmholtz Centre for Infection Research.

Written evidence from witnesses:

– [Add names of witnesses and hyperlink to submissions]

Examination of witnesses

Witnesses: Dr Sheldrake and Professor Druzhinina.

Q1 **Chair:** The Science, Innovation and Technology Committee is in session and today we have a one-off session on harnessing the power of fungi. To help us to do that we are pleased to welcome our first pair of witnesses. Dr Merlin Sheldrake is a biologist and writer, and the author of a very successful book, "Entangled Life: How Fungi Make Our Worlds, Change Our Minds and Shape Our Futures". He is a Royal Society science book prize winner; welcome, Dr Sheldrake. Joining him at the table is Professor Irina Druzhinina, who is senior research lead in the fungal diversity and systematics team at the Royal Botanic Gardens at Kew. Thank you both very much for joining us. We have other witnesses later in the morning.

Perhaps I could start with a question to Dr Sheldrake. The Committee is interested in and, in many cases, passionate about science and technology, but we are not experts and probably a lot of the people tuning in are not experts, so take us back to fungi 101 and give us an overview of fungi. How do they differ from plants and animals? Is it true, as we have read, that fungi are closer to animals than to plants in evolutionary terms?

Dr Sheldrake: Thank you, and thank you for calling this session. It feels like a very appropriate time to be having this conversation.

Fungi are a kingdom of life, which is as broad a category as animals or plants; but they are a kingdom of life that has not had a kingdom's-worth of attention. When we think of fungi, we normally think of mushrooms, but mushrooms are just the reproductive structures of fungi. Most fungi live most of their lives not as mushrooms but as branching, fusing networks of tubular cells called mycelial networks. Some fungi live as yeasts—single-celled organisms.

They differ from animals and plants. Plants harvest energy from light and carbon dioxide in the air and produce their own energy-containing carbon compounds like sugars and fats. Animals tend to move around in the world and find food, and put it inside their bodies. Fungi do things differently. They put their bodies inside their food using those branching, fusing mycelial networks. They have a different way of life from animals and plants, although they are, as you say, more closely related to animals than to plants. What we mean by that is that the last common ancestor that animals and fungi share lived more recently than the last common ancestor shared between plants, animals and fungi.

Fungi play vital and important roles in the biosphere. They are a kind of living seam that holds much of life together. They form symbiotic relationships without which no plants could exist; they help to regulate the composition of the atmosphere; they make soil; they eat rock and play vital roles in circulating nutrients around the planet. They are key

players in the long history of life, but they live most of their life out of sight and out of the reach of human senses, so it is difficult for us to notice what they do and pay attention to them.

Q2 **Chair:** Fantastic. That is a great introduction and we are grateful for that. Dr Druzhinina, how many types of fungi are there that we know about, in the world?

Professor Druzhinina: Again, thank you very much for the session. It is a great pleasure to talk about our subject in this room. If possible, I will first add a little to what Merlin said in explaining fungi, because, indeed, we animals and fungi have a common ancestor, but fungi have a slightly different evolutionary strategy compared with animals, and it is quite important in understanding them. Biology is a comparative science. Our cells have a flexible, soft membrane and can communicate with one another very well; they exchange signals and there are complex tissues, brains and multi-celled organisms. Fungi's cell structure is on a similar principle, but their strategy is to have cells covered by a rigid cell wall. They are armoured by that, which means that their cells cannot communicate as efficiently and make a brain. A fungal brain will never evolve.

They cannot take in particles, because of their armour—we cannot imagine knights dancing a tango, because they have armour—therefore, fungi have to absorb liquid nutrients. Importantly, for that, they have external digestion. That is their strategy: their cells are covered by the cell wall, which makes them digest food outside, and then take in nutrients. As Merlin said, they have to live inside their substrate and in their food. We do not see the entire kingdom, as we can see plants and animals that digest inside their body. I think that is helpful in understanding the difference. Otherwise, their cells are very similar to ours, which makes them important.

How many fungi there are is a good question. We can only estimate that, for the reasons I have given, but, as Merlin mentioned, fungi are a lot more than mushrooms. They are moulds, lichens and yeasts. Based on the estimate of Professor David Hawksworth, who was director of the International Mycological Institute, we have between 1 million and 2 million different types of fungi, but we know only 150,000, or maybe 10%, of them. It is very important, and I think very exciting, that with respect to many fungi we have information about them; we know their existence based on DNA that we can now read and which we call dark fungal diversity, but we can already harness their power, because we have that information. It is quite interesting.

Chair: Excellent, Thank you for that. We are going to go into a bit more detail in many of the areas that you mentioned, but to continue at the general level Rebecca Long Bailey and then Tracey Crouch have some further questions.

Q3 **Rebecca Long Bailey:** Thank you. Dr Sheldrake, you have already

touched on the role of fungi in the biosphere. Could you broaden your response on that and tell us what ecological functions fungi perform in ecosystems?

Dr Sheldrake: Yes. Fungi are decomposing organisms. Because of their chemical ingenuity and ability to immerse themselves in whatever they are eating, they are vital in decomposing wood and dead organic matter and cycling those nutrients back around the ecosystems in which they live.

They play vital roles in supporting the life of plants. Whenever you see a plant, you are looking at the outgrowth of fungal relationships, some of which occur in and around the roots, and are known as mycorrhizal fungi or root fungi, while some live in leaves and shoots. Plant life would not be possible without fungal life and the many ways that they have found to associate.

Fungi play vital roles in creating soil habitats. They make soil and form a sticky living seam that holds soil together. Those are three functions, but there are many, and I could go on, but I will keep it short.

Q4 **Rebecca Long Bailey:** Thanks. We have heard about Quorn, obviously, but what role do fungi play in the economy? Which everyday products utilise fungi or their derivatives?

Dr Sheldrake: Fungi play such key roles in the whole biosphere—they underwrite its regenerative capacity—that this could be a long list, but I would start with foods: cheese, coffee, chocolate, yoghurts and many other fermented foods such as soy sauce and miso. Another example is drugs: alcohol, cholesterol-lowering statins, immunosuppressants, psychedelics such as psilocybin, antiviral and anticancer compounds, and many others. Any time we cultivate a plant, we are cultivating fungi too, so any part of the economy that depends on plants depends on fungi. I am thinking of agriculture and forestry. Those are some examples.

Q5 **Rebecca Long Bailey:** Professor Druzhinina, can I put the same questions to you?

Professor Druzhinina: There are a vast number of different economic products, so I would categorise them into two big groups. In one group, we can use the fungi themselves—the fungal organisms. Of course, that would be as food; it could be a fungal protein like Quorn, a product in supermarkets that you probably know. There are also very new developments such as fungal-based materials. Fungal leather is a material that can be degraded, but it is beautiful and fancy, and ecologically friendly. We can use fungal biomass to make packaging and construction materials that are not only biodegradable but help to recycle agricultural waste. That is an important function.

We can use fungi for bioremediation. They are absorptive organisms. They absorb—that is the nature of their nutrition—and their bodies have a very large surface because of the thin filaments. The efficiency of their

absorption is really high; they can absorb a lot of different compounds with their food.

I will give two more very important roles for fungi as physical organisms. We can use them in agriculture as additive biofertilisers or biopesticides. When we add fungi that are not pathogenic but are beneficial for plants, and replace chemical fertilisers and pesticides—my area of research—the results are impressive. In China, I saw farmers dancing for the university group and having a big celebration because of the success of a product based on those developments.

Another very important functionality is the role of fungi as model organisms. As they are very similar to us, but have a cell wall, they are used for fundamental research. Paul Nurse, the Nobel prize winner, used Schizosaccharomyces pombe to discover the cell cycle. That principal role is true for more complex organisms like us, and it is very important.

Those are applications based on fungal bodies, but then there is fungal chemistry. As Merlin outlined, that can be used in medicine and in industry. It can be used for the production of biofuel. We can use fungal enzymes to degrade plant biomass and produce ethanol to replace fossil fuel. We have already mentioned medicine. Fermentation is, again, a direct effect of fungi, for food. Of course, fungal enzymes have much broader use than just for biofuel. We can use them to degrade plastic and other complex molecules. There is a broad area of application.

Click or tap here to enter text.**Tracey Crouch:** Dr Sheldrake, in your introduction you talked about fungi being a kingdom but said that there had not been a kingdom's-worth of research. I am interested in what the knowledge gaps are. How much do we know, where are the gaps, and what role do you think the Government should play in trying to fill those research gaps?

Dr Sheldrake: There are a huge number of knowledge gaps, many of which we do not know—unknown unknowns. Fungi were identified as their own kingdom of life only in the late 1960s, when they won their taxonomic independence.

Professor Druzhinina: Not fully.

Dr Sheldrake: What that means is that there are not nearly so many opportunities to study fungi as there are to study animals and plants. A lot of basic research that was done many decades ago in the world of animals and plants has still not been done for fungi. There is also a lot of applied research that has not been done for fungi, such as areas to do with fungal conservation and taxonomy. Decomposition is thought of as an unglamorous subject, but it is vital for many of the potential applications of fungi, such as in net zero and bioremediation. Those are just some examples.

The UK Government can play a much stronger role in supporting fungal research, in two main ways. The first is by not defunding mycological research. The UK is a centre of excellence for fungal research and expertise. There are institutional and amateur networks of fungal enthusiasts, so the first thing would be not to defund it, if opportunities to do so arise.

No. 2 would be to involve UKRI and conduct a review of the places where fungi are being funded by UK research councils, and to identify places where the balance between fungi, animals and plants can be addressed. That might, first, look like including fungi when they are not mentioned in grant frameworks; it might also mean issuing calls for applications for special fungal research programmes, to help address the historical imbalance. No. 3 would be to make sure that on grant-awarding committees there are people with some fungal expertise.

Q6 **Tracey Crouch:** As part of an inquiry on insect decline, we had as a witness Professor McAlister, who wrote "The Secret Life of Flies". One question I asked her about her niche, interesting subject was how on earth she became so interested in flies and fleas. Can I ask you both what on earth inspired you to become experts in all things fungi?

Professor Druzhinina: Studying biology and fungi was only my entrance point. It is quite impossible to study one group of organisms without understanding the entire field of biology. I decided to be a mycologist when I was very young, maybe 16 or 17 years old. At that time I felt that I understood botany quite well but that fungi were just unknown. Now I just understand even better that they are the unknown.

