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Time for the plastic eating fungus?

Geoff Robson and David Moore

Petroleum oil spills are no longer the most dramatically damaging form of pollution of the natural environment; plastics have now reached the number one spot. Plastic materials are essentials of modern life as you can see from the host of plastic products in your surroundings; but lack of degradability and growing water and land pollution problems have led to mounting concern about plastic wastes.

The phrase 'plastic materials' covers a range of polymers, including polyvinylchloride (PVC), polyurethanes, polystyrene, poly-amides and polyesters with a range of properties and different susceptibility to degradation. Poly-(ethylene terephthalate) (PET) is one of the most abundantly produced synthetic polymers, being used for single-use beverage bottles and textiles. Discarded PET-packaging is accumulating in the environment at a staggering rate and the properties that make PET so useful to us in our daily lives also give it an alarming resistance to bio-degradation. It could last for centuries in most natural environments.

We make around 350 million metric tons of plastic materials each year (**Figure 1**). A total of 8,300 million metric tons of plastics is estimated to have been produced globally during the past 65 years, generating, by 2015, approximately 6,300 million metric tons of plastic waste. Only 9% of this was recycled, 79% was accumulated in landfills or just discarded into the natural environment (and between 5 and 13 million metric tons of plastic end up in the ocean every year), the rest incinerated.

Figure 1. Domestic waste destined for landfill. Every home, every day, everywhere.

Plastics having a carbon-carbon backbone (homopolymers, like PVC and polystyrene) are resistant to chemical and microbial degradation. Polyurethanes contain other elements in the backbone (for example nitrogen or oxygen; called heteropolymers), and are vulnerable to enzymatic microbial degradation, which can limit the useful life of products made from them. To avoid this, broad-spectrum biocides are often incorporated into polymer blends to inhibit fungal and bacterial growth. Which, of course, only increases the adverse environmental impact when the plastic is discarded.

A lot of recent media coverage reported a newly discovered bacterium isolated from outside a bottle-recycling facility in Japan. The bacterium, a new species named *Ideonella sakaiensis*, had the rare ability to grow on PET as a major carbon and energy source, because it produces two enzymes capable of hydrolysing PET and the reaction intermediate, mono-(2-hydroxyethyl) terephthalic acid. Both enzymes are required to enzymatically convert PET efficiently into its environmentally benign monomers, terephthalic acid and ethylene glycol; which just happen to be the monomers needed for further plastics manufacture.

The last great accumulation of polymer wastes was the accumulation of lignin that occurred in the world's vast swamp forests during the late Paleozoic Era about 300 million years ago. These accumulations fossilized into the deep coal seams from which the term 'Carboniferous Period' derives. Lignin, which is the second most abundant natural polymer on Earth after cellulose, is not accumulating today because basidiomycete fungi can secrete all the enzyme systems needed to degrade plant biomass.

Polymeric lignin is full of benzene rings, so any microorganism that attempts to degrade lignin releases phenols, and phenols are widely used as anti-microbial disinfectants. This, of course, makes lignin very resistant to attack by bacteria (which is exactly why plants evolved it as a component of their cell walls). On the other hand, a specific group of fungi (known as the white-rot fungi) degrade lignin by producing oxidizing enzymes that are released from their hyphae and generate peroxides; these penetrate the wood and 'burn' the lignin in an enzyme-controlled way. In fact, the benzene rings are opened into straight-chain fatty acids which are metabolized to ATP through the tricarboxylic acid cycle. These lignin-digesting enzymes have a high potential for biotechnological applications including mycoremediation (which is fungus-based technology being used to decontaminate the environment). Recent studies of common ascomycete and basidiomycete fungi show they can produce enzyme systems needed to use plastic wastes for growth.

Among the most persistent organic pollutants in the environment are the phthalate esters used as additives (plasticisers) in plastics like polyvinyl chloride (PVC) to make them more flexible. Because they are not chemically bound, phthalates are easily released from plastic articles. Some mimic mammalian hormones and act as developmental and reproductive toxins.

Figure 2. Could this be the future? A simulation of Oyster mushrooms on waste plastic.

The common soil mould, *Fusarium*, produces a range of esterase enzymes that digest phthallates, and the white rot Oyster mushroom (*Pleurotus*) can degrade and use phthalate plasticisers as carbon and energy sources. Oyster mushrooms (**Figure 2**) will grow vigorously on a wide range of substrates including sawdust, wood chips, and cereal straw because *Pleurotus* degrades lignin efficiently; this being the basis of the commercial cultivation of Oyster mushrooms around the world. But *Pleurotus* is also an easy experimental laboratory organism and is an ideal candidate for genome engineering to amplify and extend those plastic-metabolising enzymes.

Time for a plastic-eating mushroom.

Further information

- Contributions of fungi to ecosystems: http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch10_01.htm
- Mechanism of lignin degradation: http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch10_07.htm
- Fungi as cell factories: http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch18_14.htm
- Industrial cultivation methods: http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch11_06.htm
- YouTube video about Oyster mushroom farming: https://www.youtube.com/watch?v=9-JoxKte1yQ
- BBC Plastics Watch: http://www.bbc.co.uk/programmes/articles/11CnCQR0GJfkDgJs57sR5Ps/plastics-action
- https://en.wikipedia.org/wiki/Plastic_pollution
- https://friendsoftheearth.uk/plastics
- http://plastic-pollution.org/

GEOFFREY DAVID ROBSON
6 SEPTEMBER 1962-15 MAY 2018

We must end this article with the unwelcome sad note that our kind and gentle friend, greatly valued colleague and co-author, Geoffrey David Robson died suddenly on 15th May 2018. He is survived by his wife Amanda, son James, daughter-in-law Katrina, and granddaughter Ava; to all of whom we extend our sincere condolences.

AUTHOR PROFILE

Geoff Robson was born in Doncaster but grew up in Huddersfield. He studied Botany and Biochemistry at the University of Salford and graduated with a first-class Honours degree in 1984. He obtained his PhD in 1987 at the University of Manchester, supervised by Professor A.P.J. Trinci, and remained in Manchester for the rest of his academic career, progressing through positions as research associate, lecturer and senior lecturer in the School of Biological Sciences. Geoff was interested in several applied aspects of fungal growth, morphology and physiology, and he received the Berkeley Award for his "outstanding and original contribution to mycology by a young scientist" from the British Mycological Society in 1994. Geoff Robson served as General Secretary of the British Mycological Society for many years and was elected President of that Society for 2013-14. His outstanding contribution to the Society was recognised by the award of the Benefactors Medal of the British Mycological Society in 2015. Geoff was involved with the International Biodeterioration and Biodegradation Society (IBBS), serving as Council member (2008-12) and President (2012-14), and he also acted as Secretary General of the International Mycological Association Congresses (a Division of the International Union of Biological Sciences) (2008-2014); and was a Council member of the Federation of European Microbiological Societies from 2014. He served on the Eukaryotic Microbiology Division of the Society for General Microbiology (now Microbiology Society) (2008-10) and several editorial boards including *FEMS Microbiology Ecology*, *Mycological Research* (now *Fungal Biology*), and *Applied and Environmental Microbiology*. He was a Fellow of the Royal Society for Biology (FRSB) and Visiting Professor, King Saud University, Riyadh, Saudi Arabia (2015-16).