Q7 **Tracey Crouch:** Dr Sheldrake.

Dr Sheldrake: I have always taken an interest in the living world and other lives unfolding around me. I was studying plant sciences as an undergraduate and it became clear that plant life could not happen without fungal life, but in our lectures and course material little attention seemed to be given to those hidden lives. I became more and more fascinated by them and then went on to begin formal study at graduate level. That revealed to me how absent fungi are from educational structures. I had an undergraduate education in biology, and fungi were not represented as much as they should be. In secondary and primary education they are almost totally absent, which is a big problem.

Q8 **Tracey Crouch:** Conservation is an important subject. How are fungi faring, and what notable challenges or pressures do they face?

Dr Sheldrake: Fungi face lots of challenges, from unsustainable agricultural practices like over-ploughing, over-application of chemical fertilisers, fungicides and pesticides, and from habitat destruction like deforestation. They are under-represented in our litanies of preservation. Less than 0.2% of global conservation priorities are fungal. It is a really big problem. There are a number of steps that can be taken to address it, but the reason we need to address it is that when we sabotage fungal

communities and habitats we undermine our efforts to limit global heating and stop the rapid loss of biodiversity. We are destroying a library of ingenious fungal solutions that have adapted and evolved over 1 billion years, many of which could be useful to humans in the future. The bank of fungal diversity that exists should be protected to help us to move forward in generative relationship with these organisms.

Q9 **Tracey Crouch:** Do you want to add to that, Professor?

Professor Druzhinina: Yes. The questions are very connected. When we talk about knowledge gaps, it is not true that fungi are under-studied, or ignored. We have meetings on fungal genetics where thousands of scientists gather in California, every second year, but the research is very heterogeneous. There are some model organisms and some applied areas where we have quite deep understanding, such as yeast biology. What is not studied is fungal diversity, taxonomy and evolution, as we still do not know 90% of fungal diversity. That is linked to conservation. It is very important to communicate that, when we lose fungal diversity before we even know of it, we are losing products and applications—potential medications, antibiotics and enzymes that can be used for biofuel and plastic degradation. The knowledge gap and habitat conservation, because they live inside, are very interconnected aspects.

Q10 **Tracey Crouch:** We are going to go on to environmental challenges in a broad sense, but the Committee is this morning looking at fungi in a broad, general way. Dr Sheldrake, at the weekend I listened to the ZOE podcast that you did, and, while I completely respect that mushrooms are just one aspect of it, could you explain for the benefit of the Committee and those watching why we should be more scientifically interested in mushrooms?

Dr Sheldrake: In mushrooms, or fungi in general?

Q11 **Tracey Crouch:** You were talking about mushrooms on ZOE, in terms of nutrition and benefits.

Dr Sheldrake: Yes, mushrooms have long been a vital food for humans. There are many ways that we can work to include mushrooms in our food systems. They can be grown on agricultural waste like corn stalks. They can be grown in a matter of weeks inside without the need for large areas of agricultural land—apart from the areas of land needed to provide the agricultural waste—and are nutritious. They have all sorts of interesting chemical and medicinal properties that are in need of further research, as well.

Mushrooms have been used as medicines and foods by human cultures around the world for an unknowably long time. That is a bank of cultural knowledge and wisdom that we are not fully taking on board at this time.

Chair: Thank you very much indeed. Just before I bring Chris in, Graham Stringer wants to ask a question.

Q12 **Graham Stringer:** In your book, Dr Sheldrake, you quote Lynne Boddy as saying that nobody is looking at fungal biology, which obviously isn't true but is a way of exaggerating the lack of focus on fungal biology. You just gave a devastating statistic of 0.2% as the percentage of work on fungi in environmental protection. That is incredible. Can you give us any equivalent figures for the percentage of scientific research in this country that is devoted to fungi?

Dr Sheldrake: I don't have a percentage for you about the research in general on fungi, but it would be easy by looking at UKRI, and particularly at NERC and BBSRC, to find the number of grants awarded to fungal projects every year. I do not have some easy figures on that.

Q13 **Graham Stringer:** Do you have a ballpark figure?

Dr Sheldrake: I don't have a ballpark figure, no.

Q14 **Chris Clarkson:** I want to turn to the subject of net zero, which you have already briefly touched on, Dr Sheldrake, and I specifically want to think about how fungi could be used perhaps to help reach our ambitions for net zero. Do specific species have properties that could assist with, for example, bioremediation and dealing with pollution? We have heard about plastic degradation. Are there species that we should be looking at, and what are the barriers to implementing that as part of our net zero project?

Dr Sheldrake: Yes, it is a very big question. Fungi touch so many aspects of the biosphere that one could talk about this at length. I will choose the area that I research—mycorrhizal fungi. These fungi live in and around plant roots, and plants supply them with energy-containing carbon compounds like sugars and fats that they produce in photosynthesis. These fungi are stationed at the entry point of carbon from the atmosphere into the soils. The soils have a very important store of carbon—the largest terrestrial store of carbon.

The mycorrhizal fungal communities play vital roles not only in getting carbon into the soil but in stabilising the carbon once it gets into the soil. We do not think enough about the underground ecosystems and mycorrhizal communities that play such an important role in regulating the composition of the earth's atmosphere. Our work has shown that more than 90% of mycorrhizal fungal hotspots on the planet are at immediate risk. They are not protected, simply because they have not been considered. One of the ways that could be addressed is by, first, not destroying the underground mycorrhizal communities that play such vital roles in getting carbon into the soil and keeping it there. Another would be taking those fungal communities into account when doing restoration projects and researching different ways to restore ecosystems as part of nature-based solutions to global heating.

Q15 **Chris Clarkson:** Is it the case at the moment when, for example, we look at, almost, rewilding, or biosphere management, that we are not really paying attention to the role that fungi play in that?

Dr Sheldrake: Some people are, but I would say that on the whole we are not paying nearly enough attention. That is not because people do not think about fungi. We have people coming to us all the time asking for data about which fungi are where. There is a huge public appetite for this, and a huge appetite among conservation and restoration organisations, but there is just not adequate data. SPUN, an organisation that I work with, is working to map the communities, to provide usable datasets that people can use to factor into their decisions when they make conservation priorities and do restoration projects.

Q16 **Chris Clarkson:** Excellent. Professor Druzhinina, what are the challenges in large-scale implementation? I am thinking particularly about bioremediation.

Professor Druzhinina: There is the development of fundamental research on diversity—knowledge of diversity. I would probably specify that bioremediation and the fungal ability to degrade complex compounds—xenobiotics, or the compounds that we introduce that are not native to the environment—is an important role that fungi can play in net zero policy in general. Fungi can be used for cleaning, or removing pollutants, in many different areas. When I did my PhD in the late 1990s we talked about radionuclides and the continuing consequences of the Chernobyl accident, and discovered that fungi can accumulate radioactive caesium-137 and strontium-85. That is definitely one application.

Fungi can be used to degrade pesticides and clean polluted sites. Petroleum degradation and hydrocarbon degradation is another area. With metal pollution and pesticides, there is a constant need and demand for the development of these technologies. For that, we need again to underline knowledge about the diversity, evolution and properties of fungi, to make better predictions about their properties, and which fungi can do more and do it better.

It is very important now to talk about the potential of fungal enzymes in developing technologies for sustainable degradation of plastic waste. That is a newly emerging frontline and many mycological laboratories are addressing it.

Q17 **Chris Clarkson:** How much research is going into that area at the moment? In particular, are big commercial entities thinking about it in practical terms? Are big companies looking at how they incorporate something like that?

Professor Druzhinina: Yes, we are at the beginning of the yellow brick road, and we have to think about different layers of explanation. Our target is technology that will be versatile and can be flexible, directed at many different types of plastics, and able to work in many different conditions—something similar to the degradation of plant biomass. Cellulolytic enzymes are now used in making paper, textiles and cattle feed. We don't think about it; it is available and the technology is already implemented.

We need the same for plastics. It is not as if one of us can find a magic fungus that will do the job. No, we need a versatile toolbox. We can do research on different layers. First, we need to study fungal diversity and bacterial diversity, and search for enzymes encoded in their genes that have potential. Then we need to take that information and use what we call microbial cell factories, which are organisms such as yeasts that can produce the enzyme that we want. Then we need people to engineer the enzyme for better activity and efficiency in plastic degradation. For that, we need bioinformaticians; we need computer scientists with artificial intelligence competence. Then the engineered proteins can be taken upstream for technology development for industrial waste management. That will be the target technology.

I strongly support Merlin's point regarding implementing fungi in the educational curriculum. After all, to degrade plastic, we need to harness young people to do artificial intelligence algorithms that will be a lot more efficient if they already have the underlying background knowledge. As university professors, we frequently feel that we waste time teaching basic mycology to master's students and PhD students, because we could have a higher start; we could already rely on their knowledge of the basic things and have them start at that level.

To answer your question about how many new laboratories, plastic degradation is a well-recognised target or goal for many microbiological and mycological laboratories and it can be addressed at different levels. I am searching for enzymes. My colleague is developing artificial intelligence to search for genes in the genomes. Another colleague will model protein plastic interaction. There is a network, a crossroad, of different sciences, so it is a truly interdisciplinary approach.

Q18 **Rebecca Long Bailey:** Professor Druzhinina, you mentioned earlier the use of fungi in packaging. Would you tell us a little bit more about that application, and about construction if it extends that far? What are the potential environmental advantages of using fungi in that way? Are there any limitations in its use at the moment, and how can they be overcome?

Chair: We are a bit short of time, so answers as succinct as possible, please.

Professor Druzhinina: It is a very new technology and development. Very simply, we can use agricultural waste, which can be wood chips or straw, and cultivate mycelium just in that material. At the same time, it is already shaped such that it practically makes a box. Then, at a certain moment the mycelium penetrates the wood chips in such a way that it becomes almost homogeneous, a very light and robust material. It can be dried and used as a packaging material instead of Styrofoam and it can be degraded and discarded at any place.

On limitations to new technology, we need to spread information. There are some safety issues that we still need to estimate, because some fungi

can be pathogens. For that, again we need fundamental research to predict potential risks and minimise them.

Q19 **Rebecca Long Bailey:** Dr Sheldrake, is there anything you want to add?

Dr Sheldrake: I have just been working with an architectural firm called PRP Architecture doing a range of experiments on creating different materials and testing them. Advantages include the ability to use agricultural waste, which would otherwise be a pain to get rid of, as feedstock for those materials. They can be decomposed rapidly after use, which in single-use packaging is obviously a big advantage. They are quickly grown inside in quite straightforward-to-make facilities. There are lots of things going for them. The materials tend not to be very durable, so they might not be useful for high-traffic areas where they would receive a lot of contact, but for insulation, acoustic tiles, packaging and that kind of thing they have huge potential. It needs investment and research.

Q20 **Dr Davies:** We have already discussed research at length, and the fact that we don't know what we don't know. I have a very quick basic question about the balance between fundamental and applied research in mycological sciences. Is the balance right currently? If not, how should it be changed?

Dr Sheldrake: There is a new centre for applied mycology at Cranfield, which is really good news. On the whole, I would say that applied mycology has had more investment because there is more promise of a return from that knowledge. Fungi can be well established in industry: for example, in fermentation, the production of citric acid and the use of aspergillus fungi. Those are well woven into the fabric of long-established industries. On balance, there has probably been neglect of basic research, and that could be addressed. Of course, the basic research will then have lots of potential replication.

Professor Druzhinina: I totally agree. Medical mycology is quite strong in the UK. I joined Kew two years ago as the head of fungal taxonomy group and, to my surprise, I then realised that I have to apply—and I am glad to—for UKRI funds on different topics, because fungal taxonomy and diversity research is very unlikely to be supported. That is a very interesting and striking example and it is something that can be addressed. I am now recruiting for something that is an interesting example. We announced the position of fungal taxonomist at Kew Gardens and received 42 applicants. From them, only one was a person from the UK. This person had a degree in molecular biology, not in mycology. That illustrates that right now there are no UK-trained experts in fungal taxonomy and basic mycology, which I invite you to address in the entire programme from school education up to UKRI funding for PhD positions and projects, because there is an underlying need.

Q21 **Graham Stringer:** There are a lot of questions I would like to ask, but I have a very simple question about pre-18 education and fungi. In your

book, Dr Sheldrake, you give a fascinating description of lichens and symbioses. Does the nature of lichens feature in A-level biology?

Dr Sheldrake: I don't know whether it features in A-level biology today. It didn't feature in A-level biology when I took it.

Katherine Fletcher: It was in mine.

Graham Stringer: I'll ask you the question then.

Katherine Fletcher: It was in mine, but I am very old.

Dr Sheldrake: I spent time studying lichens at A-level. My biology teacher was a lichen expert, which helped to get me interested. I spent time measuring lichens on gravestones in Tintagel churchyard, but the symbiotic way of life and the balance between competition and co-operation was not emphasised as much as it could be.

Q22 **Graham Stringer:** I want to turn to diseases later on. To get a sense of the amount of money going into research, the world's frog population is being decimated, or worse, by fungi. How much research is being done on that in this country? Professor Druzhinina?

Professor Druzhinina: It is quite hard to say.

Q23 **Graham Stringer:** Is it a small amount compared with other research, or is it a lot of research?

Professor Druzhinina: I believe it is quite a small amount compared with other research. Would you agree?

Dr Sheldrake: Yes. I would say it is a small amount compared with other research. There is not enough research in general and enforcement in general of bio-control. Some countries have very strong bio-control regulations, which are well enforced, on the importation of soils and plants and biological material, and research into what needs to be bio-controlled. The two things go together. It is not nearly as strong in this country as it should be.

Professor Druzhinina: Biological control and the use of fungi is a hot research topic globally. Fungi are applied to control pests in agriculture in many countries in South America, and in India and China. It is researched here and in the European Union, but we have to be more responsible when we introduce bioactive organisms into the environment. We need more risk assessment studies and safety documentation for that. It is not only the amount of the research but which kind of research. Finding a new bioactive fungus and spraying agricultural fields is probably not what we target. We have to be responsible in developing the technology, so it is not only the volume of research but the quality and the targets.

Chair: Graham has asked some important questions that we may put to UKRI and ask them to provide some statistics to the Committee for our consideration on this.

Q24 **Dawn Butler:** On the back of what Graham has just asked, how can we be world leaders if we are not investing in research? Are we world leaders because we have talent coming in from other countries?

Dr Sheldrake: There is a long history of mycology in this country and venerable institutions like Kew have long been a kind of sheltering place for mycologists and have supported mycological work. We have a rich tradition and we have many experts. We are under-investing in it, but everyone is under-investing in it. The fact that we have a strong pool of talent and are under-investing in it still means that we have a rich pool of talent; it just means it could go further.

Q25 **Dawn Butler:** It has been absolutely fascinating. Thank you both. I don't want to put you on the spot, but my last question is, what is your best fungi joke?

Dr Sheldrake: It is one that makes sense in Spanish. Micelio es tu celio. Mycelium is your celium.

Professor Druzhinina: For me, it is just playing around with fun guys.

Dawn Butler: You both seem like quite fun guys.

Chair: That was a very mean question, Dawn, but they were very impressive answers.

Q26 **Katherine Fletcher:** I am going to throw a couple of hypotheses at you. I have been very struck by your highlighting of the lack of research to give fundamentally confident answers. With your expertise, there are probably some things that the general public can do to engage on their mycelial journey. For example, when roadsides have a lot of very deep topsoil dredged up they get little plants in tubes put in, and we see all those trees struggling for several years. I wonder whether chucking them a bit of dead wood to help the fungal community get going would make a difference. Am I smoking my socks, or am I on the fun guy to be with spectrum?

Dr Sheldrake: There are definitely things that the public can do. Leaving dead wood lying around is a really good example. We tend to neaten up gardens, growing spaces, public parks and so forth. Dead wood is a vital habitat for fungi. Arboriculture is starting to change. Trees used to be managed as a public health question; it is now much more about what is living in the trees and how important they are in the ecosystem at large. Leaving dead wood around is a good thing.

Q27 **Katherine Fletcher:** It helps things to get going. Professor Druzhinina, would you add anything? What can the public do? It might not be proven, but it is probably right.

Professor Druzhinina: Definitely, but my problem is the removal of leaves from greens in the autumn. That is the microbiome; that is the biomass. The greens also probably need a healthy microbiome. For me, instead of the removal of leaves, in some places they could probably be

kept. We have a little garden at Kew where we leave them. It also derives soil microbiome from the very rich micro-organism community that plants have inside their bodies and on the surface of leaves.

Q28 **Katherine Fletcher:** If you want to restore a habitat, you have to feed the fungi as well as the trees and plants.

Professor Druzhinina: Absolutely. Fungi will feed the trees.

Q29 **Chair:** Dr Sheldrake, in answer to Rebecca Long Bailey you talked about the role of fungi in helping the rapid decomposition of agricultural waste. Can you give us an insight into what you mean by rapid, and how does that compare with other means of decomposition?

Dr Sheldrake: I was referring specifically to the harnessing of agricultural waste and the use of that as a feedstock, for example feeding corn stalks to fungi in order to produce something useful, whether that be edible mushrooms or mycelial packaging. If you take, say, a bag of freshly harvested corn stalks, pasteurise them and inoculate them with mycelium, you will have solid mycelial growth within two to three weeks; you will have mushrooms growing on that five days later.

Chair: Thank you both for a fascinating introduction to our session this morning. We are very grateful for your evidence.

Examination of witnesses

Witnesses: Professor Field and Professor Dyer.

Q30 **Chair:** I now introduce Professor Katie Field. Professor Field is professor of plant-soil processes at the University of Sheffield. Joining her at the table is Professor Paul Dyer, who is professor of fungal biology at the University of Nottingham.

Katherine Fletcher: Hear, hear.

Chair: With support for that institution. Professor Dyer co-founded a fungal foods university spin-out company called Myconeos in 2018, to which he may refer. Perhaps I could begin with a question to Professor Field. Could you give us some examples of how the relationship between plants and fungi is beneficial for crop production?

Professor Field: Merlin earlier gave us a nice introduction to the world of mycorrhizal fungi, an area in which I specialise. These fungi form intimate partnerships with plant roots and they are in almost every plant you see around you today, including crops that we eat. Pretty much all crops form these associations. In return for transferring sugars and fats that a plant has made when it is photosynthesising, sucking CO_2 out of the atmosphere, it transfers those sugars and fats to the fungus living in its roots and in return the fungus increases access to soil nutrients for the plant. It does that in a couple of different ways. First, the fungus associated with the roots is able to grow way beyond the zone that the roots are able to reach, so it increases the area of soil that the plant can

access. Secondly, they are superfine; they are much thinner than plant root hairs. They are able to access soil nutrients that are lying in pockets in the soil that the plant root cannot get into.

Thirdly, they are able to access different forms of nutrients. They have an incredible power to degrade minerals in the soils—rocks—and from that to liberate mineral ions that they can assimilate and transfer to the plant. They can be useful for crops in fields by increasing access to soil nutrients. Another way is by enhancing defence against pests and pathogens, much as a vaccination works in people. When a fungus colonises the roots of a plant it gives it a boost in its immunity, and when another invading pathogen approaches, the immune system kicks into play much more strongly and quickly than it would otherwise.

Q31 **Chair:** Decomposing rocks seems an extraordinary attribute. How long does the process take for different types of rock?

Professor Field: We call it biological weathering. It happens because the fungus exudes acids from the tips of their hyphae. This can happen surprisingly quickly. In some experiments we have done we can see the hyphal tips trenching through mineral chips on slides. This can happen quite quickly, but it also happens over geological time, contributing to global geo-chemical cycles which are responsible for sculpting the atmosphere that we breathe. I guess it depends on how big the rock is.

Q32 **Chair:** In agriculture does it provide any kind of use during the lifetime of crops?

Professor Field: Absolutely. It happens in an agricultural timescale, so it would happen across a season. It is happening all the time they are growing.

Q33 **Chair:** Are farmers and growers aware of the use and potential applications?

Professor Field: I was part of a project involving the Universities of Leeds, Sheffield and York, as part of the White Rose University Consortium, and we held a farmer workshop just last week where we were talking directly to farmers in the region. They have a huge appetite for harnessing fungi in their systems, particularly in regenerative agricultural systems, so they are aware.

One of the key problems is that there is a lot of mis-selling of the power of fungi in agricultural systems. They are often viewed as a cure for all sorts of problems, but the management techniques employed by and recommended to farmers can be quite anti-fungal in what they are doing. It creates a vicious circle of farmers buying inoculants or bio-stimulants, chucking them on their fields and thinking they are doing a great thing and they are not getting the results. A lot of the work we are doing is giving them the hard facts and the evidence so that they can make informed decisions on what they are doing.

Q34 **Chair:** Does this have a parallel with the debate and practice in the use of insecticides, for example? This Committee's inquiry has been looking at integrated pest management in which beneficial insects can be an alternative to insecticides. Is that the right way to think about fungi?

Professor Field: In some respects, probably. I don't have much expertise in that area so I don't want to speak to that too strongly, or draw too many parallels. Certainly, there is a danger in what is being recommended and what we have evidence for that works in practice.

Q35 **Chair:** In current use, as opposed to the potential use of fungi in agriculture, how extensive is the positive and proactive use?

Professor Field: The biggest success stories probably come from where farmers are completely overhauling their land management techniques and adopting more sustainable circular or regenerative approaches. In typical, conventional intensive practices, where you are ploughing a lot, applying a lot of chemicals and using varieties of crops that respond well to those conditions, you discourage beneficial interactions with fungi in those systems. Therefore, adopting no-till regimes, or switching to organic amendments to your soils, has a beneficial effect.

Q36 **Chair:** Thinking globally, how does the practice in UK agriculture compare with other countries? Are we doing well? Are there stand-out countries from which we should be looking to take evidence?

Professor Field: It is less a nationally based thing; it is more about scale. At large scale, agriculture in general is not so good. It tends to be very intensive and damaging and there is a lot of soil erosion. At smaller scale in the UK, certainly from the farms I have interacted with and the research we have done, there is a lot of receptivity. People want to do this and be able to implement these things, when it is a financially viable option for them. I think that is the main constraint at present.

Q37 **Dr Davies:** We have just discussed the symbiotic relationship between plants and fungi. How important do you think that is in the face of a changing climate and other environmental stresses?

Professor Field: It is critically important. What we need to remember is that the associations between plants and fungi have existed since the dawn of plant terrestrialisation, so we are talking 500 million years. They are as old as the plants themselves. They played a critical role in building the terrestrial biosphere as we know it. In doing that, they have had an influential role in the development of our atmosphere. A lot of the air we breathe can be attributed to the actions of the mutualistic fungi in the soil around us. In turn, that composition in the atmosphere leads to climate, weather patterns and so on.

Q38 **Dr Davies:** Professor Dyer.

Professor Dyer: There is evidence that climate change can affect the plants themselves. Things like plant exudates from the roots very much influence the microbial composition of the roots. That means that,

whereas we have beneficial ones at the moment that promote plant growth and protect them from diseases, there is a risk that we will get changes, because the plants are under stress, that might have detrimental impacts on the microbiota itself.

Professor Field: To build on that, a changing climate has direct effects on the mycorrhizal associations themselves. A lot of the research we have done in my group shows that the functionalities, the amount of benefit a plant gets from the fungus and the amount of carbon the fungus gets from a plant, are very dynamic and dependent on climatic conditions, like carbon dioxide concentration, temperature and so on.

Q39 **Dr Davies:** If we are looking at mainstream agriculture and using fungi to our benefit, what role do you think the Government have in promoting that with industry and farmers?

Professor Field: I have a list. Fundamentally, the main thing is to distil facts from fiction in this area. We need to promote evidence-based messaging and implement regulations on sales, effectiveness and standards, certainly for things like bioinoculants. We also need to put in place regulations and policies that allow farmers to do management systems profitably so that they can make what they need to from the land, but also enhance the fungal symbioses.

In the previous session, you touched on the chronic underfunding in this area. I guess that is because it is beneath the soil surface and we cannot see it and there is not an instant result. Funding cycles tend to be three years, three to five if you are lucky. That is simply too short term to implement the sort of research programmes that would make a difference in this area. It is about longer funding programmes, not necessarily more money. It is about time, particularly when you are working in agricultural systems to run field trials, which take years to establish, and then you have the cycle. That is one of the primary challenges.

Q40 **Chair:** That is a fascinating point. A similar point about the requirement for long-term cycles was made in our inquiry into insect decline. The funding comes through UKRI and the research councils. The councils and bodies consist of fellow academics in these fields, rather than politicians, as it were, so why is it systemically the case that too short funding cycles are being imposed by people who are meant to know the whole design of the structure?

Professor Field: There are probably lots of different reasons. There are a lot of competing interests in research councils for a finite pot of funding. Understandably, at the core of research councils they want to make it go as far as they can, so to sink a huge amount of money into one long-term project, to the detriment of shorter-term projects that may have a more rapid impact, is a very difficult balance. I am sure that Paul has thoughts on this.

Professor Dyer: I echo what you said. There are some longer projects. For instance, there is the UKRI sLoLa scheme which concerns longer projects bringing people together. Historically, it is almost as if they have given three-year projects to see what can be achieved and might lead on to something beyond, but, as Katie says, that is fine if you can do the work within three years, but for longer field projects particularly it is an obstacle.

Chair: Thank you. Forgive me, James. I interrupted your questions.

Q41 **Dr Davies:** That's fine. I have just one further question. Professor Field, you touched on the idea of regulations that could be put in place to move us forward in this area. One area was mis-selling, I think. Another was helping farmers to be more profitable when they use fungi. There is also, I suppose, safety, isn't there? To what extent do existing regulations not already cover those areas? Do you have an idea of the nature of the regulations required?

Professor Field: I am not an expert in that area, so I don't want to say too much. There is one example that I have a little bit of knowledge about. In regenerative agriculture, one of the key principles is the reuse of waste products and recycling of waste into the system. Part of that is quite often using sludges, slurries and manures to improve the nutrient content of the soils, and the carbon content and all of that stuff. However, the treatment of those waste products is not currently sufficient to remove all of the bioactives that are present there, such as pharmaceutical products, personal care products and veterinary medicines. They can reach the soil.

A project that I am involved with at the moment looking at the impact of bioactive compounds on soil concentrations is showing that, although they do not impact the communities of fungi living in the soil, there is a devastating impact on what they are doing. By implementing that without correct regulation on treatment of the waste, you have the indirect effect of minimising the impact the fungi could be making on the crop. There are layers of different regulation.

Q42 **Stephen Metcalfe:** Good morning, and thank you very much for joining us. Katie, you said that current agricultural practices are not terribly supportive of beneficial fungi. Is there anything you want to add to that? If farmers—presumably, it is mostly farmers—were to change some of their practices, would they see a benefit from the improvement in the fungal activity that takes place in their soil, bearing in mind how important fungi are to soil?

Professor Field: It is difficult to say, isn't it? I guess it is not just that one individual practice is going to have a massive impact; it is the combination of factors. Maybe it is easier if I outline some that are detrimental to fungi and then we can go from there. The first is application of chemical-based fertilisers and pesticides. Fungal associations do not happen in a high-nutrient environment because the

plant does not need them. If you are adding lots of fertiliser to your field, the fungus is not needed, so it doesn't do its thing.

Secondly, obviously fungicides are going to have a negative impact. Thirdly, it is the type of crop that you are growing. A lot of modern cultivars, the elite cultivars that are grown commercially, are very responsive to a high-nutrient environment, so they do not want to make the associations because it has been bred out of them. They are tolerant to all of the pesticides and fungicides that have been thrown at them, and are quite resistant to fungi in the first place. By breeding for those traits and selecting just for above-ground traits, you are inadvertently deselecting traits that would make them better functioning with fungal partners.

There is a crop-breeding approach that could be done at a commercial level and then there is soil management. Tilling is obviously dreadful. Ploughing is bad for fungi. It breaks up their fungal networks and turns over the soil. You lose a lot of the soil itself and a lot of essential nutrients come out. There are probably more. It is generally pretty bad for fungi. By changing how you manage your soil, you can make up for some of those things, but it would take a multi-pronged approach. There isn't just one intervention that would be the silver bullet.

Q43 **Stephen Metcalfe:** You covered, certainly in the first part of that, some of the practices that are particularly bad for fungi but you probably didn't explain why the farmer would want to make his soil better for fungi. If it doesn't affect the crops—

Professor Field: Yes, sorry. If you can increase how well the crop is functioning with the fungus, and if the crop is accessing a lot of nutrients through fungus in the soil, you can apply less fertiliser, so you bring the cost of production down. It also has massive benefits environmentally because by not buying fertilisers and applying them there is less need for them to be made.

Professor Dyer: There are also water efficiency gains. The fungi that form the mycorrhizal networks seem to be able to recruit nutrients more efficiently under water stress. The plant itself might struggle, but the fungus is very good at getting them, as Katie said, from mineral sources. That is another benefit to the farmers.

Professor Field: There is another benefit in terms of soil structure. We frequently see that soil with a high diversity of fungal component has a much better structure, so it is able to hold on to nutrients and it is much more aerated. It is a healthier and better functioning soil.

Q44 **Stephen Metcalfe:** Excellent. Okay, thank you very much. I would like to move on, if I may, to fungi as a food. To what extent could eating fungi contribute to a sustainable food system? Paul, are there any specific environmental advantages in cultivating fungi for human consumption?

Professor Dyer: Thank you for the opportunity to address the Committee. Fungi generally have the ability to make a big contribution to our food strategy. There was a recent Government food strategy policy document by Henry Dimbleby in which he encouraged the use of alternative proteins. Fungi are wonderful examples of that. If you will forgive me, I have brought a prop. I have some Quorn mycoprotein. If anyone has not tried it you can perhaps try some afterwards. This is a wonderful example of the impact that fungi can have, in that, in terms of things like greenhouse carbon emissions, water use and land use, they are far more efficient than current sources of animal protein.

Mycoprotein is the whole fungus. We heard before about the fungal mycelium. This particular company grows it in 150,000 litre fermenters, the largest in the world. The UK is a world leader in this area. It is then harvested, compressed and processed to get the food I have here. It is about 40% to 50% dry weight protein. It has very good dietary fibre. It also has vitamins. On the environmental emissions of mycoprotein production, it is about 10% of the carbon emissions of cattle and about 30% of chicken. For land and water use, it uses about 10% of water of current beef production, and there are some estimates that it uses about 12% of the land area.

Quorn is not the only company that is working on it. There are other UK companies. There is one called ENOUGH Food that has recently been launched. I come from Nottingham—I spotted a Nottingham link earlier—where we have a little start-up company called Adamo Foods that is looking to make fungal steak. They are using a different species. If you go on their website, you will see some lovely, juicy-looking steaks. They are encouraging the use of fungi as alternatives to current animal proteins, not necessarily to replace but certainly to complement. It can make a big difference.

Q45 **Stephen Metcalfe:** You said it was a 40% to 50% higher protein yield.

Professor Dyer: The actual protein content is about 40% to 50%, but as a whole food it is very healthy because there is dietary fibre in it, and vitamins.

Q46 **Stephen Metcalfe:** Okay. There are a number of different fungi that could create that. You said that there is one that is being used to create steaks.

Professor Dyer: It was interesting listening to Irina earlier because she mentioned that there might be about 1.5 million to 2 million fungal species. The ones that we use for mycoprotein date back to the late 1960s. Lord Rank did a survey of 3,000 species, which seemed an extraordinarily large number at the time, but now we know it was a vast under-sampling. They found the best protein-rich ones at the time.

One particular project that I have been trying to push is to see if there is other untapped potential in the fungal kingdom. One other main fungal

food is tempeh, which is produced in Indonesia from a fungus called Rhizopus. Particularly in Asian foods, you get things such as soy sauce and sake, which are produced from fungal fermentation. There are some other fungal foods, but there is a relatively limited number of species.

Q47 **Stephen Metcalfe:** Is there a downside to eating fungi-based protein, as opposed to other sources, such as meat?

Professor Dyer: Obviously, I am biased; I am a fungal fan. I genuinely think, not really. In fact, in allergenicity, mycoprotein has been shown in independent studies to be about a hundredfold less allergenic than soy protein. It has environmental benefits. It is also low in fat. You will know about cholesterol and the problems with heart disease. Filamentous fungi have a different compound called ergosterol that they use, which we can convert to vitamin D, so you have various health benefits from eating it as well.

Q48 **Stephen Metcalfe:** Great. Your recommendation is that we should eat more.

Professor Dyer: I will give you a trial at the end of the session.

Chair: Dawn has a supplementary.

Q49 **Dawn Butler:** Regarding the steak that is made from fungi, is that where I saw a 3D machine making steak, or is that something else?

Professor Dyer: There are some trials using 3D printing of fungal mycelium. They are still, as far as I am aware, at the very early stages. Most of the steaks and whole-cut meats are made by growing fungi in what is called static culture. In fact, we have a company in Nottingham working on that. In New York, another company has vast rooms full of fungal mycelium that they are growing up. You can see pictures of them carving off steaks.

Dawn Butler: Thank you.

Q50 **Chris Clarkson:** First, I am delighted to find out that by drinking lots of sake I have been helping. We have been talking about what the biotechnology sector is doing to innovate the way that we consume fungal proteins. Specifically, though, Dr Dyer, are there any particular challenges to doing this on a large commercial scale? Quorn is not the cheapest protein, especially when we are thinking about encouraging people to eat more of it. If meat protein is cheaper, people will buy it. What are the big challenges to large-scale production? What can the biotechnology sector do to innovate in that area?

Professor Dyer: There are two aspects that I can think of to answer that. First of all, a current area of research is precision fermentation. That is where you would normally work with yeasts, the single-celled fungi. They have been genetically modified to produce a specific product. One area that is very topical at the moment is trying to use yeast to produce casein, which is a key dairy protein. There is the prospect of producing

non-cow milks, and even cheeses, which is quite exciting. It removes the methane emissions from the cattle. There is a start-up company in London called Better Dairy looking at that, and there are other companies in other countries. They have begun to produce casein, so you have the prospect of vegan cheese that really is cheese made with casein. The difficulty though is the scale-up.

There is a particular organisation in the UK called CPI, which is one of the UK's main areas for access to larger fermenters, but even then there is a bit of a bottleneck accessing sufficient scale-up. Quorn is an exception, in that each of its fermenters are in the order of about up to hundreds of millions to build. It has built them gradually over the years, but other companies coming in face quite an obstacle in scale-up.

Q51 **Chris Clarkson:** I will have to wait a while before I can get my mushroom latte at Starbucks.

Professor Dyer: There are other mushrooms that grow on the waste of coffee. I don't know if you know that. You may have heard of oyster mushrooms. I think Merlin even mentions them in his book. They are grown on spent coffee grounds. Starbucks may be helping you.

Chris Clarkson: You can actually make very nice martinis out of those. Chris's top tip.

Q52 **Dr Davies:** Could I come in very quickly? The concept that we eat more fungal-based foods is very interesting, but what about cost? If we are looking at cost of living pressures on families, are they a solution in that respect? If not now, do you think they will become so?

Professor Dyer: I don't want to speak just about Quorn, of course. It is a more general thing. Even traditional mushrooms are a very good foodstock. They don't have the protein levels of the mycoprotein, but in terms of nutrition they have very good roughage and very good vitamins. There is a variety of mushroom species, not only button mushrooms. In Asian countries, shiitake and oyster mushrooms are eaten as a staple food. Those are relatively cheap.

Even foodstuffs like mycoprotein are not super-expensive relatively; they are slightly a premium product but they aren't excessively so. In a broader sense, you have to consider the general environmental issues as well. Although meat might seem cheaper in the short term, given the growing human population globally, the environmental impacts of the CO_2 and the methane emissions, you could argue that there are hidden costs that perhaps we should account for.

Q53 **Chair:** Would you expect to see a big fall in the costs over time, or does the nature of production limit any anticipation of a fall in prices?

Professor Dyer: It is difficult to say. Because it is seen as such a beneficial foodstuff both on health grounds and on environmental grounds, there are a number of companies worldwide entering the sector.

There is a company in America called Nature's Fynd that isolated a fungus from Yellowstone National Park, and they are now growing that up as a parallel to Quorn.

Q54 **Katherine Fletcher:** Presumably with quite a temperature range tolerance as well.

Professor Dyer: On the science side, it is very interesting because it grows at a slightly higher temperature, so you can grow it more efficiently. A company called Mycorena in Sweden is growing a mycoprotein. There is competition coming. That said, you still need the infrastructure to grow the fungi and you need to provide them with glucose and mineral nutrients. The prospects for the price coming down a lot are probably limited.

Q55 **Graham Stringer:** What sort of threat to food security in this country and worldwide are fungal diseases?

Professor Dyer: They are a major threat. Matt will talk about this later. It is estimated that about 15% of global food crops are lost annually due to fungal diseases, and in severe infections you might have a 60% to 70% loss in yield. There are some famous stories. You may be aware of the risk to bananas. There is a particular fungal disease of bananas called Panama disease that is gradually spreading worldwide. Because the bananas are clonal, or at least the Cavendish variety is, they have no resistance to it. It is very difficult to control with fungicides.

As well as that, there are perhaps lesser-known ones such as stem rust of wheat. There is a particularly virulent race called Ug99 that emerged in Uganda about 20 years ago, and is now beginning to spread worldwide and threaten wheat production. Even for soybean, which has now been spread a lot in the world, there is a particular soybean rust fungus that is now beginning to spread worldwide and is threatening there.

When you add the risk of climate change, as Katie said, the plants themselves might be stressed due to climate change effects and the fungus can then move in. In the UK, there is a fungus called Fusarium culmorum on wheat that causes a slight disease, but not too bad. As the temperature has gone up, there is another disease called Fusarium graminearum that has come in from warmer regions, and that causes a more severe disease. Although we are saying how wonderful and beneficial fungi are, the other side of them is that they are very damaging in terms of the diseases they cause.

Professor Field: There is a role for fungi in helping combat fungi. With the mycorrhizal fungi, for instance, if we have a healthy soil mycobiome, that can improve the tolerance and resistance of plants to some of these diseases. There are parasitic nematodes as well. You can increase the tolerance of the load of nematodes by having a healthy mycobiome in your plant roots. It is all about maintaining the optimal balance.

Q56 **Graham Stringer:** I realise there won't be a simple answer to this. You

mentioned that one of the solutions might be using other fungi. Is one of the solutions to move away from monoculture so that you don't have only one sort of banana but you have a lot of different bananas, and if the fungi get one we are still left with some bananas, basically?

Professor Dyer: That is definitely an obvious solution. There has been encouragement over the years to try to do better plant management from that aspect. The problem though, if you are a farmer, is that you want a field that is uniform and is going to give a high crop, so often the pressure on them economically is to use monocultures, unfortunately.

In the particular case of bananas, because they are what is known as triploid, they are sterile and you cannot easily breed them. In fact, history is repeating itself. In the last century there was another banana cultivar called Gros Michel that was the first banana to be consumed worldwide. Apparently, it tasted delicious, even better than our current one, but it was killed by the same fungus that swept worldwide. It was from the 1950s onwards that we got the Cavendish monoculture variety replacing it.

Q57 **Graham Stringer:** Are there any obvious reasons why the risk from fungal disease in food is increasing? You gave a pretty frightening picture of the increasing number of diseases and threats to different food sources. Is there any particular reason?

Professor Dyer: Another factor is the use of fungicides. Historically, we have been able to use since—

Q58 **Graham Stringer:** Is it a bit like antimicrobial resistance?

Professor Dyer: That's right. We have been treating them with fungicides to stop the disease. For perhaps four or five years, we would have field control of the disease, but then in the same way as you get the evolution of antibiotic resistance you get the evolution of antifungal resistance. Suddenly, for what was a very efficient fungicide, in the space of perhaps two years the efficiency is lost and you need to move on to another one.

We have a particular problem with fungi because, as we heard earlier, they are very closely related to human cells; we are on the same evolutionary branch. Trying to find antifungals that kill the fungus but do not affect other mammals is very difficult. There are relatively few antifungal-class agents that we can use. Sad to say, they are systematically evolving resistance to all of them.

Q59 **Graham Stringer:** You are educating this Committee. Are the policymakers in Government educated in these areas? Are they aware of the problems?

Professor Dyer: You would best know that.

Graham Stringer: Not necessarily.

Professor Dyer: I think the antibiotic threat, because of human health, often gets the headlines, but just behind it the evolutionary resistance to antifungal drugs is a major problem, and not only in terms of plant disease. As you will hear later from Matt Fisher, there is a serious number of human and animal diseases that we currently control with antifungal drugs, and in the same way we are getting resistance to those as well. We really need the next generation of antifungals. Again, as with antibiotics, the problem is the major cost in developing them. In industry, who is going to fund that?

Professor Field: There is also the unintended consequence that if you come up with a brand-new antifungal agent that wipes out all fungi, where does that leave you with the beneficial fungi? You have wiped them out as well. A precision approach is possibly needed.

Chair: Thank you. We have time in this session for three quick questions. Katherine, I think, had a supplementary and then Dawn and Tracey.

Q60 **Katherine Fletcher:** Thank you, Chair. I just want to follow up on the idea of reservoir populations for a healthy fungal soil microbiome, especially in a farming context. There is lots of money going into farming at the moment—public money for public goods. If you get weedkiller and you overspray it on your lawn, you get a big yellow patch, so it is obvious where the over-margin spray is. Is that true for mycorrhizal fungi? How far is a margin for a fungal treatment? Are you taking out the adjacent woodland if you put an antifungal treatment on your rape? What is the margin? I am sorry, I do not know who to ask. Forgive me. My bias is towards Nottingham, but we will do a little bit of Sheffield.

Professor Field: Sheffield is not so bad.

I don't know that we know that. It is a case of there being lots of different species of fungi, and if you knock out some of them others grow in their place. You want to maintain the beneficial ones and repress the more damaging or weedy varieties. If you are applying—

Q61 **Katherine Fletcher:** Don't worry, I don't want to take up loads of time. You would adhere to the idea that having reservoir populations of woodland fungi and grassland fungi is a good thing.

Professor Field: We know that is a good thing. Ley strips and herbal leys can act as reservoirs. Using a cover crop can help.

Q62 **Katherine Fletcher:** That is maybe part of the mechanism as to why a cover crop works.

Professor Field: Absolutely.

Q63 **Katherine Fletcher:** Would you add anything, Professor Dyer? Do you know anything about the numbers?

Professor Dyer: I must admit that is not my area.

Katherine Fletcher: Yes, fair enough.

Q64 **Dawn Butler:** It sounds like a constant battle. We have increasingly become resistant to antibiotics, and then that plays out in the fungi world. Professor Field, you talked about having a list of things. Can you supply that list to the Committee? I do not know if you have had a chance to go through the list of things that we need to do as legislators.

Professor Field: I can, certainly.

Dawn Butler: The same for you, Professor Dyer; if there is anything that we have not covered today, can you send a list to the Committee and then we can put that into our report? We would appreciate that. Thank you.

Q65 **Tracey Crouch:** Professor Field, you answered questions on large-scale agricultural aspects. On behalf of the small growers in this country, the 330,000-odd people like me who have allotments, do you think there is enough known about what we, the small growers, can do to incorporate fungi into that space and the benefits that it can have? Certainly, if you go to a local garden centre to buy a fertiliser, it would be the standard fish, blood and bone. Any kind of mushroom compost is—

Professor Field: Sure. There is a huge appetite out there. People are always very enthusiastic about it when you talk to them. We work with a large number of allotment growers in Sheffield and we have a number of projects helping them understand the fungi in the soil and what they are doing, and why they need to mulch it. Small growers are prone to misinformation, and there is a lot about fungi, particularly mycorrhizal fungi, such as that you can just chuck an inoculum on it and it is going to do you wonders. It doesn't work. Then people get discouraged and they don't do it any more, so they apply the fungicides. It is about nurturing what is already there. The species and groups of fungi that are in the soil already are the ones that are best adapted to help your plants grow in your environment.

Implementing the sustainable regenerative techniques that are common with larger-scale farming—minimum tillage, direct drilling, applying lots of organic composts and organic matter to your soil, not digging up huge amounts of it, and minimising the amount of chemical based phosphates and nitrates, particularly the very plant-available stuff—will encourage the fungal communities to be there and to give the benefit to your plant.

Q66 **Tracey Crouch:** Do you think there is enough being done to tackle that misinformation?

Professor Field: Probably not. I spoke with the RHS quite recently. It is updating its guidance to growers in line with a more evidence-based approach rather than advocating the spreading of inoculum and things. There possibly could be more done, but it is a delicate balance between weaving a magical tale of wonders in the soil, and what is useful, what will work and the evidence for it working.

Chair: Thank you very much indeed, Professor Dyer and Professor Field, for your evidence this morning.

Examination of witnesses

Witnesses: Professor Fisher and Professor Stadler.

Q67 **Chair:** We now turn to our final panel of witnesses. We are going to look into questions about fungi and human health. To help us with that, I am very pleased to welcome in person Professor Matthew Fisher. Professor Fisher is professor of fungal disease epidemiology at Imperial College London. Joining us remotely from Germany is Professor Marc Stadler, who is the head of department for microbial drugs at the Helmholtz Centre for Infection Research. Thank you both very much indeed for joining us today.

Perhaps I can start with a question to Professor Fisher. You have, I think, heard some of our previous fascinating panels. When it comes to public health, could you first of all talk about the potential risk to public health from different types of fungi? What health risks do they present?

Professor Fisher: Hello. Fungi impose a huge global burden on public health. There are over 6.5 million people annually who have a serious fungal disease. The burden of mortality is about 2.5 million per year worldwide. To put that into context, malaria kills 600,000, bacterial antimicrobial resistance kills 700,000 and tuberculosis kills 1.3 million. They are up there with the big hitters in global mortality. We have heard about food security as well. When humans are deprived of food, that also has health consequences, and some of them are catastrophic. There are ecosystem impacts of unhealthy environments caused by losses of beneficial fungi. It is a very wide and multi-sectoral problem.

Q68 **Chair:** Are there any particular fungal species that are most concerning from a public health perspective?

Professor Fisher: Absolutely. The major public health burden is caused by a thermotolerant mould called Aspergillus fumigatus, which is ubiquitous in our environments. It is in almost every breath we take. Because of its ability to grow at temperatures above 37°, if your immunity is not able to handle it, it will cause a severe and life-threatening invasive fungal infection.

Q69 **Chair:** You say it is thermotolerant. Up to what temperature?

Professor Fisher: It is very happy growing at 40° or 50°. You can take it up to 80° and still not kill it. The reason it is thermotolerant is that it is a saprotroph. It is there. It is rotting down carbon and nitrogen in our environment. It is the major driver of composting processes. We are reliant on this organism, but it is highly sporulating and it is a very ubiquitous bioaerosol.

Q70 **Chair:** Is it the case that most people have resistance to it, or not?

Professor Fisher: We have to have resistance to it. The fungi kingdom is a billion years old. When we dragged ourselves out of the ocean as vertebrates 400 million years ago, we invited ourselves into the world of fungi in terrestrial environments rather than the other way round, so we had to evolve immunity to those fungi that could grow at normal body temperatures and wanted to rot us down. That is why we have very sophisticated immunity—C-type lectins specifically exist on our macrophages to find, seek out and destroy Aspergillus conidia in our lungs.

Q71 **Chair:** Is the implication that some people have degraded immunity or are missing the appropriate protection and it is dangerous for them?

Professor Fisher: Absolutely. There are many risk factors. If you have cystic fibrosis, you are predisposed to this infection. Fungi have to be considered in the context of multi-morbidity. There will be something that has degraded your immunity and that then makes you susceptible to a huge exposure to the fungal kingdom. HIV/AIDS was first observed because men started getting pneumocystis pneumonia, a lung respiratory infection. Why were they getting it? Because their immunity was being taken down by the infection.

If you have lung cancer, a clinician gives you some form of immunosuppressive drug. That is then going to predispose you to a fungal infection. The clinician is always fighting fungal infections in the context of the other morbidities that they are treating.

Q72 **Chair:** Thank you. I read in preparation for this session that among deaths from HIV/AIDS up to about half were certainly attributable to fungal infections. Is that correct?

Professor Fisher: Absolutely. Cryptococcal meningitis is, after TB, the major killer in HIV/AIDS in highly prevalent areas.

Q73 **Chair:** I see. Thank you. Before I turn to Stephen Metcalfe, could I ask Professor Stadler whether he would like to add anything to the very comprehensive assessment that we have had from Professor Fisher of the public health threats from fungi?

Professor Stadler: I think it was very well explained by Matt. We are searching for new antifungals and new antibiotics, so I am not really in a position to comment on this matter. What happens is frightening. The HCI is getting substantial amounts of money right now to combat bacterial and even viral infection, but with fungi there could be more funding. We have to act now before it is too late, because we are running out of effective drugs.

In the last panel, we heard about Aspergillus fumigatus and the azoles that are being used in agriculture as well as in human therapy, and that too is a big problem. We need new compounds that can only be used for humans and that will tackle the Aspergillus. Basically, my job is to find new drugs.

Chair: We are going to ask some more questions on that. Since you have now come up on the big screen, I can see in great detail your choice of fungi-related knitwear. Thank you for selecting that for your appearance this morning.

Q74 **Stephen Metcalfe:** Good morning both. Is fungal disease evolving in the same way as antimicrobial resistance has evolved? The microbes are able to combat the drugs. Is that true of emerging and evolving fungal disease, Matthew?

Professor Fisher: My goodness, yes. We have a genome programme where we are looking at antimicrobial resistance in Aspergillus fumigatus. We very readily find Aspergillus that is resistant not just to the azoles but also to the benzimidazoles and the SDHIs.

To put it in context, there are four classes of antifungal drug licensed for use in humans. There are many more used in agriculture. Because of the similarity of fungi to animals, we all end up using the same modes of action for fungal drugs. What is innovated for agriculture has also been innovated for use in humans. The reason we see such a great increase in antimicrobial resistance in Aspergillus is that it is always exposed to the agricultural fungicides—the azoles, the benzimidazoles and the SDHIs.

The clinician is also using near-identical chemicals, the clinical azoles itraconazole, voriconazole and posaconazole, to treat patients. The problem comes when spores that have resistance are soft-blown on the air in the environment and affect a human, and the drug no longer works or works so well.

Q75 **Stephen Metcalfe:** Wow. Professor Stadler, do you want to add to that?

Professor Stadler: Maybe I should add that I come from the research group that found the strobilurins, the class of fungicides that are only used in agriculture. The big agri companies sold those in combination with the azoles and others. That was working pretty well, but now the strobilurins have lost their effectiveness. They have also been prone to resistance. This is a problem that will now hit us even harder because we need to rely more on compounds like the azoles, which shows that you cannot really separate the agri and the pharma sectors in that respect.

Q76 **Stephen Metcalfe:** Thank you. That is very helpful. To simplify, the concerns that we have about antimicrobial resistance and everything around that should equally apply to fungal disease and how we deal with that, and the classes of drugs that we need to develop. That helps us. It is an area that we have looked at and continue to look at. Are there any drivers promoting the emerging evolving diseases and fungal threats that are specific to fungi rather than microbes? Is there any activity that we are undertaking that is particularly driving this and that is different from what drives antimicrobial resistance?

Professor Stadler: We are getting older on average.

Q77 **Stephen Metcalfe:** Did you say we are getting older?

Professor Stadler: Yes. The older you get, the weaker the immune system will normally be, so we have to be very careful now. There are immunocompromised patients, as Matt has already mentioned—people who are undergoing organ transplants or taking immunosuppressants, which are, by the way, often derived from fungi. The number of patients who are susceptible to fungal diseases will increase. We have newly arising pathogens like Candida auris that were not even recognised at first because diagnostic methods were lagging behind. There is a lot of work to do to prevent larger outbreaks in the future. I am pretty sure that it will be good to expend more effort on mycology.

Q78 **Stephen Metcalfe:** Excellent, thank you. Do you want to add anything to that, Matthew?

Professor Fisher: The process that Marc alludes to is emerging fungal infections. We heard from Merlin and Irina about the enormous, deep well of fungal organisms. They can emerge and they can spread through our global trade routes to colonise the planet. We have seen this with the amphibian-destroying chytrids that have driven a wrecking ball through tropical ecologies. Those forests are silent now when before they had a great biodiversity of amphibians. There is the destruction of North American bats.

We are seeing the same with humans. The spread of Candida auris is a very good example. It also has to be viewed in the context of antimicrobial resistance because it is very resistant to our clinical antifungals. Therein probably lies a clue to why it has emerged and spread. It has colonised a niche that has been cleared by our very broad use of fungicides. It has higher thermal optima than other Candida yeasts. At least the hypothesis exists that it has responded to global increases in temperature. That raises the idea that as we heat the planet we also raise fungi to the extent that they can then infect our higher body temperatures.

Q79 **Stephen Metcalfe:** Are there other fungi that might benefit from that rise in temperature which could present a significant risk to us?

Professor Fisher: Fungi will evolve to adapt to higher temperatures. There is a deep well of fungi that cannot affect us because their growth optimum is 36°. They cannot grow at higher temperatures. If you perniciously select them year on year, perhaps they will evolve to our higher temperatures, and then they will become a problem.

Q80 **Dawn Butler:** The evidence that we have taken today makes it very clear that we have to think about all of this differently and invest a lot more. Professor Stadler, you talked about the immune system and us getting older. Seventy per cent. of our immune resistance is in our gut. Where is the link between fungi, phages, probiotics and all of that? How is that linked together?

Professor Stadler: The gut is an interesting aspect because the gut microbiota can also be beneficial. There are a lot of papers being published, even in the top scientific journals, that ignore fungi. There are a lot of probiotics that are derived from gut-inhabiting yeasts, but for the fungal infections that we have mentioned, most of them enter via the lungs. Aspergillus fumigatus does not enter via the gut, but I am not a medical doctor. I am a biologist—a sort of chemist, but not an MD.

Q81 **Dawn Butler:** Professor Fisher, as we learn more about fungal threats, do you think that raising awareness of those threats is contributing to making your job, and the jobs of everybody else who gave evidence here, better? Or is it fearmongering and therefore more harmful?

Professor Fisher: It is a bit of both. Obviously, the raising of awareness has resulted in changes to the funding landscape. The UK has done very well in funding the MRC Centre for Medical Mycology in Exeter, which is the only institution of its type in the world, and there is a huge amount of interest in sustainable soil communities and locking down carbon through fungi. That is all good, but there is a level of public panic, I suppose, around fungi. We see this very much with the mouldy homes aspect, which we might want to talk about separately. Yes, there is a level of anxiety but there is also heightened awareness, which can only be a good thing.

Q82 **Dawn Butler:** When we took evidence on AI, we saw some evidence and information that there may not be an off-switch for the AI machine. Is a zombie apocalypse driven by fungal infections a possibility?

Professor Fisher: The manipulation of host behaviour by fungi in a way that increases their transmission rate is quite a complex adaptive phenotype. All the bits exist, don't they? They produce strongly psychoactive chemicals, which can influence our behaviour dramatically, and they can spread and invade humans, as we have seen with Candida auris. I would say that it is incredibly unlikely, but fungi are doing a very good job of—

Dawn Butler: It is possible.

Katherine Fletcher: Watch out if you're an ant.

Q83 **Chair:** If anyone wants to see a pretty alarming depiction, they should watch "Planet Earth" and see how cordyceps take over ants and spread to others.

Professor Fisher, you mentioned mouldy homes as an area of particular recent controversy and interest, with abject consequences associated with it, including the death of a young child. Is it on the rise, or has it always been with us? Are there reasons to think that it is becoming more lethal?

Professor Fisher: What we are referring to is the tragic death of Awaab Ishak in a Rochdale housing estate.

Humans are an indoor-dwelling species, so the major exposure to fungi that we receive is from our indoor air. Of course, we have great immunity to fungi, and we are expecting to be exposed to them, so they nurture our immune system. However, if you are in a mouldy home, that exposure may become hundreds of thousands of spores per cubic metre. In that context, they can provoke hyperinflammatory responses, such as asthma, and can cause very serious infections. If a child is raised in a mouldy home, and the maturation of their immune system in the first 100 days of life is in a very mouldy environment, they could become sensitised, and that will have injurious consequences for their entire life.

The context is that our homes are degrading, our housing stock is becoming old and we have a problem with damp and mould. A very good parliamentary report was drafted recently by the House of Commons. Certainly, indoor mould exposures are diseases of inequality and poverty, and they should not exist. We should have dry, mould-free homes.

Q84 **Chair:** Is that attainable, in your view, with the right policy and funding environment?

Professor Fisher: It is not rocket science. We know how to build ventilated, dry homes with no mould problems.

Chair: Thank you, that is very clear.

Q85 **Dr Davies:** Continuing the theme of antifungal resistance, we know that it is a problem, but is there sufficient recognition that it is a problem? Shall we start on the international level, with Professor Stadler?

Professor Stadler: As I have stated before, much more money goes to AMR, the global resistance against bacteria. We are even developing some antiparasitic compounds. To a lesser extent, there has been more focus on natural products and antiviral drugs, but I think we should invest more in the discovery of new antifungal drugs.

Only one new compound drug based on fungal metabolites has made it to the market and there is not much in the pipeline, as far as I can tell. Due to the efforts that have been made in the last 10 years, a lot of new antibiotics that are active against bacteria are in the pipeline and are now at least in late pre-clinical studies. I would rather we had more candidates for antifungals in our pipeline because we always have a high attrition rate.

It is not difficult to find new compounds that act against bacteria or fungi. There are fungicides, as other people have already said, but there is always a problem with selectivity. Sometimes you see toxic side effects, even if only in the animal model, and then you have to stop a project after four or five years of intensive research. Something we have to keep in mind is the timeline for discovery. We are about to launch an antibiotic against bacteria and nematodes after almost 10 years of intensive research, and we are not there yet. Hopefully, it will be in clinics next year.

Q86 **Dr Davies:** Thank you. If you were a policymaker, would you say that it is investment—money—that is the main issue, rather than expertise or other matters?

Professor Stadler: With regard to anti-infectives, one reason that all the big pharma companies suddenly or gradually dropped out of the business is that, no matter what kind of drug we develop, we will always have to invest the same kind of money. We are talking about, let's say, £2 billion, and it is not until you are really on the safe side that you can make some money out of it.

Of course, it is much more lucrative to develop an anti-diabetes drug or a blood pressure lowering agent than an antibiotic that will in the end be kept as a last resort and be used to treat for three weeks only a relatively small number of patients in hospital, maybe over their lifetime. On the other hand, if you are doing a good job and develop a drug, such as statins, that people will take over 20 or 30 years of their life—a packet a week—it makes a big difference. Of course, there is a commercial aspect that has to be considered, but that means that the public must do more to develop these drug candidates.

Q87 **Dr Davies:** Thank you very much. Lastly, from me, Professor Fisher, is there anything that you would particularly like to see in the Government's AMR strategy in respect of this?

Professor Fisher: The UK Government 2019 AMR strategy mentions fungal infections in the glossary but not in the text, so we need to get it into the text.

Dr Davies: That would be a start.

Chair: Thank you very much.

Q88 **Chris Clarkson:** First, Professor Stadler, darf ich sagen, wir allemaal lieben deinen Pizpulli. Es ist einfach perfekt.

What advances have been made in research and technology to better aid our understanding of fungal threats? How can we practically apply that knowledge to develop health strategies? We have just come off the back of a pandemic, and I don't think it inconceivable that there could be some sort of super-resistant fungus that causes disease in the future. How are we going to understand the best way to apply this science?

Professor Stadler: Is that question for me?

Q89 **Chris Clarkson:** Yes, and then I will turn to Professor Fisher, who made some interesting points on RBH that I would like to pick up.

Professor Stadler: I can only say that we are now getting to the bottom of things. When it comes to the development of biotechnological production processes, thanks to the advent of omics techniques and synthetic biology we are now much faster in developing a compound into

something that can be studied in large quantities and maybe even serve as a basis for a semisynthesis.

These things have certainly revolutionised natural products research. I come back to the stuff that I mentioned before about diagnostics. The omics techniques are a great chance for us to be able to identify new threats much quicker and develop new fungicides for other drugs from natural products much faster. This is a good opportunity, but we also have to train people who can handle these methods. That is what I am doing.

Q90 **Chris Clarkson:** Thank you. Professor Fisher, I declare an interest: Rochdale Boroughwide Housing is my local housing association, and I could say lots of things that would probably get me sued.

You said that applying this knowledge is not rocket science, and I completely agree with you. Are we taking the knowledge that we are developing from this new research and using it to inform debate?

Professor Fisher: Staying on the topic of drug development, we have some very successful UK companies in this space. F2G up in Manchester has developed olorofim, an entirely new mode of action antifungal that works incredibly well against Aspergillus fumigatus. Innovation happens in both spaces—the agricultural and the biomedical. Agricultural companies have developed parallel modes of action. Ipflufenoquin, which is currently going through licensing, is exactly the same as olorofim; it hits the same target enzyme. We are spinning the roulette wheel of resistance another notch because we will have an identical drug being used in agriculture that will raise resistance to our brand-new, flagship UK-developed drug, olorofim. This is also happening with Fosmanogepix, another highly active new mode of action antifungal that is an agricultural innovation.

The big policy gap is that there is no risk assessment mechanism for assessing the dual-use problem. If we use something in the environment, is it going to raise resistance to and degrade the activity of our clinical antifungals? That is a policy question that has to be addressed. The US Environmental Protection Agency has just run a request for evidence on that, which the UK has responded to. A similar process needs to happen in the European Union and in the UK.

Q91 **Chair:** Thank you very much. Is vaccination available to prevent any of these fungal infections?

Professor Fisher: No, there are no vaccines against fungal infections. There have been attempts to develop them for Candida, but they have been unsuccessful. Marc, would you like to say anything on this point?

Professor Stadler: I can only agree. Vaccinations are more for viruses. That is one reason why we focus more on bacteria and fungi in our natural products research. I do not see a path forward for development of

a vaccine because we also have a lot of beneficial fungi in and on our bodies.

Chair: Thank you. That is very clear.

Q92 **Tracey Crouch:** Professor Stadler, could you give us some examples of specific fungal compounds that are used for their medicinal properties?

Professor Stadler: We have already mentioned some of them. Brexafemme, or ibrexafungerp, is newly arisen. It was the last drug launched to the market. It is a semisynthesis triterpenoid enfumafungin drug. Then we have the pneumocandins, which have been on the market for some time, and are also based on metabolites. They are lipopeptides. Then we have the azoles, which are synthetics, and the others that Professor Fisher has already mentioned.

I do not expect many developmental candidates belonging to new classes with new modes of action to be launched in clinics in the coming years. In that respect the pipeline is rather empty.

Q93 **Tracey Crouch:** Last week in the House of Commons we had some research presented to us on the healing powers of herbs and spices. A bit like vinyl, it has come back into vogue. Are there traditional medicinal uses of fungi that are beginning to gain attention in modern research? They have probably always been there but they have fallen out of fashion.

Professor Stadler: This is my hobby. For many years, I have been studying the medicinal mushrooms of China and other Asian countries. We had a collaboration with the Kunming Institute of Botany, and we have worked with people in Vietnam and Japan. For instance, at present, we are working on the neurotrophic compounds from medicinal mushrooms. In Asia, this is a big market. There are a lot of extracts that are not really standardised according to the guidelines of ethical western drugs but somehow they must be effective, because we see the effects in the clinics. In some cases, these activities or effects can be attributed to beta-glucans and other micro-molecules, but we have recently found a number of compounds that are terpenoids. They can already be used to cure neurodegenerative diseases such as Alzheimer's, Parkinson's and so on.

The trick will be to find out their mode of action; we have to be careful with that. Some of them are derived from edible mushrooms. We had a funny story recently. We were working on the chicken of the woods, which is a very nice edible mushroom. The students kept asking me to go to the forest and collect them, but they did not extract them; they always needed more material because they ate them. After eating the mushrooms their papers became cleverer—or at least, that is what they claimed.

A lot of stuff can be gained from that. A lot of fairy tales are associated with it, but you have to get to the bottom of them and work on the fungi

using irregular methods as well as the well-established ones we use to find new compounds from moulds and other fungi. Then you can find out whether there is some part that is of use. By the way, we will soon publish some new compounds from the zombie-ant fungi—we are also working on those. We could culture them, for a start. They are not so dangerous.

Q94 **Tracey Crouch:** I read a very small study that said that eating one mushroom a day reduces your chance of recurrence of breast cancer by 66%, and if you add a cup of green tea, you reduce the risk of recurrence by 90%. Are there specific areas you think researchers should focus on to advance the interest in fungi and particular conditions?

Professor Stadler: We are aware of that report. Our workload is dedicated to finding a single principle. In many of these studies, if they do some follow-up and fractionate the compounds—the constituents—even in green tea, the activity in in vitro assays and so on will be lost, and will restart if they mix the components again. It is not easy to follow up. We normally give up on them if we see that the activity is lost. The same also goes for some instable compounds; there is a lot of stuff that we are unable to explain.

On the other hand, in some cases, if you try it out and it works, that is okay. For instance, some studies show that the consumption of mushrooms can have some immune-stimulating effect. But it is very difficult; if those mushrooms contain only beta-glucans, how can they enter the bloodstream? Maybe there is some interference with the microbiota in the gut. These phenomena are really difficult to study. Maybe this could be an avenue to look at the mode of action of the macromolecules—to find out using the newly emerging techniques to tackle the microbiota.

Q95 **Tracey Crouch:** Thank you. Professor Fisher, can you tell us very briefly whether you think the pharmaceutical industry is doing enough to harness the potential of fungi as a valuable resource in drug development?

Professor Fisher: It is starting to wake up. One of the most exciting recent findings is the use of psilocybin therapy for treatment-resistant depression. The results of those studies are starting to look really promising. Yesterday I looked at the website of the Imperial College Centre for Psychedelic Research into mental health care. There are trials for psilocybin as a treatment for anorexia nervosa, fibromyalgia, obsessive compulsive disorder and gambling addiction, and micro-dosing with psilocybin to help with depression, anxiety or mood problems. Obviously, if those work, patients do not have to go on to heavy-duty anti-depressant drugs. There is definitely a big swing into this area, which would be helped by better regulation and so on. Certainly, fungi are having a moment, and Merlin says it very well in the YouTube that you referred to earlier.

Q96 **Chair:** I understand that penicillin and statins are derived from fungi. These are huge transformational drugs. Professor Fisher, am I right in sensing that there is nothing comparable—at least that is visible—in the pipeline at the moment?

Professor Fisher: It is wonderful that Fleming's serendipitous discovery kick-started the antimicrobial revolution, but I cannot speak for anything on my radar that is of comparable importance. Marc, do you have anything in mind that is equivalent to the discovery of penicillin?

Professor Stadler: Not really. Antibiotics—the beta-lactams—will remain unparalleled. You should not forget cyclosporin, which makes a lot of money. We have mycophenolic acid and Fingolimod, which is also a memetic product derived initially from a fungal metabolite, even though you will not see the similarities if you look at the structures. There are good examples and it really pays to define them and test them as broadly as possible.

You should not forget that statins, as well as cyclosporin, were initially found in a screen for antifungal compounds. Their beneficial activities were only discovered later when they were available as pure compounds and the pharma industry could put them into their target assays.

Q97 **Chair:** On that point, Professor Stadler, you mentioned earlier in your evidence that you go overseas to look for samples. Some scientists have argued that, whatever its intentions, the implementation of the Nagoya protocol that governs the use and development of samples of materials taken from different countries is so bureaucratic that it hinders research. What is your perspective on that, as an international scientist?

Professor Stadler: I agree. I am really happy that I have some long-standing collaborations with my friends in, for instance, Thailand, Kenya and so on, where we can sort out those problems. It also means that my friends and colleagues can be sent with their students to be trained in our lab, but we cannot even get an extract from a natural source without having to sign NPAs and other documents beforehand. This has already prevented us from entering into collaborations with scientists from certain countries.

On the other hand, we sometimes have people who come from, for instance, Brazil and work on our Thai fungi. We can do that for any purpose, but big hurdles have been set to establish collaborations with people in low-income countries, and so on. That hinders scientific progress because in the end it would be better if you could spend more effort on training people so that they can do the research they need to do in their home country. It is a serious problem.

Q98 **Dawn Butler:** Thank you, both, and everyone, for your evidence today. It is clear that something that seems quite niche is actually quite fundamental to everything, from agriculture to health.

Professor Stadler, you mentioned big pharmaceutical companies. When

we took some evidence previously on phages, it was evident that big pharmaceutical companies focus on profit and not wellness. That is probably part of the reason why we do not get the investment that we should, and it means that the Government need to step in. To summarise, if money was no object and you could have whatever support you wanted, what would be your vision?

Professor Stadler: If money were limitless, there would still be the problem of finding enough qualified staff. Something that is going to hit us very badly, at least in Germany, where we have a lot of problems already, is the number of qualified people. We will have to take measures against that in the future. On the other hand, the things we are already doing are quite nice. The only problem is that we lack funding to develop large-scale production processes; there is always some bottleneck with the MEDCHEM. As I said, it is a lack not only of financial resource but of qualified people.

Q99 **Dawn Butler:** So education is key. Thank you, Professor Stadler. Professor Fisher, I put the same question to you. You talked about the first 100 days of a child's life and mould in homes. You talked about how we built up resistance when we walked out of the ocean. If nothing was limited for you, including money, what would be your vision?

Professor Fisher: Well, clean, mould-free homes, very simply. We need to understand and leverage the huge complexity of the fungal kingdom. There are at least 20 new mode of action antifungal drugs in pre-clinical development. If we could release those, we would boost greatly our antifungal armamentarium. If we focused our natural product discovery more on to the fungal kingdom, we would discover new anticancer agents and new foods, and we would lock down carbon. There is everything to play for. That is my vision. Don't blink; go for it.

Dawn Butler: Brilliant. Thank you both so much, it has been very interesting.

Chair: I thank Professor Stadler and Professor Fisher for their evidence this morning. I thank all six of our witnesses for an absolutely fascinating session. You have given us much food for thought on which we will reflect as to what recommendations to make and to whom. I think Professor Dyer talked about being a fungal fan; you have turned us all into fungal fans through your evidence this morning. That concludes this meeting of the Committee.